Responses of cabbage (*Brassica oleracea var. capitata),* Swiss Chard *(Beta vulgaris)*, and Pepper (*Capsicum annuum)* seedlings to growing media pre-enriched with vermicompost

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Abstract

Seedling production is mainly achieved by using growing media as substrates; most nurseries in South Africa use pine bark and vermiculite in their ‘in-house’ medium. For the growing medium to effectively anchor and yield healthy and sound seedlings to develop into a mature vegetable crop, it must have a balance of certain physical, chemical and nutritional properties.

The study was conducted concurrently at two nurseries (Top Crop Nursery and Sunshine Seedlings®) differing in nursery management and growing media types to investigate physical, chemical, and nutritional properties of growing media to develop various growing media mixes. These media were tested for their suitability for vegetable seed propagation, by monitoring and recording seedling growth parameters from sowing to the saleable seedling stage. Top Crop Nursery used the wattle and pine bark, whereas Sunshine Seedlings® used their standard growing media (75% Coir, 13% Peat, 12% Vermiculite + 0.2% Osmocote®). The study then tested the responses of cabbage (*Brassica oleracea var. capitata*), Swiss chard (*Beta vulgaris var. cicla*), and pepper (*Capsicum annuum*) seedlings.

When developing growing media mixes, the pre-enrichment of growing media with vermicompost at varying levels of 0-20% was practiced at both nurseries. Top Crop Nursery had 15 treatments, with three controls (treatment 1, 2, and 3), where treatment 1 was pure pine bark, treatment 2 was pure wattle bark, treatment 3 was 50% pine bark and 50% wattle bark. Treatments 4 to 7 were pure pine bark with vermicompost pre-enrichment ranging from 5 to 20%. Treatment 8 to 11 were pure wattle bark with compost pre-enrichment ranging from 5 to 20%, whilst treatment 12 to 15 were 50% wattle bark + 50% pine bark with the same pre-enrichment ranging from 5 to 20%. Sunshine Seedlings® had 6 treatments with two controls (treatment 1 and 6), where treatment 1 was Sunshine Seedlings® Seedling Mix with 0% vermicompost, and treatment 6 being the Sunshine Seedlings® Mix without Osmocote®, with 0% vermicompost.

From sowing, emergence was recorded daily, until all replications showed no further germination. Other parameters (root development, leaf number, seedling height, pest and diseases, general appearance of the seedlings) were recorded on a weekly basis throughout the seven weeks of each experiment. Measuring chlorophyll and seedling mass was carried out at the saleable seedling stage, at week 7. Seedlings were randomly sampled for seedling mass (wet mass taken in field, dry mass taken after laboratory oven drying). From both nursery sites, statistical analysis for days to emergence, leaf number and seedling height showed no significant differences. Seedling mass, chlorophyll content and nutrient uptake showed significant differences, with cabbage showing greater mass gains over the seedling growing period, up to 10.46 g per 20 seedling tops.

Statistical analysis revealed differences in nutrient uptake by the three crops at both nurseries. Pepper showed higher nitrogen, potassium and boron uptake than Swiss Chard and cabbage, with the most significant nutrient uptake noticed in treatment 2 (Wattle bark = 0% vermicompost), treatment 3 (Pine bark + Wattle bark + 0% vermicompost), treatment 4, 5, 6, 7 (Pine bark + 5 to 20% vermicompost), treatment 9, 11 (Wattle bark + 10 to 20% vermicompost), treatment 14, and 15 (Pine + Wattle bark + 15 to 20% vermicompost). In most treatments, especially in treatment 5, 7 (Pine bark + 10 & 20% vermicompost), 8, 9 (Wattle bark + 5 to 10% vermicompost) and 15 (Pine + Wattle bark + 20% vermicompost), Swiss Chard had the highest uptake of phosphorus, iron, magnesium, aluminium, zinc, and manganese. Cabbage only showed a high uptake of calcium and sulphur, especially with treatment 2 (Wattle bark + 0% vermicompost), 10, 11 (Wattle bark + 15 & 20% vermicompost), 12, 13 (Pine + Wattle bark + 5 & 10% vermicompost), and 15 (Pine + Wattle bark + 20% vermicompost).

The study demonstrated that wattle bark affects seedling growth more so positively than pine bark; however, the Sunshine Seedlings® mix produced much more desired growing media attributes for almost seedling growth parameters, more especially the root development. The addition of vermicompost had very little to no effect on plant growth; however, the effect of the slow-release fertilizer, Osmocote® made a noticeable impact. Conducting this study in two separate nurseries did not allow for precise comparisons, therefore, a similar study should be conducted at one site, to compare treatments under similar growing conditions.

Declaration

I**,** **Nkosikhona Brian Sokhela,** student number **217037573** declare that this study is my original work and it is appropriately referenced where some information was taken from other sources. I did all the write-up, and analyses involved and this work has never been submitted for any other degree or other institution. Should this work or any part of it be found to belong to someone else, I will be held responsible for plagiarism.

Signed: ______   __________   **Date:** 24/02/2022

N.B. Sokhela

I hereby certify that this statement is true and correct.

Signed: _____   __   **Date:** 24/02/2022

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General Introduction

Seedling production is, with few exceptions the most effective way of producing vegetable crops, and it has become very popular in South Africa. Commercial, emerging, small-scale farmers, and even the community are relying on seedlings for field vegetable production, for marketing saleable vegetables, food security projects, and even household consumption, and therefore, it is a growing and a very important enterprise nowadays (Summer, 2019, pers. comm.).

Nursery seedling production is the mostly used system to produce sound and good quality seedlings, however, the industry is impaired by numerous challenges, including high infrastructure establishment cost, input cost, and even management cost (Osborne, 2019, pers. comm.). Amongst the input and management costs, the largest expenses incurred are costs for water, growing media, fertilizer, and labour. Growing media require careful handling, storage, and also need to be well-balanced in order to be able to provide a firm and good substrate to the growing seedling, and, most importantly, it must be able to provide the necessary properties to enable good plant growth. Most importantly, these attributes (physical, chemical, and nutritional properties) must be more or less like soil properties.

The main aim of the study was to establish cost-effective, environmentally friendly growing media using common organic media used in South Africa. This was done by producing vegetable seedlings in different growing media types, three crops (cabbage, Swiss Chard, and pepper) monitoring plant growth and comparing treatments from sowing to marketable vegetable seedling stage, and also evaluating the responses of the three crops to the different treatments.

Problem Statement

Most nurseries produce seedlings using growing media, such as pine bark and vermiculite, without mixing it with any other growing media. Such media, however, often lack certain essential properties required for seedlings growth, especially a high water-holding capacity, adequate porosity and pH, as well as high calcium, with low sodium prevalence. The nursery operation Sunshine Seedlings® is striving to maintain a balance of important growing media properties using a mixture of 75% coir, 12% vermiculite, and 13% peat. The resultant medium is subsequently enriched with the slow-release fertilizer, Osmocote®, however, concerns with this mixture are:

- Time consumption and cost of leaching coir before use to reduce the sodium concentration to minimum permissible levels, most plants can tolerate up to 70 parts per million (70ppm) or 10 grams per litre (Summer, 2018, pers. comm).
- High cost of importing peat, its high acidity, and its environmental unfriendliness as it is considered non-renewable (Fonteno, 1996).
- South Africa grows about 1.3 million hectares of timber particularly pine and wattle (Miller & Jones, 1995), therefore, pine and wattle bark are in ample supply, unlike coir and peat. The former media are also cheaper than coir and peat.

Hypothesis

Coir and/or peat can be substituted by either pine or wattle bark, when pre-enriched with Vermicompost and still maintain the needed physical properties, especially a high water-holding capacity, while also adding nutrients essential for seedling growth in nurseries.

Aim and specific objectives

This study aimed to investigate the physical, chemical, and nutritional properties of standard growing media, used in two nurseries; Top Crop Nursery and Sunshine Seedlings Nursery®, to compare seedling production and growth responses to each growing medium.

- To assess the physical, chemical, and nutritional properties of each growing medium.
- To determine the growth and quality of different vegetable crops in various media.

Chapter 1

Literature Review

Growing media and their properties in relation to vegetable seedling growth.

This review outlines features of growing media in detail by describing the various types of growing media commonly used in South African nurseries. As various vegetable crops have different requirements, the physical, chemical, and nutritional properties of media are discussed to show alternative media types that would be more cost effective, environmentally friendly and provide physical, chemical, and nutritional properties necessary for plant growth.

1.1 Description of growing media

Seedlings are young, fragile plants that require a specialized growing environment; this controlled environment allows consistent growth, since plants are very sensitive to alteration in environmental factors such as extremes in temperature, light, and water availability. In the early days of plant production in nurseries, soil was used as a natural substrate to grow seedlings, and is still used by many emerging producers in open seedbeds, but it bears risks of low emergence and seedling losses of almost 50% (Landis, et al, 2008).

Soils are associated with various challenges: due to compaction, they might restrict rooting depth, resulting in reduced nutrient and water uptake. For these reasons, the majority of seedling producers have shifted from soil to growing media as substrates for planting into. The choice of medium depends on various factors, including personal preference, growing medium properties including physical, chemical, nutritional aspects as well as the growing medium's biological properties.

1.2 Growing media and their uses

Growing media, similar to ordinary soil is a substrate in which plant roots establish, absorb water and nutrients from in order for the whole plant to grow. Growing media is the collection of various sizes of particles of organic and/or inorganic material to provide for attributes like water holding capacity, air-filled porosity, pH, other physical, chemical, and nutritional properties essential for plant growth. Growing media is available in a wide range of types, ready to use or to be used as mixtures at own nurseries. According to Landis, et al, (2008), the primary functions of the growing media are to:

- Provide physical or structural support to the growing plant;
- Serve as a substrate for roots in order to absorb and transport nutrient and water to the growing plant; and
- Provide adequate root aeration.

Commonly used growing media types are:

- **Seed propagation media** – mainly for germinating seeds and it must be of finer texture, be sterile, and be able to keep moisture around the germinating seeds.
- **Rooting cuttings media** – this type is for cuttings, must be very porous and be able to prevent waterlogging and allowing good aeration to favour root formation.
- **Transplant media** – this must be the coarser media used when smaller seedlings or rooted cuttings are transplanted into large containers.

1.3 Common growing media types used in South Africa and their properties

According to Landis et al., 2008, the most commonly used growing media by nurseries in South Africa are wattle bark, pine bark, peat, vermiculite, perlite, and vermicompost. When selecting the growing media to use, nutritional status, water holding capacity, electrical conductivity, pH, availability and costs of the growing media are the main the desirable properties that are considered.

1.3.1 Organic types

(a) Wattle bark, Pine bark and Sawdust

Wattle and pine bark growing media are the largely used types of growing media in South Africa due to its abundant availability, low and affordable cost, good physical properties, especially when used as a container medium (Mupondi, *et al*, 2010). Their particle sizes can be graded by sieves to any desired sizes (Wilkerson, 1981). South Africa grows about 1.3

million hectares with timber, mainly pine and wattle (Miller & Jones, 1995), therefore pine and wattle bark is in a large supply in South Africa than coir and peat.

According to Smith, 1992, the pine bark is made from the pine bark, where the bark is a by-product at the paper manufacturing industry, where the bark is removed before milling, therefore composted, using the ring de-barkers. After the bark is removed, it is composted, temperature is increased, urea and water are added to provide additional nitrogen. In most cases, black plastic sheets are used to cover the pine bark during composting. Based on the nutritional research done on composted pine bark, additional trace elements and phosphorus is recommended before planting as most of these nutrients leach out during composting (Smith, 1992). Whitcomb, 2003, suggested that the use of wood substrates like saw dust promote a high microbial activity, therefore result into a high nitrogen requirement by approximately 30%. Both Smith, 1992 and Whitcomb, 2003 further indicated that, many years ago, wood substrates were commonly used, but in recent years the pine bark has been found to be the best to use.

(b) Compost and animal manure

Most small scale and subsistence seedling producers use composts and animal manures as growing media whilst they are also marketed as an additional organic fertilizer, and some as growing media. There are some considerations when deciding on using the compost or manure as growing media, where Robins & Evans, 1914 indicated that there is a high possibility of toxicity in sludge as it has a potential of high levels of heavy metals like zinc and copper. They further indicated that the high nutrient contribution of the animal manures, especially nitrogen is associated with the disadvantages including the fine particle size of the weed seeds, and possibility of high levels of sodium.

Compost and manure can be useful when used as an organic fertilizer in mixtures with the ingredients of poor nutrient levels and poor physical properties, for example high clay content, very coarse textures, low water holding capacity, etc. Landis, *et al*, 2008, also indicated that animal manures vary in their nutritional composition as the ruminants' manure will have a lower nutrient level compared to the monogastrics (pig and chicken) manure.

A study by Mupondi, *et al*, 2010 on the pine bark and goat manure mixture (which was termed PBG) versus the commercial pine bark growing media (termed PBCO), testing them on cabbage, tomato, and lettuce, the PBG showed to have done well in seedling growth and proved to be a good substitute for PBCO.

(c) Vermicompost

Vermicomposting (worm compost) is produced by castings earth worms to feed, digest and decompose the organic material such as vegetable and fruit wastes, peels, and even animal manure, under controlled bio-oxidants (Deminguez, 2010). Vermicompost has been used as an organic fertilizer and have proved to be an effective premix in producing good plant growth on *Brassica oleracea var. capitata* (cabbages) (Lazcano, *et al*., 2010). It can be used as a growing media whilst it can be used as an organic fertilizer. Some previous studies have shown that vermicompost improves physical properties of the growing media and increasing water holding capacity in growing media with larger particle sizes (Deminguez, 2010). According to the study conducted by (Cox, 2008), based on comparing different rates of vermicompost blend mixed with bark growing media, it showed that commonly accepted recommendations is to use compost at about 30-40% by volume as most vermicompost tend to have a high water holding capacity.

(d) Peat

Peat is made of partially decayed vegetation and organic material that forms in wetland bogs and swamps when the plant material is not fully decomposed due to acidic and anaerobic conditions in the wetlands (Bragg, 1998). It is commonly used in nurseries and greenhouses as pre-mixes to increase the water holding capacity of the growing media (Whitcomb, 2003). It is mainly made of trees, grasses, fungal, animal remains, and even insects collecting at the downstream or wetland. Peat will accumulate faster when it forms under very wet conditions, however it will have a slow decomposition than the peat forming in drier areas.

Robins & Evan, 1914, classified peat according to three different types:

- **Peat moss** – tan to light brown in colour, and it is least decomposed form amongst peat types.

• **Sphagnum moss** – this type comprises of young and undecomposed residues and plant material.

• **Reed-sedge peat** – this one is made of marsh grasses, cattails, reeds, fungi, sedges and other plants found in swamps. In many cases this type of peat advances to the peat humus, which is in an advanced stage of decomposition, and it is usually dark brown to black in colour, and has a reduced water holding capacity that peat moss.

According to Bragg, 1998, using peat for horticultural use is needs patience as it is time consuming to harvest and process it. Harvesting can take up to six years, stacking, drying, and milling can take up to twelve months, depending on the type of machinery or harvesting method used.

Peat is known for its high water retention due to its reduced total pore space, air volume and water availability and water buffering (Handreck & Black, 2005). Sunsilicates, 2018 suggested that peat does not make a good growing media on its own, due to its low pH (9 to 4), however, it performs better when mixed with other growing media types with a low water holding capacity. Peat mixes are used by many nurseries for seedlings plugs whilst it is not easily available in South Africa, resulting to many growers diverting to bark growing media (Smith, 1992).

Bohne, *et al*, 2012, in their study on evaluating the influence of peats from different origins on germination and early growth of Chinese Cabbage, they discovered that the peat from Germany, Sweden, Finland, Estonia, Ireland, vary in their decomposition rates and the Nitrogen: Phosphorus: Potassium (N:P:K) concentrations. Their study showed that peat that has a high decomposition rate have a high concentration of the nitrogen (N), phosphorus (P), and potassium (K) in the root-zone than in the in the shoots. This shows that the more peat decomposes, the better the nutrient cycling is, however, the peat's attribute to retain nutrients reduces the nutrient uptake by the plants, therefore requiring far more time to decompose to the fully usable form.

(e) Coir

The coconut fibre, commonly called "Coir" is an organic plant material detached from the outer husk of coconuts. Unlike most organic materials, Coir takes very long time to break down and decompose, therefore, it is very suitable for hydroponics because it can retain nutrients for later use by plants (Handreck & Black, 2005). Whilst others consider it as a waste product, the nurseries use it as one of the best growing mediums. Coir has a good water holding capacity, at the same time, providing good aeration for the roots (Newman, 2007). Coir comes in two forms, both made of coconut husk;

- The coco chips – its particle size is like wood chips
- Coco fibre – particle size similar to the potting soil

At Sunshine Seedlings Nursery, Coir is the major component (about 73%) of the growing medium, due to its good aeration and water holding capacity (Mzobe, 2019, pers. comm.). It comes with a neutral pH of between 5.2 to 6.8, meaning that it comes ready for use by most plants without adding lime. Coir also comes with a nutritional value as it is found to be rich in potassium, manganese, iron, copper, and zinc. Since coconuts are grown and produced in coastal areas, most nurseries and horticulturalists are concerned with the total soluble salts that coir comes with, that might affect their electric conductivity. Sunshine Seedlings Nursery is leaching their coir with clean water for at least five days to leach out these salts.

1.3.2 Inorganic (Mineral) types

(a) Vermiculite

Vermiculite is light in weight, porous and has higher water retention capacity. Vermiculite particles can either be micron, super fine, fine, medium or large, of which the finest parcel sized vermiculite can be used for seed germination (Haasbroek, 2018). This type of growing medium is a silicate mineral, that is clean, odourless, and do not contain any toxins, and it does not deteriorate or decompose. It has a neutral to alkaline pH, usually ranging between 7.0 to 9.5 (Handreck & Black, 2005). It expands under hot conditions, very light and tends to float in water. Due to the high cation-exchange capacity of vermiculite, it can hold air, nutrients and moisture that can be used later by plants. Vermiculite helps promote faster root growth and gives quick anchorage to young roots when mixed with peat, composted bark, and organic compost (Van Schoor, et al, 1990). According to Mzobe, 2019, pers. comm., this is the main reason why it is the essential component of the standard growing medium at Sunshine Seedlings Nursery.

(b) Perlite

Perlite is an inorganic component growing media that is produced from the heated igneous rock under very high temperatures. It is commonly used as a mixture in nurseries growing media just like vermiculite, however, it only differs from vermiculite by the fact that it is a finished product of weathering, therefore it has no or very low water holding capacity. Perlite is whitish, powdery to granular material that is light in weight, with a neutral pH, odourless and sterile (Landis, et al, 2008).

(c) Sand

Sand is one of the growing media types that are readily available and inexpensive. When one choosing sand to use as growing media, the particle size and sand type must be considered. Sand also vary in their nutrient composition as the sand derived from the calcareous sources such as limestone are rich in calcium carbonate but may have extremely alkaline pH (Landis, et al, 2008). The use of sand is mainly for increasing porosity, however, their small particles can reduce aeration and drainage, therefore the mixture of small, medium to large particle size is important to maintain. Most sands come with high salinity that might be detrimental during seedling production, therefore it is recommended that the sand is washed with clean water to flush out the salts before use.

1.4 Physical, chemical, biological, and nutritional properties of growing media

1.4.1 Physical properties of growing media

Bragg, 1998, suggested that the true physical aspect of the growing media is defined by relationship between the air, water, the amount of solid particles and their arrangement in the growing media.

(a) Porosity

The sum of the spaces in the micro pores and macro pores are the breathing pores of the soil, and they are known as porosity. Porosity is calculated as a percentage of volume of solids to the total volume of the soil profile (Landis, et al, 2008). Generally, in the soil as well as the growing media's porosity goes hand in hand with water holding capacity and soil aeration. Growing media that have large particles that have more aeration and less water holding capacity whilst the one with medium to small sized particles will have less aeration and more water holding capacity. Growing media with large particles will dry out quicker than the growing media with smaller particles will always be filled with water, and to some extend be waterlogged. In practice, a growing medium which has a mixed particle size is ideal for good water holding capacity and aeration, and that is a particle size of about 0.8 to 6 mm.

(b) Water holding capacity (WHC)

Water holding capacity generally refers to the ability of the soil to retain the available water for use or to be absorbed by plants. According to Landis, et al, 2008, this refers to the percentage of total pore spaces that remain filled with water after the excess water has been drained gravitationally. A good growing media has a well-balanced water holding capacity, macro and micro pores in order to allow drainage of excess water and prevent waterlogging.

Water holding capacities of different growing media also depend on growing media size and types, for example, the fine textured sizes retain more water than the coarse textured ones. According to Handreck & Black, 2005, a peat moss holds more water than other growing media of similar texture due to their "sponge-like" effect. When mixing the growing media, over mixing must be avoided to reduce the chances of compaction as this may result into compaction od the growing media, and therefore have chances of waterlogging and capping of the top layer, and thus impeding the water penetration.

The size and height of the container also has an effect on water holding capacity. Since all the irrigation water pours from top to bottom, the bottom part of the container will mostly have water and mostly fine particles of the growing media remaining there. In practice, the short containers make a short profile, therefore there is a limited simulated "rooting depth", and they have higher chances of waterlogging than taller containers.

(c) Aeration

Aeration refers to the percentage of the pore space that remains filled with air when water is drained away from the profile (Brady & Weil, 1996). According to (Plaster, 1992), the ideal soil air should be up to 25% of the soil profile, whilst the other proportions are filled water and minerals. Plant roots need oxygen for healthy living, and also to give off carbon dioxide, and this all needs to occur through the macro pores, therefore, a good growing medium should contain more of the macro pores.

1.5 Chemical and nutritional properties of growing media

1.5.1 Chemical properties

(a) pH

The pH of growing medium refers to the measure of growing media's acidity or alkalinity, and it is measured on a pH scale in kcl with a range of 0 to 14, where the values below 7 mean acidic, and ones above 7 mean alkaline (Tisdale, et al, 1985). Majority of plants grow best at slightly acidic pH ranging between 5.5 to 6.5. the main issue of pH is their interaction with plants as they play a major role on plant growth and the effect on nutrient availability to plants. Some nutrients become unavailable to plants when pH levels are either high or low, for example, when pH levels are high, phosphorus binds with calcium and binds with iron and aluminium when pH levels are low, therefore becoming unavailable to plants.

(b) Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is the inherent growing media feature that is difficult to change significantly and it is defined as the total growing media capacity to hold the exchangeable cations. Since most growing media are generally infertile, this is an important aspect to consider when working with growing media. This feature influences the media's ability to hold onto essential nutrients and provides buffering against growing media acidification (Brown, 2007). Growing media with high clay content and high organic matter are found to have higher CEC, of which most growing media have a very low clay content. CEC is a major determinant of the nutrient storage capacity, therefore it helps determine the frequency of the fertilizer requirement because most nutrients are lost in nurseries through irrigation, therefore growing media with a very high CEC are preferred (Tisdale, et al, 1985).

1.5.2 Nutritional properties of growing media

After emergence, the growing plant use up all the small amounts of energy and as they grow vigorously, their nutritional requirements rise rapidly, and they rely on the growing media as their substrate for nutritional supply in order for them to meet their nutritional requirements. It is for this reason why the growing media needs to be consistently be fed with basic nutrients required for plant growth, especially nitrogen for vigorous growth and keeping the leaves green.

According to Landis, et al, 2008, most nursery managers prefer using growing media that comes with low fertility levels to prevent damping-off during transplanting period. When the low-fertilizer growing media is used, the soluble fertilizers are added gradually through fertigation throughout the production period.

Most organic types of growing media have a significant amounts of macro elements, specifically nitrogen (N), phosphorus (P), and potassium (K), whereas the inorganic types have very less to none of these, except the micro elements like aluminium (Al), sulphur (S), iron (Fe), etc. (Nelson, 1996). Studies and experimental trials have shown that compost, manures, pine bark, and even wattle bark come with considerable amounts of the N:P:K ratio than the other growing media.

Table 1.1: Comparisons of different growing media in terms of physical and chemical properties (Newman, 2007)

Growing Media	Bulk Density	Water Holding Capacity	Air Porosity	pH	Cation Exchange Capacity
Vermiculite	Very low	Very high	High	6 to 8	High
Peat moss	Very low	Very high	High	3 to 4	Very high
Pine bark	Low	Low	Very high	3 to 6	High
Wattle bark	Low	Low	Very high	3 to 6	High
Coir	Low	High	High	6 to 7	Low
Perlite	Very low	High	High	6 to 8	Very low

Sand	Very high	Moderate	Very low	Variable	Low
Vermicompost	Low to Moderate	High	Moderate	5.5 to 6.5	High
Field soil	All variable				

1.5.2.1 Elements essential for plant growth

Nelson, 1996 collectively mention that there are seventeen (17) common essential elements in terms of plants nutritional requirements, of which three of those (oxygen (O), hydrogen (H), and carbon (C) are called non-fertilizer nutrients and they are obtained naturally. There are basically two types of nutrients; macro and micro nutrients, where the macro nutrients are considered essential for in larger amounts the plant growth and should be incorporated to the substrate before planting, whereas the micro nutrients are only needed in small amounts, and they are mostly synthesised as the by-products of the macro nutrients. Both Nelson, 1996 and Bragg, 1998 classified the macro nutrients are mainly, nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), Sulphur (S), and even calcium (Ca), where the rest of the nutrients are regarded as micro nutrients. All these nutrient requirements become fully essential at transplanting period.

All the fertilizer application in the nursery is incorporated through fertigation, and each nursery decides on their own ratio or levels of each element to apply, that is monitored daily for pH, macro and trace elements. The main focus will be on the elements regarded as the macro elements since they are crucial before planting.

(a) Nitrogen (N)

Nitrogen application to seedlings, especially at the nursery is so essential since there is so much water being used and leaching of nutrients from the growing media and root zone (Allemann & Young, 2001). At a seedling stage, nitrogen is important for seed germination, the healthy plant and green colour of leaves. It is advisable to use optimum amounts of N fertilizer, in splits, more demand during first three weeks, therefore slightly reducing it as its loss is very high, especially where the there is a high run of water. The continuous constant N applications will result into seedlings having tall seedlings with weak stems and that will result into deteriorated seedling quality. Nitrogen is supplied in many fertilizer types; Double Ammonium Phosphate (DAP), LAN, UREA, and also in Ratio formulation (2:3:2, etc)

(b) Phosphorus (P)

Phosphorus promotes root development and thus ensures more vigorous growth. It is a very important element for all rooting crops, especially when planted in field, however they promote the good root development in all seedlings, ensuring good plant anchorage and good water and nutrient uptake. Bragg, 1998 highlights the most important function of phosphorus as the energy transfer during photosynthesis where it forms part of the Adenosine Triphosphate (ATP) molecule. The availability of phosphorus in the growing media can be affected by the high levels of pH, calcium and zinc. Phosphorus is available in various forms of Mono Ammonium Phosphate (MAP), Double Ammonium Phosphate (DAP), and also in Mono-potassium dihydrogen ortho-phosphate (KMP).

(c) Potassium (K)

According to Handreck and Black, 2005, the main function of potassium is to regulate the movement of solutes between the soils in the plant cells in order to balance the cations and anions.

(d) Calcium

Calcium is one of the major elements that are essential for healthy plant growth, regular cell division functions and strengthening cell walls of the plants but needed in lesser amounts (Marschner, 1995). Unlike other major elements like nitrogen, calcium is not added to standard fertigation in nurseries, instead it is incorporated in the growing media as limestone.

(e) Magnesium, Iron (Fe) and Manganese (Mn)

Handreck and Black, 2005 refers to the magnesium, manganese, and iron as the nutrients that are mainly essential for the chlorophyll production and the photosynthetic processes in plants.

(f) Boron (B)

Main function of boron is to aid in the formation of new cells at the root tips, stem ends and flower buds.

(g) Zinc (Zn)

Zinc is mainly responsible for the nitrogen usage and mobilization of nitrogen and the production of hormones controlling leaf expansion, stem and root elongation.

(h) Molybdenum (Mo)

Molybdenum aid with the nitrogen conversion from gas into soluble nitrogen compounds by the microorganisms. The leguminous crops have a special need for molybdenum above all other crops (Handreck and Black, 2005).

(i) Sulphur

Sulphur is said to contain amino acids, the building blocks of protein. According to Handreck and Black, 2005, the main importance of sulphur is to help the plant maintain its odour throughout all its growth stages.

(j) The use of Osmocote® (slow-release fertilizer)

Osmocote® is a slow nutrient-release inorganic fertilizer that greatly comprise of the N:P:K ratio, plus magnesium, sulphur, boron, copper, iron, manganese, molybdenum and zinc. It is coated with resin and vegetable oil, to allow the controlled release of nutrients throughout the production period. It is very useful and effective when used in nurseries since most nutrients get lost easily in damp environments, especially nitrogen. Osmocote® can be used on a wide range of plants; annuals and perennials, and even indoor ornamental plants. One must be careful when applying osmocote as it is costly, and needs to be applied in very small amounts, be incorporated and irrigated. Osmocote® can provide a long term effect of up to five months, depending on the temperature it is exposed to; at high temperatures, it does not last longer, whereas at lower to optimum temperatures, the lasting period is longer.

1.5.3 Biological properties of growing media

Growing media, especially organic based growing media are mostly preferred for many beneficial physical, chemical, and nutritional properties, and may even contain some microbes, of which some are of beneficial activity, whilst others might be harmful. These growing media may contain pathogens like bacteria and fungi, however, these can be treated, using sterilizers and pasteurizers before use (Noguera, et al, 2000). Some growing media like vermiculite are known to be completely sterile as they are exposed to certain high temperatures, up to 1°C when manufactured to kill some pathogens whereas some organic ones are not completely sterile as they contain some weed seeds, undecomposed dead insects, and some pathogens. When using composted bark, the benefit of the microbial activity that comes with it will help suppress common fungal pathogens and nematodes.

1.6 Seedling quality parameters

Seedlings are the plants, the young and growing ones. They have all the vegetative plant parts (roots, stems, and leaves) similar to a mature plant, however, they are very young, tender, and fragile. Like a young baby, the seedlings need a special care, nurturing and frequent and close monitoring. Generally, a healthy plant, especially the seedling should show the signs of vigour, hardiness and well developed to be established in an open field to a mature vegetable plant. According to Haase, 2008, the plant's physiological and morphological factors are the main parameters to determine the seedling quality, and these include leaf size and colour, root growth potential, uniformity, stem elongation growing upright, nutrient uptake, hardiness in withstanding optimum heat, cold, and moisture stress.

1.6.1 Root parameters

The roots are the first part that develop from the seed, two to three days after sowing, and they are located beneath the growing media. The primary functions of the roots are to anchor the plant into the soil (growing media) and to absorb water and nutrients from the soil and transport it through the stem to all the plant parts, especially the leaves in order to fulfil the major photosynthetic function (Wien, 1997). As they mature, they develop root hairs which assist further in absorbing water and the nutrients from the soil. Roots are very sensitive to heat, freezing spells, acidity, salinity, and other toxins that come into contact with the soil, therefore the entire plant rely on what the plant roots take up from the soil as it gets transported throughout the plant.

The roots absorb water and nutrients from the growing media using the root hairs. The root has the cortex – that stores some carbohydrates, and a xylem – that transports water and solutes, including nutrients from the soil to the leaves (Hufford, 1978). The importance of good physical properties of the growing media like; aeration, water holding capacity is essential to facilitate the transportation of water and these solutes up the plant.

1.6.2 Stem parameters

The primary functions of the stem are to support the plant parts growing above the ground, more especially the leaves, and also to facilitate the transportation of water, nutrients, and other internal fluids from the roots to the leaves (Wien, 1997). The external part of the stem is soft when the plant is young, and with the aid of calcium, they become strong as the plant matures, making it difficult for the insects and other pests like cutworm to cause harm.

The stem has the cell walls, that needs to be strong enough for the turgidity of the internal cells, well developed xylem cells to facilitate the effective transportation of water and solutes up the stem to the leaves (Hufford, 1978). The importance of nutrients like calcium are essential for the strong cell walls, and therefore, the nutrient balance in their application is crucial in the growing media (Hufford, 1978). According to Hufford, 1978, excessive nitrogen in the growing media might promote rapid growth, but results into elongated stems that are weak and eventually, they do not survive the transplanting phase.

1.6.3 Leaf parameters

The leaves are the main part of the green plants as they facilitate the major process of plant food manufacturing through photosynthesis. They have the green organelles known as chloroplast which interact with the radiant energy to manufacture sugars and starches. The leaves are the first determinants of vegetable plant's type, where one can tell the seedling type, if its cabbage, spinach, etc. growth stage as it is mostly measured in leaf numbers. They are also used to determine the soil or growing media's moisture status as they wilt when ran out of water. They are also the determinants of growing media's nutrient status and levels, especially nitrogen (N), phosphorus (P), and potassium (K), and this is determined by the colour of the leaves and the tip burn of the leaves (Allemann & Young, 2001). The green and healthy leaves represent the well fed leaves, especially with nitrogen, whilst purple leaves show the phosphorus deficiency, and the pale leaves indicate nitrogen deficiency, but this must not be confused with some diseases that might affect the seedlings.

The leaves are the greenest part of the plant, and they are the best indicators of any irregularities in the plant; either the shortage in water supply, element toxicity or deficiency, even the entire health of the plant. The leaves are the photosynthetic part of the plant. They have chloroplast pigment that interacts with radiant energy and solutes inside the leaf to form sugars in a form of sucrose during the process called photosynthesis (Hufford, 1978).

The leaf has the xylem for the transportation of solutes especially from the roots to the leaves, and also around the plant, the phloem for the transportation of food stored in the leaves to the other plant parts. The other important part of the leaf are the tiny holes within the epidermis, called stomata that has specialized cells surrounding it called guard cells. The guard cells are very important for the opening and closing of the stomata during the transpiration and respiration processes.

1.7 Containers used when using growing media

Commonly, the nurseries use two types of containers, the seedling trays and the plant pots. Seedling trays are generally effective when producing plants from seed for transplanting at a later stage, whereas plant pots are very effective when growing plants that require a deeper and wider root space where plants are grown up to a full and mature plant.

1.8 Features of containers

(a) Size, type and shape of the seedling container

The container, which the seed is planted into has a shallower depth than soil profile, therefore, its effective rooting depth is shallower than that of a field grown plant. Most nursery containers are made of plastic and polystyrene; therefore, they are not prone to any organic or biological decomposition and are reusable.

(b) Container height

Size and height of the container are important criteria, as they need to match seedling plant size at the point of sale. Plants with a longer rooting depth must be planted into the containers with a bigger volume, whereas shorter containers must be used for plants sold when seedling has grown shorter roots. When the height of the container is increased, the surface area is increased, rooting depth increases, and also the plant's water requirement increases (Bilderback, 1979). Plants sold with a larger root system must be planted into the containers with a volume that allows for the seedling's root growth and development.

(c) General condition of container

Most nursery containers are re-usable, they are commonly washed and dipped in the disinfectant solutions to get rid of the pathogens, making them safe and sterile for the next use. According to Summer, (2019, pers. comm.), new containers, particularly seedling trays will produce more uniform and high quality seedlings than the previously used seedling trays.

1.9 Seedling trays

Seedling trays are containers used to propagate plants in, mostly for seeds and cuttings. They are very effective when propagating small seeds in particular. Containers are available in a wide range of types and sizes; there are plain, open trays, divided trays, containers with detachable cavities. Plastic containers and polystyrene trays are most popular. Different shapes and sizes exist. Most plastic trays consist of 6's, 12's, 30's, whilst the polystyrene ones usually come in 90's, 100's, 120's, 180's, 200s, 220's, and 242 etc. (Mzobe, 2019, pers comm.)

The larger seedling trays with a higher number of cavities are more suitable to seedlings that require a very short growing period, or are used for plants with a tap root system (Bilderback, 1979). Vegetable seedlings are usually maintained for 4-6 weeks in the nursery. The longer the period of the seedlings in the seedling trays, the more extended the root growth, and the bigger the space they require. If seedlings are kept for an extended period in a small space, they become the root-bound, and possibly eventually die. According to Osborne, 2019, it is advisable to transplant seedlings that have grown beyond the seedling phase into plant pots, if transplanting them in to the open field is impossible at that time.

1.10 Plant pots

Plant pots are larger containers that are used to grow plants that have passed the seedling stage, or if seedlings need to stay in the nursery until they are bigger in size **(**Mastalerz, 1977**)**. Plant pots are available in a wide range of sizes, types, and shapes, and their use must be based on plant species, size, potential root zone extension, and the intended planting size of the plant.

Discussion

Seedlings are young plants that have just emerged from seed, therefore they are fragile and vulnerable to field and environmental conditions, they need a very conducive growing environment that is monitored every day and regularly. During olden days, field soils were only used and on open seedbeds, of which some emerging and small scale growers still do, however that practice carries an estimated risk 50% of emergence and survival (Landis, et al, 2008). For these reasons, majority of seedling producers have shifted completely to using growing media in varying forms. Most commercial seedling growers are even conducting many studies and have developed knowledge sharing platforms where some of the topics look more into varying types and properties of growing media, including the physical, chemical, nutritional and even biological properties of growing media.

Growing media, similar to ordinary soil is a substrate where plant roots grow, absorb water and nutrients from it. It is the combination of different particles of organic and inorganic material that are collected to provide for attributes like water holding capacity, air-filled porosity, pH, other physical, chemical, and nutritional properties.

It has been noted that the three general types of growing media that are commonly used (seed propagation, root cuttings, and transplant media) must be used according to their suitability, of which the mixture of the seed and root cutting media is mostly used in nurseries on seedling trays, of which transplant media is mainly suitable for transplanting in plant pots and it is much coarser than the others.

Wattle and pine bark growing media are the largely used types of growing media in South Africa due to its abundant availability, low and affordable cost, good physical properties, especially when used as a container medium.

There are nurseries, especially the small scale and emerging growers who still use composts and animal manures are used as growing media whereas some purchase it from the market, using it as an additional organic fertiliser. Through some studies, composts and manures are found to be very useful when used in mixtures with the ingredients that are poor in nutrient levels and poor physical properties like high clay content, very coarse textures, etc., whilst they have shown to be high in some nutrients, especially nitrogen, and to some extent phosphorus, of which they produce very tall plants with weak stems and leaves.

Vermicompost have shown good results and plant growth on *Brassica oleracea var. capitata* (cabbages) It can be used as a growing media whilst it can be used as an organic fertilizer as well due to its nutritional level lower than the one for manures. Some previous studies have shown that vermicompost improves physical properties of the growing media and soils by decreasing bulk density and increasing water holding capacity. In one study on the use of vermicompost, Hashemimajd, *et al*, 2006, used it in the mix with sand at varying levels of 15, 30 and 45% of the pot volume, using tomato and they only realized that at 15% rate, there is a significant differences compared to the 30 and 45%.

All studies done on peat suggested that usage of peat for horticultural use is needs patience as it is time consuming to harvest and process it; harvesting can take up to six years, stacking, drying, and milling can take up to twelve months, depending on the type of machinery or harvesting method used. Handreck & Black, 2005 stated that peat has an ability to keep nutrients from leaching out of the soil or growing medium, which may be advantageous when mixed with some growing media with a low water holding capacity, or be undesirable when mixed with others or used alone. Peat has a high acid with a pH (3 to 4), therefore making it difficult in making a good potting soil alone, it must be mixed with other ingredients that will have a higher pH, alkaline of greater than 8.

Coir takes a very long time to break down and decompose, making it very suitable for hydroponics because it can retain nutrients for later use by plants. Coir has been found to be rich in potassium, manganese, iron, copper, and zinc. Since coir is a made from coconut husks, produced in coastal areas, it comes with a high salt content, making it difficult to interact with most nutrients due to its high sodium content, most nurseries and horticulturalists avoid it, whilst Sunshine Seedlings Nursery leaches their coir with clean water for at least five days to get rid of these soluble salts.

Vermiculite is found to have a high cation exchange capacity, therefore it makes it able to hold air, nutrients and moisture that can be used later by plants. Van Schoor, et al, 1990 have conducted some studies on vermiculite and they found it to be helpful in promoting faster root growth and gives quick anchorage to young roots when mixed with peat, composted bark, and organic compost.

The use of sand is mainly for increasing porosity, however, their small particles can reduce aeration and drainage, therefore the mixture of small, medium to large particle size is important to consider. Most sands contain high levels of salinity that might be detrimental during seedling production, therefore it is recommended that the sand is washed with clean water to flush out the salts before use.

Most organic types of growing media have a significant amounts of nutrients, specifically nitrogen (N), phosphorus (P), and potassium (K), whereas the inorganic types have very less to none of these, except the micro nutrients. Organic growing media may on the other hand contain pathogens like bacteria and fungi, which will however be treated, using sterilizers and pasteurizers before use. Some growing media like vermiculite are known to be completely sterile as they are exposed to certain high temperatures, up to 1°C when manufactured, to kill some pathogens whereas some organic ones are not completely sterile as they contain some weed seeds, undecomposed dead insects, and some pathogens. elements like aluminium (Al), sulphur (S), iron (Fe), etc.

In Germany, they have conducted a study on assessing growing media quality using the Near-Infrared Spectroscopy, where they measured the chemical characteristics of the Chinese White Cabbage (*Brassica napus var. Chinensis*). According to Terhoeven-Urselmas, *et al*, 2008, the NRIS predicted the overall general chemical characteristics of peat and the fresh cabbage weights showed a far better rating than the dried ones.

Like all other plants, seedlings have all the vegetative plant parts (roots, stems, and leaves), however, they are very young and fragile, needing a special care, nurturing and frequent and close monitoring. Generally, a healthy plant, especially the seedling should show the signs of vigour, hardiness and well developed to be established in an open field to a mature vegetable plant. According to Haase, 2008, the plant's physiological and morphological factors are the main parameters to determine the seedling quality, and these include leaf size and colour, root growth potential, uniformity, stem elongation growing upright, nutrient uptake, hardiness in withstanding optimum heat, cold, and moisture stress.

Commonly, the nurseries use two types of containers, the seedling trays and the plant pots, of which when using them, one must consider type of the container, size, condition, type and size of crop grow and media type to use. This is mainly based on the potential root-zone size of the crop, intended level or growth stage of the crop to be planted, and the growing media type to use amongst the seeding, transplanting or for cuttings so that the particle size can be adjusted accordingly.

Whilst other elements are applied into fertigation, calcium is not added; therefore, the calcium pre-enrichment of growing media for production of seedlings has been investigated as a practice to enable the availability of calcium to the plant from as early as the sowing stage till seedling stage. Most nurseries rely on gypsum for this purpose, of which the additional pre-enrichment of calcium has not been proven to be necessary.

Conclusion

Growing media can be termed as a "simulated soil" that can be adjusted to any rooting depth, have its properties be altered in any particle size, nutrient levels, etc. to suit the plant requirements. There are various types of growing media available and used by various nurseries; organic and non-organic types. Most of the organic ones like peat, pine and wattle bark, compost and animal manures come with certain nutrients like nitrogen, and some disadvantages as well of weed seeds, diseases, insects, and some undesirable micro-organisms. The growing media also come with the desirable and undesirable physical, chemical and biological properties that vary according to type. The most desirable physical properties are water holding capacity, porosity and aeration, and most of the growing media discussed in this study have a good water holding capacity, except for sand, that is important in retaining water and nutrients for plant absorption and use.

Coir and vermiculite are the most desirable growing media in terms of water holding capacity, however, since coir is made of the coconut husks, grown in coastal areas, it comes with a high salinity content that requires a thorough leaching before use, whereas vermiculite comes with no nutrients but useful in water holding capacity. The most limiting factor of the growing media is the pH that is very acidic (like peat and pine bark) or very alkaline (like coir, compost, perlite, and vermiculite), as a result, the use of the pH stabilizers like gypsum and lime is very important. It is also important to have knowledge of the anatomy and physiological aspects of the plants. This is vital in understanding their growth habit, root types, leaf and stem types, and their interaction with water so that the water stress or over watering is avoided in every means.

True physical aspect of the growing media is defined by relationship between the air, water, the amount of solid particles and their arrangement in the growing media. This is very crucial in growing media selection, making own combinations and mixes. This will also influence the pre-enrichment choice, especially in terms of lime choice and amounts, in order to balance the growing media pH.

Most importantly, growing media should be treated as soil, the growers need to test it at the laboratory for all properties, especially the chemical and nutritional properties in order to be well informed about what it contains, and what is required to obtain a good crop.

Many studies on growing media have shown that whilst the nursery production has the fertigation programme running for most part of the nursery period, the use of pre-enrichment is mainly beneficial with the use of lime, gypsum just for the stabilization of growing media pH, the use of vermicompost is so beneficial in improving the physical, chemical, and nutritional status of the growing media.

Chapter 2

Preliminary investigation into particle size of growing media

2.1 Introduction

The balance of particle size in terms of (clay: sand: silt) is crucial in growing media as much as it is crucial to field soil. According to Fonteno, 1996, the particle size provides for easy distribution and uptake of irrigation water and nutrient uptake. Each particle size has its own contribution into the distribution of water and air porosity, therefore allowing for permissible infiltration, water-holding capacity, aeration within growing media in order for the seedlings to grow well. The importance of particle size balance even goes further to determine the physical properties of growing media like bulk density, total porosity, available and unavailable water, and the total moisture content (Fonteno, 1996). Many studies have also shown that some processes or activities like growing media handling, overworking it may alter the particle size of growing media, especially the pine, wattle bark, coir, and other organic types (Mzobe, 2019, pers. comm.).

The aggregate size for growing media varies similarly to soil; from fine to coarse, where silt and clay is finer than sand. According to Plaster, 1992, the ideal soil for optimum plant growth should be at least 40% sand, 35% silt, and 25% clay, therefore the growing media is aimed to be at this aggregate sizes in order to provide for the acceptable levels of physical properties, especially air porosity, water-holding capacity.

2.2 Objectives

The main objective of this exercise is to characterize the two growing media; pine and wattle bark, and to analyse the mixes prepared with these media for varying physical, chemical and nutritional properties.

The Sieve Analysis Test was performed on the Pine and Wattle bark growing media, they were then separated according to their particle sizes as obtained from the Sieve Analysis Test, after which where they were then analysed at the laboratory for nutritional properties.

2.3 Materials and Methods

The standard sieve analysis test that is used for general field soils, performed by Plesnik, *et. al*. (2011) of the Department of Civil & Environmental Engineering in Carleton University was followed.

The appropriate sieves with varying sizes (table 2.1) were obtained, prepared. and stacked with a pan at the bottom, so that the smallest particle size was above the pan, then stacked them with the largest particle size at the top in order to allow passing of smaller particles through to the bottom.

Table 2.1: The sieve numbers and sizes (Plesnik, *et. al*. 2011)

Sieve number	**Sieve size (mm)**
10	2,000
40	0,425
60	0,250
140	0,150
200	0,075
Pan	0,000

A representative growing media sample (for both wattle and pine bark) was obtained and measured about 500 g to 1 kg. each sample was then oven-dried at 110°C for ten minutes, thereafter, the oven-dried sample was poured onto the stack of sieves and covered the stack with a lid to prevent dust from escaping during the test. The stack of sieves was taken and placed on the shaker, then secured the shaker with the rubber ties before starting the shaker. The shaker was then set to run for 10 to 15 minutes and started the shaking process. When the shaking process was complete, the mass of each sieve and the retained growing media was weighed. The scale was set to zero before the container was placed on the scale and then poured the retained particles into the container in order to obtain its weight for each of the sieve and recorded each mass retained on each sieve. Some particles stuck in the openings were removed using a brush.

For each growing media type, the same process was repeated three times, to get at least a reasonable average mass to take up to cumulative mass. The calculated average mass ((Reading 1 +Reading 2 + Reading 3) ÷ 3) was therefore used to calculate cumulative mass (Grand Total of Average Retained Mass – Each Retained Mass per Sieve Number) up to total percent passed ((Each Retained Mass per Sieve Number ÷ Grand Total of Average Retained Mass) x 100).

2.4 Results and Discussion

Both wattle and pine bark were processed similarly, where a sample mass was limited to 500 grams. Both wattle and pine bark show almost the same amount (37% and 38%) of coarse particles at sieve number 10, medium sized particles being the next dominant particle size is the medium sizes, where again both wattle and pine bark showed to have 43% and 49.5% of particles on sieve number 40, 60, and 140. At sieve number 200, pine bark showed to be retaining up to 4%, whereas the wattle bark retained up to 12%. Both wattle and pine bark retained the same amount of 9% of silt at the pan, when all the macro particles of the growing media have landed on the above sieves (Table 2.2 & 2.3).

Table 2.2: Sieve Test Analysis and Results for Wattle Bark

Sieve number	Sieve size (mm)	Reading 1 (grams)	Reading 2 (grams)	Reading 3 (grams)	Average Mass retained in each sieve (grams)	Cumulative Mass (grams)	Total Percent Passed (%)
10	2,000	200,85	136,37	223,63	186,95	321,52	36,77
40	0,425	45,36	51,22	40,86	45,81	275,71	9,01
60	0,250	51,76	68,97	55,78	58,84	216,87	11,57
140	0,150	120,89	105,44	108,88	111,74	105,13	21,98
200	0,075	54,67	68,18	58,85	60,57	44,57	11,91
Pan	0,000	26,5	70,69	36,51	44,57	0,00	8,76
TOTAL		**500,03**	**500,87**	**524,51**	**508,47**		

Table 2.3: Sieve Test Analysis and Results for Pine Bark

Sieve number	Sieve size (mm)	Reading 1 (grams)	Reading 2 (grams)	Reading 3 (grams)	Average Mass retained in each sieve (grams)	Cumulative Mass (grams)	Total Percent Passed (%)
10	2,000	374,99	53,39	154,79	194,39	312,09	38,38
40	0,425	16,79	143,27	98	86,02	226,07	16,98
60	0,250	28,52	106,88	69,67	68,36	157,71	13,50
140	0,150	63,66	64,37	151,23	93,09	64,62	18,38
200	0,075	9,99	18,29	31,33	19,87	44,75	3,92
Pan	0,000	1,54	131,58	1,14	44,75	0,00	8,84
TOTAL		**495,49**	**517,78**	**506,16**	**506,48**		

According to (Plaster, 1997), the ideal soil for optimum plant growth should be at least 40% sand, 35% silt, and 25% clay, and the sieve test analysis conducted showed that the wattle bark had 37% coarse particles, 43% medium particles, and 21% fine particles, which, closely relate to the ideal particle distribution required for good plant growth. Pine bark showed to be comprising of 38% coarse particles, 49.5% medium particles, and 13% fine particles, which is also an acceptable as an ideal particle size composition for a good plant growth as it provides for good water holding capacity and balanced aeration.

Conclusion

Sieve test analysis is a very important tool mainly used to measure the particle size composition in soil, however it has been found to be useful in growing media as well. the ideal particle size composition allows for a good aeration and good water holding capacity. It has been found very important to oven dry the growing media, to allow the media particles to pass through the sieve holes when the sieves are being shaken during the sieve test analysis process, as moist growing media will be trapped at the sieves and restrict the free flow of especially the finer particles through the sieves. The importance of repeating the sieve analysis process, a least three times was also realized as it gave a reasonable average of the possibly particle size distribution, more especially by reducing the discrepancies that might happen during the experiment.

The whole sieve analysis process showed that both wattle and pine bark have reasonable balance of particle sizes, and their physical properties are of an optimum state for plant growth.

Chapter 3

Growing media analysis for physical, chemical, and nutritional properties

3.1 Aims

This chapter was aimed at determining the physical, chemical, and nutritional properties of the growing media selected for the project (wattle and pine bark, peat, coir, vermiculite, and Sunshine Seedlings mix) in order to determine the growing media's suitability for cropping, growing healthy and sound seedlings and therefore determine the additional elements or properties required to add on the growing media for adequate properties required for plant growth.

3.2 Objectives

The main objective of this chapter is to test for the:

- **Physical properties –** specifically the water holding capacity and air-filled porosity.
- **Chemical properties –** specifically the sodium (Na) and Acid Saturation (SAR).
- **Nutritional properties –** Nitrogen (N), Phosphorus (P), Potassium (K), and Calcium (Ca),

3.3 Introduction

The growing media is the substrate where plants, especially the small plants grow and it need to provide for the adequate, balanced physical, chemical, and nutritional properties. There is a wide range of organic and inorganic types of growing media available for use. Five growing media types were selected for the project; wattle bark, pine bark, vermiculite, coir, peat, compared to the Sunshine Seedlings (75% Coir, 13% Peat, and 12% Vermiculite) mix, in terms of all the properties, performance during seedling growth up to the mature stage of vegetable plants. Vermicompost was only tested as a pre-enriching agent in order to determine how much physical, chemical, and nutritional properties it contained.

3.4 Materials and Methods

This experiment was conducted at Cedara Salinity Laboratory, using the Australian Standard Method. The first exercise after the investigation of the properties was to eliminate the growing media types that show very high and very low levels of some properties in terms of tolerance levels as stipulated by Machado & Serralheiro, 2017 in table 3.1.

Table 3.1: Critical Physical and Chemical properties permissible levels for plant growth (Machado & Serralheiro, 2017).

Growing Media Properties	Threshold level
pH	5.5 – 6.5 kcl
Sodium	Not more than 2 mS/m
Calcium	Must always be greater than sodium levels
Air Filled Porosity	At least 20%
Water Holding Capacity	At least 40%

Five growing media types were used; wattle bark, pine bark, vermiculite, coir, peat, compared to the Sunshine Seedlings mix, and vermicompost was also analysed. The elements were analysed first where a representative sample of potting media of approximately 200 ml was taken whilst it was moist. It was further moistened with DH_2O (distilled water) until it was possible for water to just seep through the fingers when squeezed. From the moistened sample, material of 100 ml of firmly packed material was taken. The sample was placed loosely into a plastic container marked at each chosen sample size. A pressure of 10 kPa (0.102 kg/cm^2) was applied in order to compress the sample, which was then scooped out into a screw top plastic centrifuge container, then adding extracting solution that should give a 1.5 times the volume of the of each sample. The bottle was then sealed with the screw top lid, gently shaken the sample to disperse the media and placed the sample in an end – over – end shaker, turning at not more than 10 revs/minute (rpm) for 90 minutes. Samples were then centrifuged for 5 – 10 minutes at 3000 rpm. Using the METROHM, Johannesburg, South Africa.The samples were then analyzed for Electrical Conductivity (EC) and pH.

Sodium Adsorption Ratio (SAR) was determined by using the calculation (SAR = [Na] ÷ {([Ca] + [Mg]) ÷ 2}$^{0.5}$, where Na, Ca and Mg are elements concentrations that are expressed in $mmol_c$/L.

For the determination of **Air-filled porosity (AFP)**, the sample was filled up into the porous polyethylene beakers, sealed with gauze and secured by a rubber band to prevent the sample loss. The sealed beaker was dropped five times (in and out) from a height of 5 cm in the container filled with enough water to reach above the top of the beaker. At the 6th time, the beaker was pressed down into the container allowing the sample to take up enough water, permitting the beaker to stand by itself on the container surface. The beaker was then allowed to stand at the bottom of the container for 2 hours to allow complete the saturation of the sample. After 2 hours, the beaker was removed vertically from the container with caution to cover four holes in the bottom of the beaker with four fingers. The sample was allowed to drain completely for 30 minute and the filtrate was measured. The air-filled porosity (AFP) was calculated using the following equations:

$$\text{AFP (\%)} = \frac{V1}{V2} \times 100$$

Where: V1 = volume of water drained from the saturated sample and V2 = volume of the beaker.

When determining the **Water Holding Capacity (WHC)**, the samples were removed from the porous polyethylene beakers into the pre-weighed aluminium tray. The wet sample and tray were pre-weighed before the drying stage. The sample was allowed to dry at 100ºC for 4 hours in the drying oven (Labotec, Durban, South Africa). The sample was removed from the oven after 4 hours and allowed to cool in the desiccator before weighing. The total water holding capacity (WHC) was then calculated using the following equation:

$$\text{WHC} = \frac{M2 - M1}{V2} \times 100$$

Where: M1 = mass of the wet sample and tray, M2 = mass of the dry sample and tray and V2 = volume of the beaker.

3.5 Results and Discussion

The analytical analysis on Table 3.2 indicated the well balanced pH Sunshine Seedlings Standard Mix, wattle and pine bark ranging where it ranged from 5.5 to 6.33, of which it is ideal for plant growth. Wattle bark showed a significantly high calcium content than all other growing medium, however, pine bark and Sunshine Standard Seedlings Mix had very low calcium content compared to wattle bark, but according to Machado & Serralheiro, 2017, they were at optimum range because they were still at permissible levels because they were higher than sodium content.

Table 3.2: Laboratory analytical results for growing media tested for physical, chemical, and nutritional properties

	Soil pH (H_2O)	Na (mS/m)	Ca (meq/L)	SAR (meq/L)	AFP (%)	WHC (%)
Wattle Bark	6.33	0.27	7.15	0.14	8	58
Pine bark	6.26	0.97	1.15	1.02	19	54
Sunshine Seedling Mix	5.55	1.15	1.68	1.08	0.98	66
Vermiculite	7.12	0.19	0.08	0.81	30	41
Coir	6.90	0.19	0.06	0.90	17	58
Peat	6.00	0.16	0.58	0.26	18	70
Vermicompost	6.52	0.22	9.51	0.21	22	64

3.5.1 Physical properties of growing media

The basic physical properties of growing media are; water holding capacity, air-filled porosity, and bulk density. Based on the literature review done on the physical properties of growing media, porosity and water holding capacity were the most crucial to be tested for at the laboratory.

As indicated in Experimental Chapter 2, coir, peat, and vermiculite in a (5:1:1 ratio) were combined and used, and when the growing media tested, Peat showed a highest water holding capacity of 70%, followed by Coir (58%), and then Vermiculite (41%), whilst Vermiculite showed the significantly high air porosity (30%) than Coir (17%) and Peat (18%). Table 3.2

above shows the laboratory analysis of different growing media that are used at Sunshine Seedlings (Coir: Peat: Vermiculite) and Top Crop Nursery (Wattle and Pine bark). These growing media types are found to have 54 to 66% water holding capacity, of which, according to Machado & Serralheiro, 2017, for an optimum plant growth, the ideal substrate should have a water holding capacity of 40%. These levels way above the permissible thresholds (Table 3.1) are advantageous to the seedlings as the nursey conditions need not to run out of water.

3.5.2 Chemical and nutritional properties of growing media

Majority of plants grow best at slightly acidic pH ranging between 5.5 to 6.5. the main issue of pH is their interaction with plants as they play a major role on plant growth and the effect on nutrient availability to plants (Tisdale, *et al*, 1985). When pH was tested in pure three growing media (Vermiculite, Coir and Peat), Vermiculite showed the highest level of pH that it slightly alkaline, coir showing the more or less neutral pH or 6.9 whilst peat shows a good, acceptable pH level of 6. In table 3.2, all other chemical properties showed to be in acceptable levels and well balanced for optimum plant growth.

3.5.3 Conclusion

The physical properties of the tested growing media showed varying levels. Water holding capacity showed to be higher than the permissible levels whereas the air filled porosity was lower than the permissible levels. Overall, the nutritional properties of these tested growing media showed that they are within the permissible range.

Chapter 4

The Effect of Vermicompost Pre-enrichment on Vegetable Seedling Production

4.1 Introduction

Producing vegetables seedlings is mainly dependant on the quality of the substrate (growing media), temperature, moisture, and nutrition, especially nitrogen and phosphorus (Allemann & Young, 2001). The favourable environmental conditions, especially the climatic conditions promote early germination of the seeds, within five days, depending on the seed type, seed size, and sowing depth (Allemann & Young, 2001). The quality of the seedlings is a great measure at transplanting stage, where amongst the quality parameters, seedling size, leaf numbers, general appearance, absence of abnormalities, pests and diseases will ensure hardiness and successful establishment possibility during transplanting.

Most pure growing media do not have well balanced physical, nutritional and chemical properties to sustain the seedlings throughout the seedling growth stage. The balanced growing media mixes were developed to provide the balanced attributes, particularly the water holding capacity, pH, porosity. The pre-enrichment with vermicompost was mainly aimed at providing nutritional content which is cost-effective, and also to provide a little bit of water-holding capacity for the growing media. The vermicompost was obtained from John Brash Farm in Howick, made from 40% cattle kraal manure, 40% pine chips, and 20% chicken litter, which was then decomposed for 12 months under anaerobic conditions (Osborne, 2019, pers. comm.).

This study was aimed at determining the effect of organic fertilizer (vermicompost) addition at four different levels (0, 5, 10, 15 and 20%) to two nursery's standard mixes on seedling growth and development of vegetable seedlings, therefore sowing the vegetable seeds into different growing media types pre-enriched with vermicompost, at two different nurseries; Top Crop and Sunshine Seedlings® for the following reasons:

- Top Crop nursery uses pine and wattle bark growing medium whilst Sunshine Seedlings uses the seedling mix (75% Coir, 12% Vermiculite, 13% Peat + 0.2% Osmocote® granules).
- At Top Crop Nursery, growing media mixing is mainly done manually whereas at Sunshine Seedlings, growing media mixing is done using the mixing machine.
- The general nursery management also differs from the two nurseries.

4.2 Project Site A - Top Crop Nursery

The first part of the research project was conducted at Top Crop Nursery, situated approximately 20km, on the north-western side of Pietermaritzburg on Old Greytown road, near Albert Falls. The planning of the project was in May 2019, actual work begun on 27 June 2019 and completed on 26 September 2019.

4.2.1 Materials and Methods

Each growing media type bases (pure wattle bark, pure pine bark, 50% wattle + 50% pine bark, was mixed with varying, four levels of Vermicompost (0, 5, 10, 15, and 20%) where Three vegetable crops were used; Cabbage, Swiss Chard, and Green Pepper, replicated three times.

In order to be able to cater for the proportions of vermicompost to apply per treatment, and three crops, the 10 litre bucket was randomly filled up with growing media, then filled up the trays for each treatment, and each treatment which was made up of 9 seedling trays as indicated above, then 30 litres of growing media could fill up nine trays.

The seedling trays were kept at a nursery, using the experimental and comparative research design (nursery), using the Randomized Complete Block Design, under standard fertigation for a period of seven weeks where they were monitored on a daily basis during the first week, until all crops have emerged, then on weekly basis thereafter.

During the seedling production period, every Monday morning, each treatment, on each replication, each crop (cabbage, Swiss Chard, and pepper) was checked for the following parameters:

- **Seedling height** - was measured on weekly basis after the emergence by using a 30 cm ruler by randomly placing it vertically against each seedling, and the height will be recorded. According to Allemann & Young, 2001, most vegetable seedlings, especially cabbage seedlings should be ready for transplanting at 13 to 15 cm high.
- **Leaf numbers -** from week 1, leaves that have developed, regardless of size, were checked on all crops and all treatments. Five plants of every treatment were randomly checked for leaf numbers that have developed, regardless of size.
- **Root development** – was measured by pulling out by hand one seedling from every treatment, replication, and crop, observing the visibility of roots and the extent of them

throughout the seedling tray's hole. The observation was then rated from 1 to 4 (0 = None, 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent

- **Uniformity, pest, diseases**, and **general appearance** – this was checked randomly and visually during the checking of the seedling height and root development. Pest and disease infestation were rated (0-3), where 0 = no signs of pest or disease infestation, 1 = one to five diseases or pest infected plants noted, 2 = six to ten plants showing signs of pest or disease infestation, and 3 = more than ten plants showing signs of pest or diseases infestation. Uniformity and general appearance were rated (1-4), where 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent.
- **Chlorophyll content** on the leaves of the three crops was checked on all the treatments and their replications at a full seedling stage. A random five (5) seedlings from each replication for all the seedling (cabbage, Swiss chard, and pepper) were tested for chlorophyll content using the (Opti-Sciences ccm-200 plus, NH03051) chlorophyll meter (Opti-Sciences Inc., Hudson, USA) as indicated in Appendix: Figure14. The chlorophyll meter is useful in measuring chlorophyll content in C_3 and C_4 plants by alive, intact leaves for fertilizer management, especially nitrogen (Mashego, *et al*, 2012). Each leaf of the randomly sampled seedling was placed on the sensor, pressed for about five (5) seconds, and the meter will give the readings that were recorded in chlorophyll content index (cci). The average figure of the five readings was taken for each replication.
- **Dry matter**. At a full seedling stage, twenty seedlings tops (stem and leaves) of all crops were randomly cut by scissors from each replication, packed in brown paper packets, weighed on site for wet (fresh) mass using the RADWAG WTB 2000 weighing scale. All samples, per replication were then taken into the Cedara laboratory oven where they were oven dried for 48 hours at 105°C. they were then taken out and dry weights recorded.

Then, dry matter was calculated as follows:

$$\frac{\text{Fresh mass (g)} - \text{Dry mass (g)}}{\text{Fresh mass (g)}} \times 100$$

Table 4.1: Treatments at Top Crop Nursery.

Treatment no.	Description
1 (CONTROL[1])	30 litres Pure Pine bark + 0% Vermicompost
2 (CONTROL[2])	30 litres Pure Wattle bark + 0% Vermicompost
3 (CONTROL[3])	15 litres (50%) Pine bark + 15 litres (50%) Wattle bark + 0% Vermicompost
4	30 litres Pine bark + 5% (1.5 litres) Vermicompost
5	30 litres Pine bark + 10% (3.0 litres) Vermicompost
6	30 litres Pine bark + 15% (4.5 litres) Vermicompost
7	30 litres Pine bark + 20% (6.0 litres) Vermicompost
8	30 litres Wattle bark + 5% (1.5 litres) Vermicompost
9	30 litres Wattle bark + 10% (3.0 litres) Vermicompost
10	30 litres Wattle bark + 15% (4.5 litres) Vermicompost
11	30 litres Wattle bark + 20% (6.0 litres) Vermicompost
12	15 litres Pine + 15 litres Wattle bark + 5% (1.5 litres) Vermicompost
13	15 litres Pine + 15 litres Wattle bark + 10% (3.0 litres) Vermicompost
14	15 litres Pine + 15 litres Wattle bark + 15% (4.5 litres) Vermicompost
15	15 litres Pine + 15 litres Wattle bark + 20% (6.0 litres) Vermicompost

The following seedling trays were prepared:

- **No Vermicompost added (Treatment 1, 2, and 3)**
    - 9 seedling trays of wattle bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine + wattle bark, (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **5 % Vermicompost added (Treatment 4, 8, and 12)**
    - 9 seedling trays of wattle bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine + wattle bark, (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **10% Vermicompost added (Treatment 5, 9, and 11)**
    - 9 seedling trays of wattle bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine + wattle bark, (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **15% Vermicompost added (Treatment 6, 10, and 14)**
    - 9 seedling trays of wattle bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine + wattle bark, (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **20% Vermicompost added (Treatment 7, 11, and 15)**
    - 9 seedling trays of wattle bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine bark (3 Cabbage, 3 Swiss Chard, 3 Pepper)
    - 9 seedling trays of pine + wattle bark, (3 Cabbage, 3 Swiss Chard, 3 Pepper)

The experimental design used was a Randomized Complete Block Design (RCBD) and the treatments with their replications were arranged as shown in Table 4.2 to 4.4.

Table 4.2: Basic arrangement of treatments (1-15) in each replication (1-3) for cabbages at Top Crop Nursery (where T_n refers to Treatment number, C_n refers to Cabbage and Replication number)

$T_{11}C_1$	T_7C_1	T_2C_1	$T_{14}C_3$	T_9C_1
T_1C_2	T_8C_2	T_3C_2	$T_{13}C_2$	T_8C_3
$T_{10}C_2$	T_9C_3	T_4C_2	$T_{15}C_1$	T_7C_2
$T_{12}C_2$	$T_{10}C_3$	T_5C_1	T_3C_3	T_6C_1
T_2C_3	$T_{11}C_2$	T_6C_2	$T_{14}C_2$	T_5C_3
$T_{15}C_3$	$T_{12}C_1$	T_7C_3	$T_{13}C_1$	T_4C_3
T_4C_1	$T_{13}C_3$	T_8C_1	$T_{12}C_3$	T_3C_1
T_5C_2	$T_{14}C_1$	T_9C_2	$T_{15}C_2$	T_2C_2
T_6C_3	T_1C_1	$T_{11}C_3$	$T_{10}C_1$	T_1C_3

Table 4.3: Basic arrangement of treatments (1-15) in each replication (1-3) for Swiss Chard at Top Crop Nursery (where T_n refers to Treatment number, R_n refers to Swiss Chard and Replication number)

T_1SC_1	T_4SC_3	$T_{10}SC_2$	$T_{13}SC_3$	T_7SC_2
T_2SC_2	T_5SC_1	$T_{11}SC_1$	$T_{14}SC_2$	T_8SC_3
T_3SC_3	T_6SC_2	$T_{12}SC_3$	$T_{15}SC_1$	T_9SC_2
T_4SC_1	T_7SC_3	$T_{13}SC_2$	T_1SC_3	$T_{10}SC_1$
T_5SC_2	T_8SC_1	$T_{14}SC_3$	T_2SC_3	$T_{11}SC_3$
T_6SC_3	T_9SC_1	$T_{15}SC_2$	T_3SC_1	$T_{12}SC_2$
T_7SC_1	$T_{10}SC_3$	T_1SC_2	T_4SC_2	$T_{13}SC_1$
T_8SC_2	$T_{11}SC_2$	T_2SC_1	T_5SC_3	$T_{14}SC_1$
T_9SC_3	$T_{12}SC_1$	T_3SC_2	T_6SC_1	$T_{15}SC_3$

Table 4.4: Basic arrangement of treatments (1-15) in each replication (1-3) for Pepper at Top Crop Nursery (where T_n refers to Treatment number, R_n refers to Pepper and Replication number)

T_1P_1	T_3P_2	T_4P_1	$T_{15}P_3$	T_9P_1
T_2P_2	T_2P_3	T_5P_1	$T_{14}P_1$	T_8P_1
T_3P_3	T_1P_2	T_6P_2	$T_{13}P_3$	T_7P_3
T_4P_2	$T_{15}P_1$	T_7P_1	$T_{12}P_3$	T_6P_1
T_5P_3	$T_{14}P_2$	T_8P_2	$T_{11}P_2$	T_5P_2
T_6P_3	$T_{13}P_1$	T_9P_3	$T_{10}P_1$	T_4P_3
T_7P_2	$T_{12}P_2$	$T_{10}P_2$	$T_{15}P_2$	T_3P_1
T_8P_3	$T_{11}P_3$	$T_{11}P_1$	$T_{14}P_3$	T_2P_1
T_9P_2	$T_{10}P_3$	$T_{12}P_1$	$T_{13}P_2$	T_1P_3

Fertigation

At Top Crop Nursery, young seedlings with two cotyledons were fertilized with water containing an Electricity Conductivity (EC) of 250-450 mS/m, whereas the actively growing seedlings are treated with water of 550-650 mS/m, hardened grown seedlings required water application only to make them firm and stronger. Draining was done for approximately over 10 minutes to ensure that it did not feed the unintended seedlings.

Table 4.5 shows the fertilizer types and rates in which they were applied through fertigation per 1000 litres.

A micro jet irrigation system was fitted for every table with a manual valve controller and sprinkler heads which covered a 1.5 metres radius. The schedule was altered according to daily changes in weather conditions. During colder days, less irrigation was applied than during hot days.

Table 4.5: Fertilizer types and application rates used at Top Crop Nursery

Fertilizer/Element Type	Amount (per 1000 litres)
MAP	40 kg
LAN (28)	50 kg
KNO3	20 kg
Solubor or Ultrabor	4 kg
Sodium molybdate	60 grams

4.2.2 Results

During the seedlings production many quality parameters were looked at comparatively, recorded, done a statistical analysis of each using Genstat.

Sowing

Sowing at Top Crop Nursery was done twice, due to the sudden death and injury to pepper seedlings at week 4, it had to be redone. The objective of the study was to determine the effect of growing media on cabbage, Swiss Chard, and pepper.

Days to emergence

Germination was checked on all replications every day, from day one (19 June 2019) after sowing. Germination on all cabbages and Swiss Chard treatments was first noticed at the germination room on 24 June 2019, five (5) days after sowing (appendix table 1). Green pepper showed germination 12 days after sowing, of which thereafter all the trays showing germination were taken to the nursery. The statistical analysis showed no difference in this parameter within each crop type and the raw data (appendix table 1) was used to show the difference of days to emergence per crop.

Leaf number

All crops showed a uniform development of leaves throughout the growth stages. Appendix table 2 indicates the raw data of development of the number of leaves per each crop per week, for the entire production period. The statistical analysis in showed no significant differences and it was not used as the Annova tables showed zero and many blank spaces.

Seedling height

Statistically, all seedling sizes for all crops, treatments, and the crop-treatment interaction showed no significant difference, and the raw data was used on Appendix table 3.

Root development

There was no significant difference in the root development and the statistical analysis was not used. Appendix table 4 shows the raw data where the root development showed to vary per treatment, where all the crops showed better root development on pure wattle bark and wattle bark mixed with pine bark as well, and the increase in vermicompost showed no effect as the root development was good (rated 3) at all treatments.

Uniformity, pest, diseases, and general appearance.

After emergence, all seedlings showed a uniform growth pattern, however, pepper and Swiss Chard showed a very slight growth variation per treatment especially from week four of growth. Cabbage showed a better uniformity throughout the growing period with very low variations. According to Osborne, 2019, the slight uniformity variations were caused by the interrupted sprinkler positioning, ceasing the fertilizer additions in the fertigation showing treatment and crop response, particularly cabbage. There were no signs of pests and diseases, only one occurrence of downy mildew on cabbage, treatment 5, replication 3 (Appendix: Figure 13).

At week five after sowing, on 25 July, some damage was noticed on about 35% of pepper that could not have its cause established, therefore, pepper was then re-sown on 01 August 2019.

During harvesting of pepper, the algae was noted as a result of capping of the growing media (Appendix: Figure 9). This was more on treatment 12 and 14.

Chlorophyll content

The statistical analysis of the chlorophyll on seedlings at the Top Crop Nursery showed no significant differences in all three sources of variations; crop, treatment, and also the interaction of the crop and treatment.

Seedling mass

Statistical data analysis of wet and dry mass showed to be very high on cabbage than Swiss chard and pepper. There was no significant difference in fresh masses per treatments and their interaction with crops whilst there were significant differences in dry masses on crop, treatments and crop and treatment interaction. Generally, the significant differences in these mass figures were a result of varying leaf and stem sizes amongst the three crops' seedlings, cabbage showed a high dry mass yield than pepper and Swiss chard.

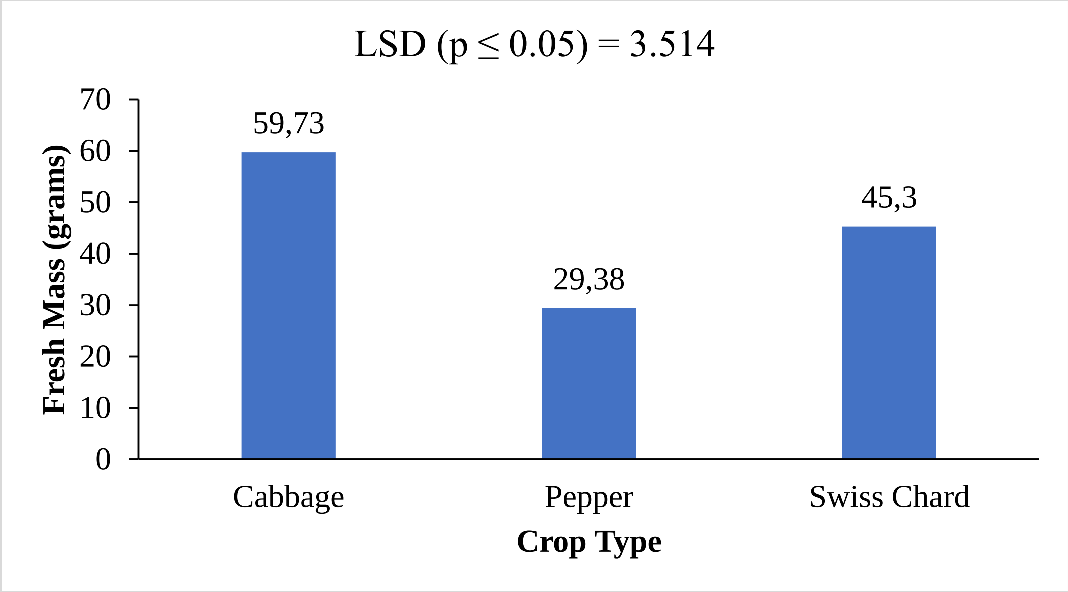

Figure 4.1: Overall comparison of seedling fresh mass of three crop types. Data presented as mean (n=20)

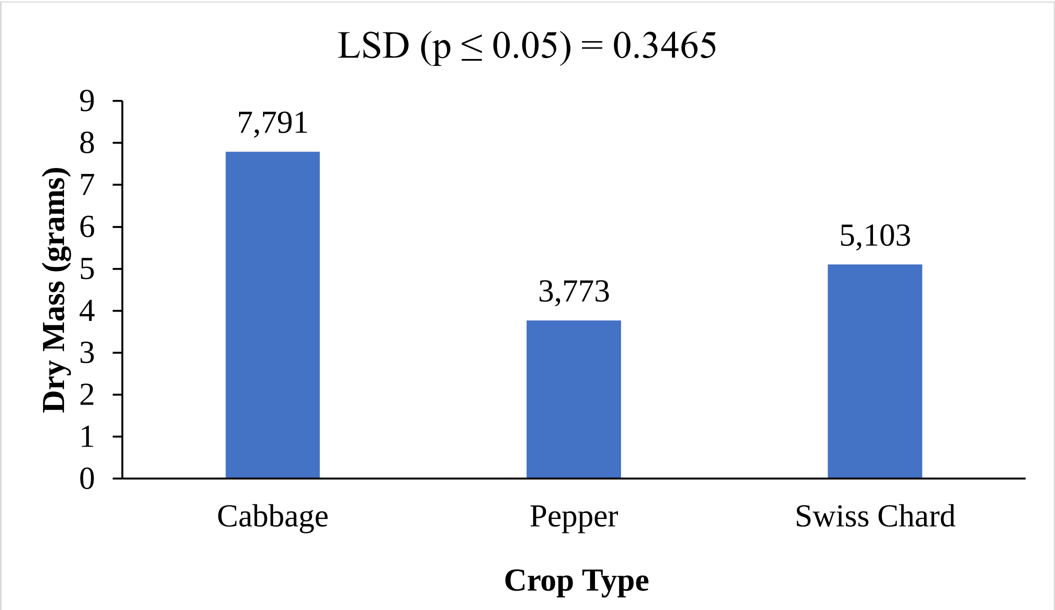

Figure 4.2: Overall comparison of seedling dry mass of three crop types. Data presented as mean (n=20)

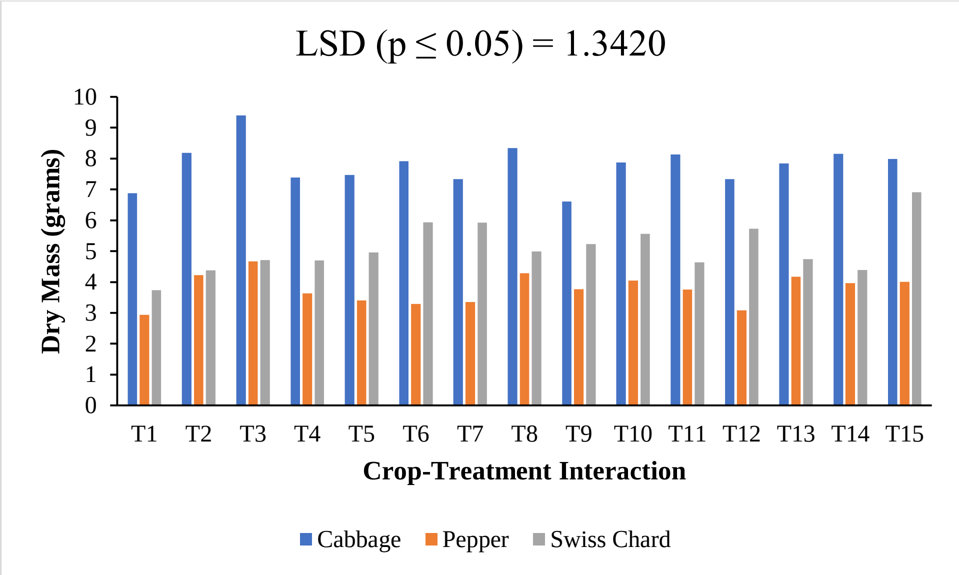

Figure 4.3: Overall comparison of dry matter for three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

4.3 Project Site B - Sunshine Seedlings®

The second part of the research project was conducted at Sunshine Seedlings® Nursery, situated approximately 8km, on the north-eastern side out of Pietermaritzburg on Chief Mhlabunzima (Old Wartburg) road. The planning of the project was conducted in June 2019, actual work begun on 01 August 2019 and completed on 26 September 2019. The standard growing media used at Sunshine Seedlings® Nursery was different from the one used at Top Crop Nursery, and the mixing and most processes were also different.

4.3.1 Materials and Methods

The Standard Sunshine Seedlings® growing media mix for vegetables is made up of (75% Coir, 12% Vermiculite, 13% Peat + 0.2% Osmocote® granules) was mixed with varying, four levels of Vermicompost (0, 5, 10, 15, and 20%). Three vegetable crops were used; Cabbage, Swiss Chard, and Green Pepper, replicated three times.

The seedling trays were kept at a nursery, using the experimental and comparative research design (nursery), using the Randomized Complete Block Design, under standard fertigation for a period of seven weeks where they were monitored on a daily basis during the first week, until all crops have emerged, then on weekly basis thereafter. According to Allemann & Young, 2001, cabbage seeds takes 7 to 10 days to germinate when sown at optimum conditions. Germination was checked on all the replications every day, from day one (01 August 2019) after sowing.

During the seedling production period, every Monday morning, each treatment, on each replication, each crop (cabbage, Swiss Chard, and pepper) was checked for the following parameters:

- **Seedling height -** was measured on weekly basis after the emergence by using a 30 cm ruler by randomly placing it vertically against each seedling, and the height will be recorded. According to Allemann & Young, 2001, most vegetable seedlings, especially cabbage seedlings should be ready for transplanting at 13 to 15 cm high.
- **Leaf numbers -** from week 1, leaves that have developed, regardless of size, were checked on all crops and all treatments. Five plants of every treatment were randomly checked for leaf numbers that have developed, regardless of size.

- **Root development** – was measured by pulling out by hand one seedling from every treatment, replication, and crop, observing the visibility of roots and the extent of them throughout the seedling tray's hole. The observation was then rated from 1 to 4 (0 = None, 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent
- **Uniformity, pest, diseases**, and **general appearance** – this was checked randomly and visually during the checking of the seedling height and root development. Pest and disease infestation were rated (0-3), where 0 = no signs of pest or disease infestation, 1 = one to five diseases or pest infected plants noted, 2 = six to ten plants showing signs of pest or disease infestation, and 3 = more than ten plants showing signs of pest or diseases infestation. Uniformity and general appearance were rated (1-4), where 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent.
- **Chlorophyll content** on the leaves of the three crops was checked on all the treatments and their replications at a full seedling stage. A random five (5) seedlings from each replication for all the seedling (cabbage, Swiss chard, and pepper) were tested for chlorophyll content using the (Opti-Sciences ccm-200 plus, NH03051) chlorophyll meter (Opti-Sciences Inc., Hudson, USA) as indicated in Appendix: Figure14. The chlorophyll meter is useful in measuring chlorophyll content in C_3 and C_4 plants by alive, intact leaves for fertilizer management, especially nitrogen (Mashego, *et al*, 2012). Each leaf of the randomly sampled seedling was placed on the sensor, pressed for about five (5) seconds, and the meter will give the readings that were recorded in chlorophyll content index (cci). The average figure of the five readings was taken for each replication.
- **Dry matter**. At a full seedling stage, twenty seedlings tops (stem and leaves) of all crops were randomly cut by scissors from each replication, packed in brown paper packets, weighed on site for wet (fresh) mass using the RADWAG WTB 2000 weighing scale. All samples, per replication were then taken into the Cedara laboratory oven where they were oven dried for 48 hours at 105°C. they were then taken out and dry weights recorded.

Then, dry matter was calculated as follows:

$$\frac{\textbf{Fresh mass (g) – Dry mass (g)}}{\textbf{Fresh mass (g)}} \textbf{ x 100}$$

Fertigation

Fertigation scheduling for vegetable seedlings at the nursery is influenced by the crop's growth stage. At Sunshine Seedlings® Nursery they apply a standard fertigation of water soluble 3:1:3 (38), at 0.75g per litre., and they do the application at an Electricity Conductivity (EC) reading of 1100 mS/cm. After four weeks of seedling growth stage, the seedlings are hardened where the fertilizer application is stopped, apply water only. The ornamental plants, grasses and cuttings can be used for draining any fertilizers in the irrigation system pipes because they do not harm them. Draining must be done for approximately over 10 minutes to ensure that it does not feed the wrong seedlings.

Micro jet irrigation system is fitted for every table with a manual valve controller, sprinkler head which covers 1.5 metres radius and full circumference of 3 metres. The schedule was done daily according the weather conditions. In low temperature days less irrigation was applied and a bit more during hot days.

Table 4.6: Treatments with three replications each at Sunshine Seedlings® Nursery

Treatment no.	Description
1 (CONTROL[1])	(50 litres) Sunshine Seedlings® Mix + 0% Vermicompost
2	(50 litres) Sunshine Seedlings® Mix + 5% (2.5 litres) Vermicompost
3	(50 litres) Sunshine Seedlings® Mix + 10% (5.0 litres) Vermicompost
4	(50 litres) Sunshine Seedlings® Mix + 15% (7.5 litres) Vermicompost
5	(50 litres) Sunshine Seedlings® Mix + 20% (10 litres) Vermicompost
6 (CONTROL[2])	(50 litres) Sunshine Seedlings® Mix (Without Osmocote®) + 0% Vermicompost

- **0% Vermicompost added (Treatment 1 and 6)**
    - 9 seedling trays of Sunshine Seedlings® mix (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **5 % Vermicompost added (Treatment 2)**

- 9 seedling trays of Sunshine Seedlings® mix (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **10% Vermicompost added (Treatment 3)**
  - 9 seedling trays of Sunshine Seedlings® mix (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **15% Vermicompost added (Treatment 4)**
  - 9 seedling trays of Sunshine Seedlings® mix (3 Cabbage, 3 Swiss Chard, 3 Pepper)

- **20% Vermicompost added (Treatment 5)**
  - 9 seedling trays of Sunshine Seedlings® mix (3 Cabbage, 3 Swiss Chard, 3 Pepper)

The experimental design used was a Randomized Complete Block Design (RCBD) and the treatments with their replications were arranged as shown in Table 4.7.

Table 4.7: Arrangement of treatments at Sunshine Seedlings® Nursery (where T_n refers to Treatment number, C_n – cabbage, SC_n – Swiss Chard, P_n – Pepper) refers to Replication number)

T_6P_3	T_3P_1	T_2SC_3	T_4SC_1	T_5C_2	T_1C_2
T_4P_1	T_5P_3	T_6SC_2	T_3SC_2	T_3C_1	T_6C_2
T_2P_1	T_2P_3	T_5SC_3	T_6SC_3	T_2C_3	T_3C_3
T_3P_3	T_5P_2	T_6SC_1	T_5SC_2	T_1C_1	T_5C_1
T_6P_2	T_1P_2	T_2SC_1	T_1SC_1	T_2C_1	T_6C_3
T_4P_2	T_3P_2	T_4SC_2	T_3SC_3	T_2C_2	T_4C_2
T_5P_1	T_4P_3	T_3SC_1	T_4SC_3	T_4C_3	T_3C_2
T_1P_1	T_6P_1	T_1SC_2	T_1SC_3	T_5C_3	T_4C_1
T_1P_3	T_2P_2	T_2SC_2	T_5SC_1	T_6C_1	T_1C_3

4.3.2 Results

During the seedlings production many quality parameters were looked at comparatively, recorded, done a statistical analysis of each using Genstat.

Sowing

The sowing operation was done and concluded on 1 August 2019 at Sunshine Seedlings® Nurseries. Sunshine Seedlings® have a bulk mixer where the growing media has been mixed for various types of crops, where for vegetable seedlings, the standard mixture of (75% Coir, 13% Peat, and 12% Vermiculite, plus 0.2% Osmocote®) is pre-mixed per ton. The seedling trays were prepared, and using the URBANAT mechanical sowing machine, sown with three crops; cabbage, Swiss Chard, and pepper. All trays placed at the germination room, of which afterwards, all the trays were taken to the nursery, where they were kept for nine weeks.

Days to emergence

Germination on all cabbages and Swiss Chard treatments was first noticed at the germination room after five days of sowing. Green pepper showed germination 12 days after sowing, of which thereafter all the trays showing germination were taken to the nursery.

The statistical analysis showed no significant differences with regards to days to emergence as all the cabbages and Swiss chard emerged on day five (5), whilst all the pepper emerged on day twelve (12).

Leaf numbers

All crops showed a uniform development of leaves throughout the growth stage. The statistical analysis showed no significant differences per each crop, treatment and also in the crop and treatment interaction, the raw data was then used and it is shown on Appendix table 9.

Seedling height

From week 1, the seedling height was measured on weekly basis after emergence. In all crops, and treatments, the seedlings were carefully pulled out of the tray, placed on the table and a 30 cm ruler placed parallel to the seedling, and measured from the roots to the tip of the plant as shown in. According to Allemann & Young, 2001, most vegetable seedlings, especially the cabbage seedlings should be ready for transplanting at 13 to 15 cm high. Statistically, all seedling height for all crops, treatments, and the crop-treatment interaction showed no significant difference and the raw data is shown on Appendix table 10.

Root development

The seedlings that had not formed roots or those starting to form their roots came out without growing media when pulled out, and by week three, the root development started to be firm and deep. The root development showed to improve with time, as seedling growth stage progressed, and the main crucial measure being at harvest (week 7). The statistical analysis of root development at Sunshine Seedlings showed no significant difference per treatment, per crop and also the crop-treatment interaction, the raw data on Appendix table 11 was used. Only treatment 6 (no vermicompost, no osmocote) that showed poorer root development (rated 1) than the rest of the treatments.

Uniformity, pest, diseases, and general appearance.

After emergence, all seedlings showed a uniform growth pattern, however, cabbage and Swiss Chard showed better crop strength and firmness. Out of the two controls; treatment 1 and 6, only treatment 6 showed the slow growth, poorest root development, smallest seedling size out of them all.

There were no signs of pests and major diseases, only one occurrence of downy mildew on treatment 6, replication 2 on cabbage.

Overall general appearance of the seedlings was good, the quality of the seedlings was acceptable through appearance, during parameter monitoring, even at full seedling stage. The only deteriorating factor realized was the use of the 220 tray sizes, that showed to restrict enough air flow for the seedlings and their leaf capacity extended, especially on Swiss Chard and cabbage. Most of the seedlings showed some chlorosis on the bottom leaves, and some showed downy mildew.

Generally, the effect of osmocote® has shown positive results in all the parameters. Treatment 6 as the second control without any osmocote®, showed the poor uniformity and general appearance when compared to other treatments. The additions of vermicompost showed a little or no significant effect on the parameters, however, on pepper and Swiss chard, a taller growth is seen at vermicompost rates of 15 to 20% (treatment 4 and 5).

Chlorophyll content

The statistical analysis of the chlorophyll content on seedlings at the Sunshine Seedlings® Nursery showed significant differences in all three sources of variations; crop, treatment, and also the interaction of the crop and treatment. Swiss chard showed to have highest chlorophyll content than the rest of the seedling crop types, where the treatments 2, 4, 5, and 6 orderly showed the better chlorophyll content, and with regards to crop and treatment interaction, treatment 4, 2, and 5 orderly showed the greater interaction, where in all of them cabbage was dominant, followed by cabbage then pepper.

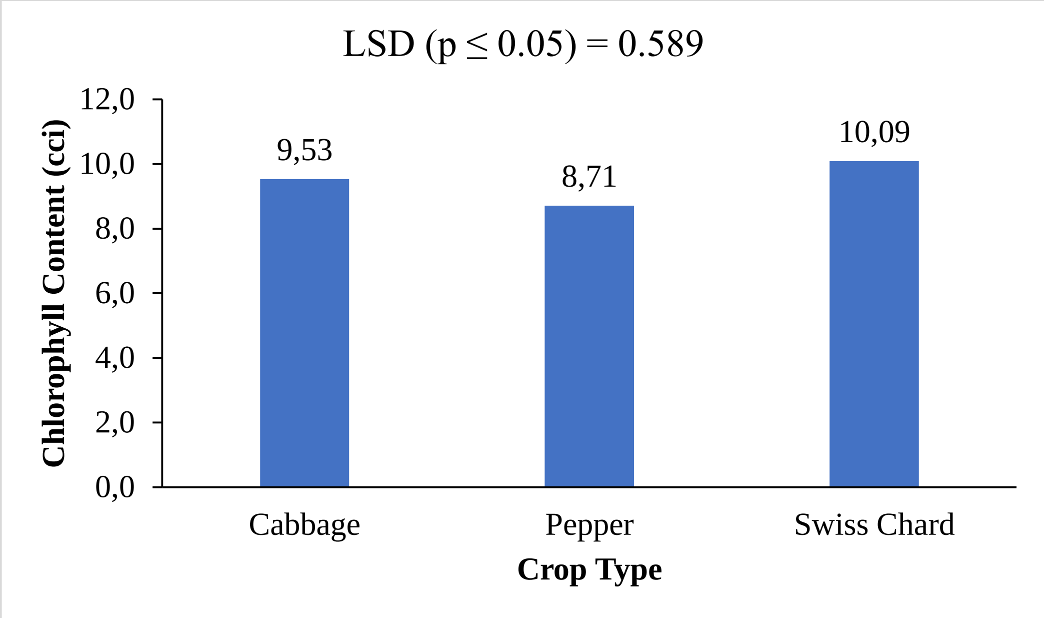

Figure 4.4: Overall comparison of chlorophyll of three crop types. Data presented as mean (n=20)

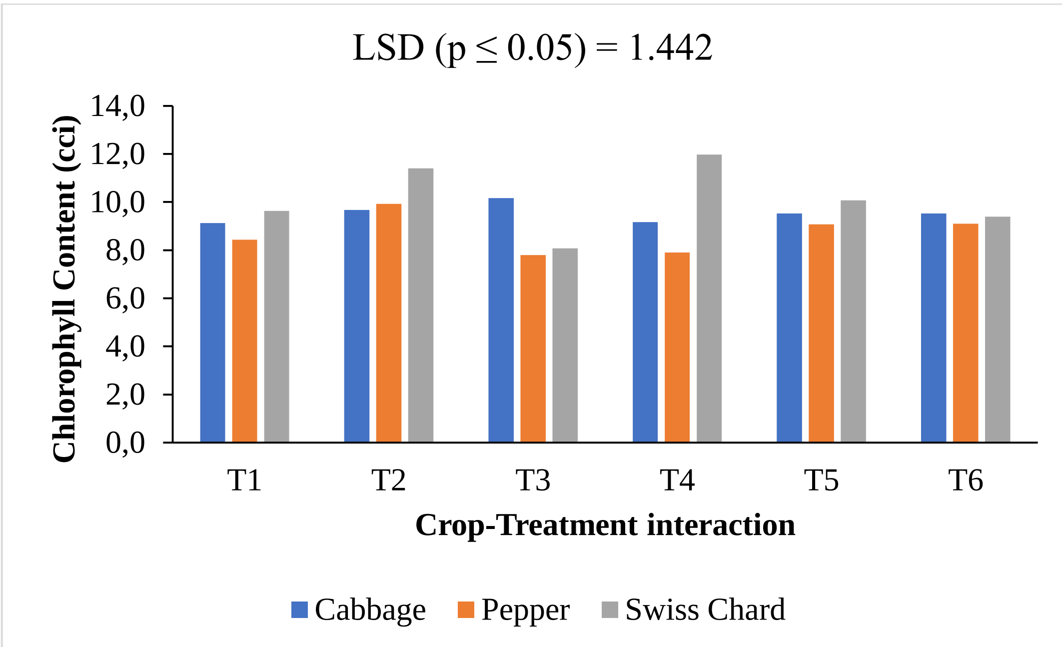

Figure 4.5: Overall comparison of chlorophyll of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

Seedling mass

Both the raw and statistical data of fresh and dry mass showed to be very high on cabbage than Swiss chard and pepper. There was no significant difference in wet masses per treatments and their interaction with crops whilst there were significant differences in dry masses on crop, treatments and crop and treatment interaction. Generally, the significant differences in these mass figures are a result of varying leaf and stem sizes amongst the three crops' seedlings, cabbage showed a high dry mass yield than pepper and Swiss chard. In a descending order, treatment 2, 3, 5, and 4 showed a high significant mass for dry mass.

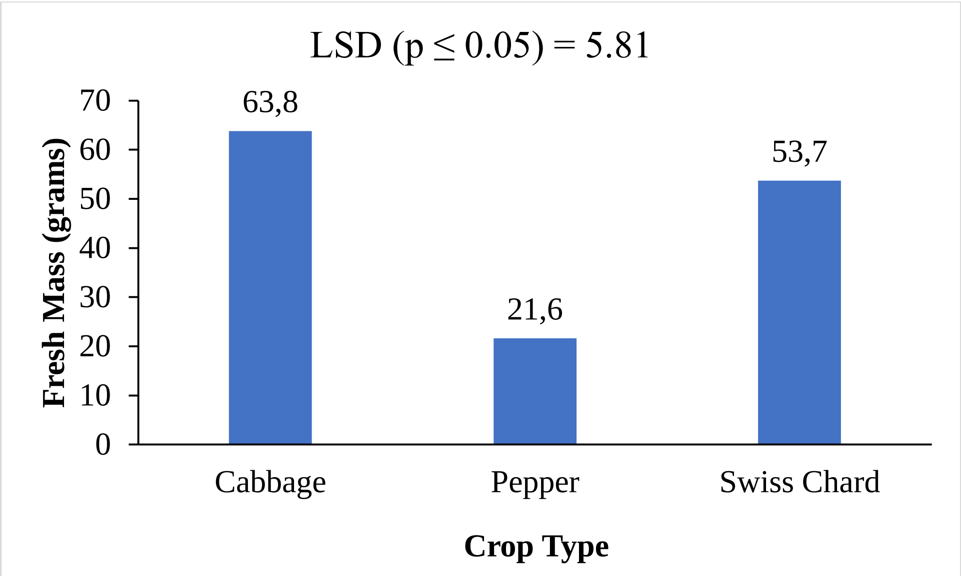

Figure 4.6: Overall comparison of seedling fresh mass of three crop types. Data presented as mean (n=20)

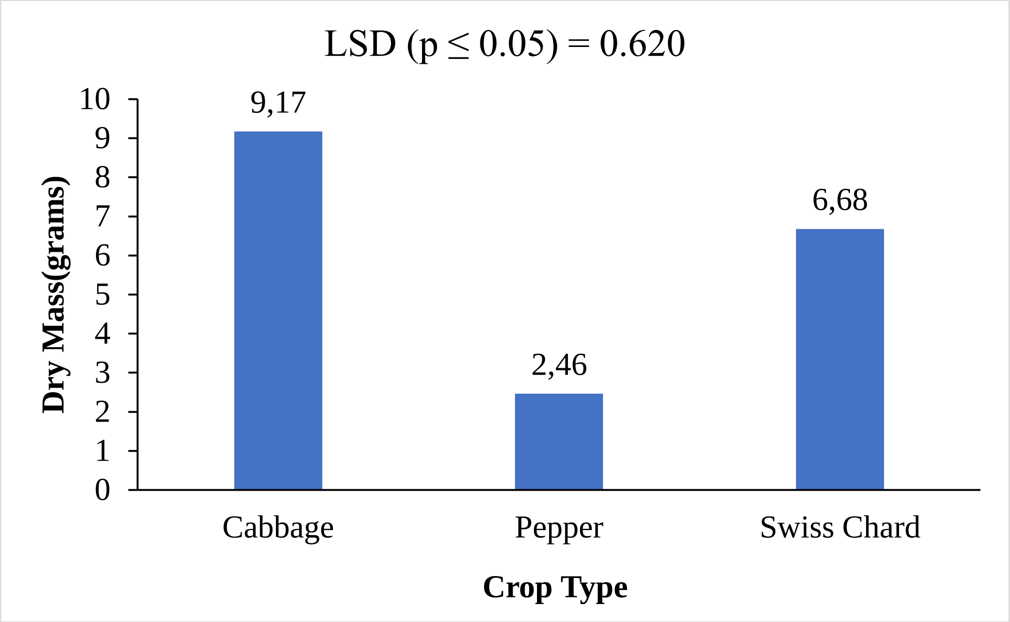

Figure 4.7: Overall comparison of seedling dry mass of three crop types. Data presented as mean (n=20)

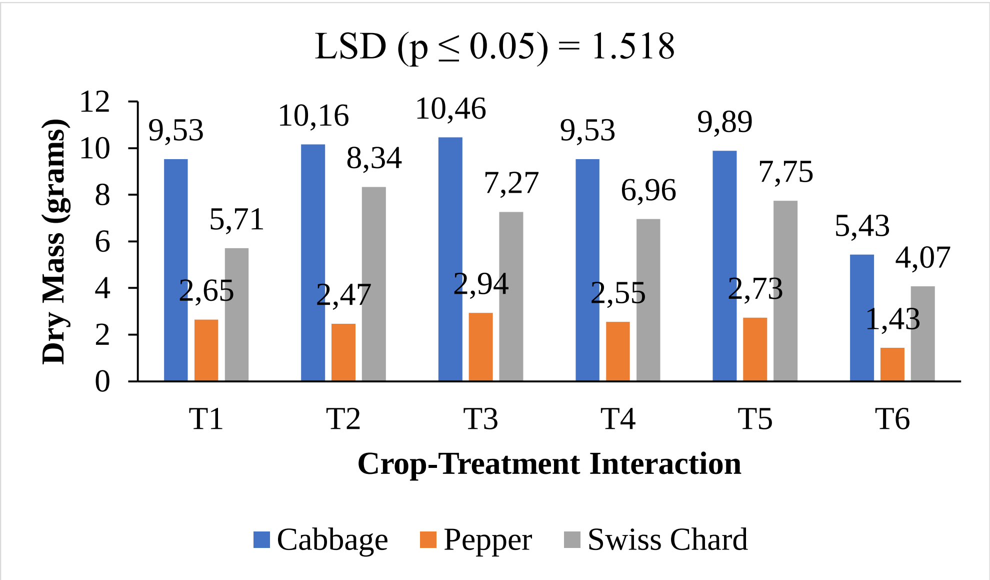

Figure 4.8: Overall comparison of dry mass of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

4.4 Discussion and Conclusion

Production of seedlings is the beginning of most vegetable crops' life from seed for a period of about six weeks, and throughout this period, extra care is needed to produce a healthy vegetable seedling that will enable successful growth in an open field, tunnels, or any chosen facility to produce the vegetable crop. The choice and composition of growing media is very important, especially to provide and balance all the essential growing media properties; especially physical and chemical properties (Handreck & Black, 1994). Where certain nutrients are not supplied by the growing media, pre-enrichment and fertigation is used.

While certain nurseries such as Top Crop Nursery use the organic growing media, which, through laboratory analysis showed to be of good physical and chemical properties, especially the aeration and pH, which is so detrimental to the vegetable seedling growth. The timing of the growing media mixture at Sunshine Seedlings® has ensured the elimination of risk factors that are associated with salinity of coir, nutrient trapping of peat and high water holding capacity of vermiculite.

The period of sowing has shown to have an effect on the growth of seedlings and number of days it takes to be ready for transplanting. Sowing during cold months have shown a length of time is takes to germination, and even the entire growth of the seedlings has shown to be extended by a week. On the positive note, producing seedlings during winter months have shown to produce more hardy and healthier seedlings, simply because the conditions during this time do not favour many pathogens, and also the heat stress is reduced (Allemann & Young, 2001).

The effect of vermicompost has shown a noticeable impact on most parameters when added on wattle pine bark, especially from 10 to 20% whilst wattle bark has shown to have a positive impact on most parameters, even when 0-5% of vermicompost is applied, it also showed to be of a good mixture combination to the pine bark, whilst pine bark alone showed to be less responsive on many parameters. On the other hand, vermicompost has shown very less effect at Sunshine Seedlings® where the growing media standard mix includes osmocote®, as osmocote® proved to be more influential on all seedling growth parameters, particularly the root development that proved to be much better than the seedlings grown from wattle and pine bark, even the Sunshine Seedlings® standard mix without the use of osmocote®.

The seedling size, leaf colours, number of leaves had no significant differences from both project sites. The general appearance of the seedlings was not much different visually, except for the texture and hardiness. The seedlings at Sunshine Seedlings® showed a stronger texture, better hardiness than the ones at Top Crop Nursery. The two project sites differ as well with their fertigation timing, where Top Crop Nursery use a combination of fertilizers whereas Sunshine Seedlings® they only use the 3:1:3 (38), but understandably, Sunshine Seedlings® uses Peat and vermiculite in their growing media mixes plus osmocote®, which play a major role in water holding capacity and nutrients slow release effect by osmocote®.

The choice of growing media must be aimed at providing the desired properties, particularly; water holding capacity, air-filled porosity, and a balanced pH, at least between 5.5 and 6.5 (Bailey, 1996).

To achieve close to all general seedling quality parameters, this study has taught that the basic nursery management is important to maintain. Vermicompost has not proved to provide the equivalent or competitive results on the seedling quality parameters, yet it has shown positive effects only when incorporated with wattle and pine bark. Overall, the Sunshine Seedlings® mix has shown to produce better quality seedlings than the wattle and pine bark. The use of osmocote® has proved to be effective in the general quality parameters when added to the Sunshine Seedlings® standard mix, however, this was experimented at two different sites that use mostly different practices, management, and also slight different growing conditions.

Root development at the Top Crop Nursery Trial showed to vary per treatment, where all the crops showed an improved root development on pure wattle bark and when mixed with pine bark as well, and the increase in vermicompost showed no effect as the root development is good at all levels on vermicompost addition (5-20%), meaning that wattle bark showed a positive impact on the root development of the vegetable seedlings. Cabbage showed an interesting response on treatment 2, pure wattle bark, with no vermiculite added.

For the precise and better comparisons, it was learnt that the same study be conducted on the same site where all the growing media types will be used in similar types of growing conditions.

Chapter 5

Seedlings' Nutritional Elements Analysis

5.1 Introduction

The fresh biomass (wet mass) samples taken during seedlings harvesting were taken to the Plant Laboratory at Cedara for processing and analysis. This process provided the nutrient types and rates at which each seedlings' crop type was able to extract from the each given substrate during the seedling production period.

5.2 Aims

The main aim of this exercise was to look at, and compare the nutritional level uptake by seedlings.

5.3 Objectives

- Oven drying of fresh biomass sampled and collected at harvesting
- Laboratory analysis to determine the nutrient uptake by seedlings
- Compare the results

5.4 Materials and Methods

This experiment was conducted at Cedara Plant Laboratory, using the Automated Dumas Dry Combustion Method using a LECO CNS 2000 (de Figueiredo, M. & Thurtell, L. 1998). In preparing the samples, three rows of 11 sample cups were placed on trays which were stored on trolleys for batch handling. As a routine procedure for all determinations, a check sample and a reagent blank was placed in each row of eleven sample cups. There were three check samples and three check samples and three blanks for every batch. An amount of 0,5g of oven-dried plant sample was weighed into a 100 ml pre-weighed beaker, ashed overnight in a furnace at 450°C. The beaker was removed and ashed contents, cool and then wet the material with a few drops of distilled water.

Using a Fortuna Optifix dispenser, a 25 ml of a freshly prepared 1:9 HCl solution was added and stirred using a rubber policeman, rinsing the rod in a beaker of distilled water in between each sample. Sample was then filtered through Advantec 5B: 90 mm diameter filter papers into a clean rack of sample cups. The filtered ashed sample was dissolved in de-ionized water at a ratio of 5:20 and then taken into the ICP Expert machine for determination of elements.

5.5 Results and Discussion

The statistical analysis was done using Genstat. The nutritional uptake by three crops was looked at per individual nutrient according to their function and importance in crop growth, and also the crop's response.

5.5.1 Top Crop Nursery

(a) Nitrogen (N)

The statistical analysis of N uptake showed that overall and through crop and treatment interaction, pepper had the highest N uptake, followed by Swiss Chard, then cabbage, whilst the treatments showed a varying significant differences of N uptake from treatment 1 to 15, where the applied vermicompost levels show no relation to N uptake.

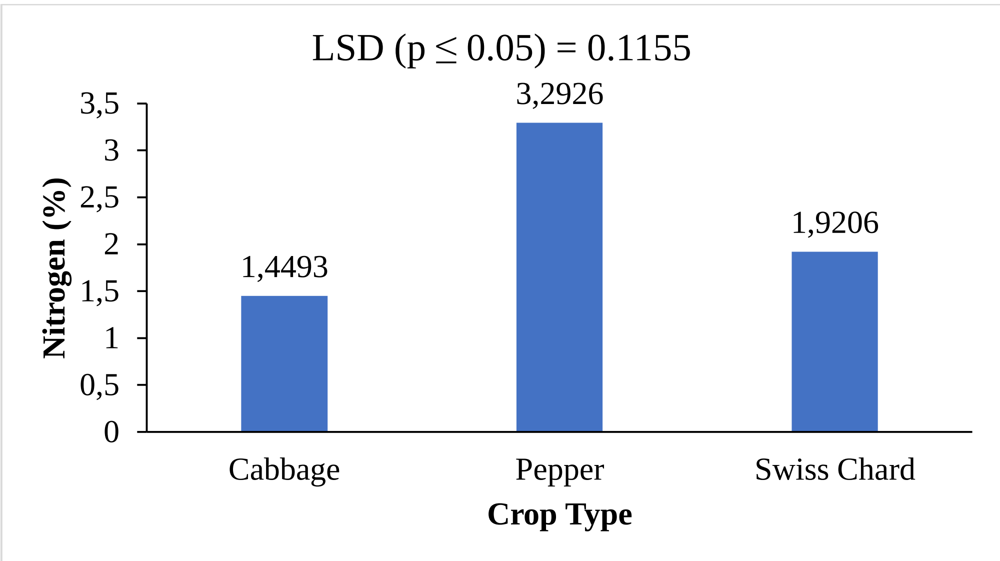

Figure 5.1: Overall comparison of nitrogen uptake of three crop types. Data presented as mean (n=20)

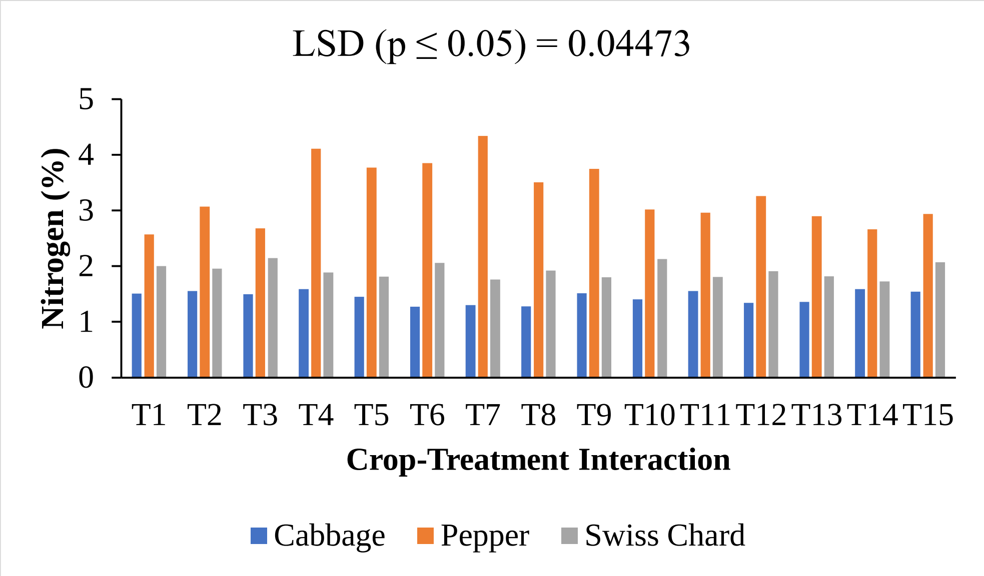

Figure 5.2: Overall comparison of nitrogen uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

(b) Phosphorus (P)

Phosphorus is known for its slow solubility, therefore slow absorption by plants. The statistical analysis of P uptake by the seedlings showed that overall, the three seedlings managed to take up a mean of only 1%, where Swiss Chard showed a better P uptake than pepper and cabbage (figure 5.3), where the crop-treatment interaction showed no relation or direct effect of vermicompost pre-enrichment (treatment 2-15) as the results showed great variation from treatment 1 to 15 (Figure 5.4). The better and earlier response or uptake by Swiss Chard was in line with the physiological factors of the three crops, as according to Allemann & Young, 2001, Swiss Chard get ready for harvesting almost twenty days earlier than cabbage and pepper.

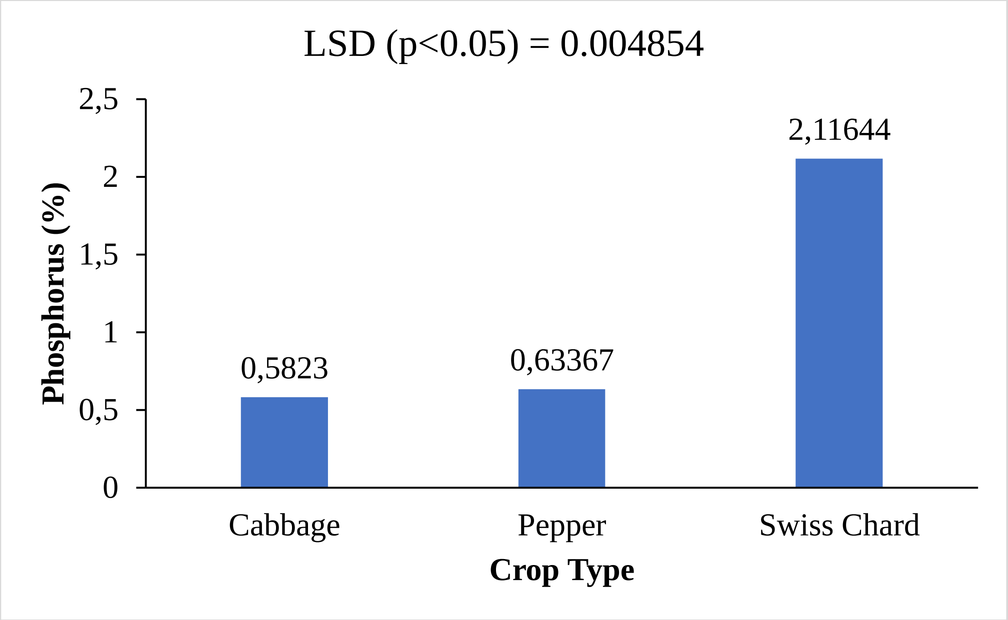

Figure 5.3: Overall comparison of phosphorus uptake of three crop types. Data presented as mean (n=20)

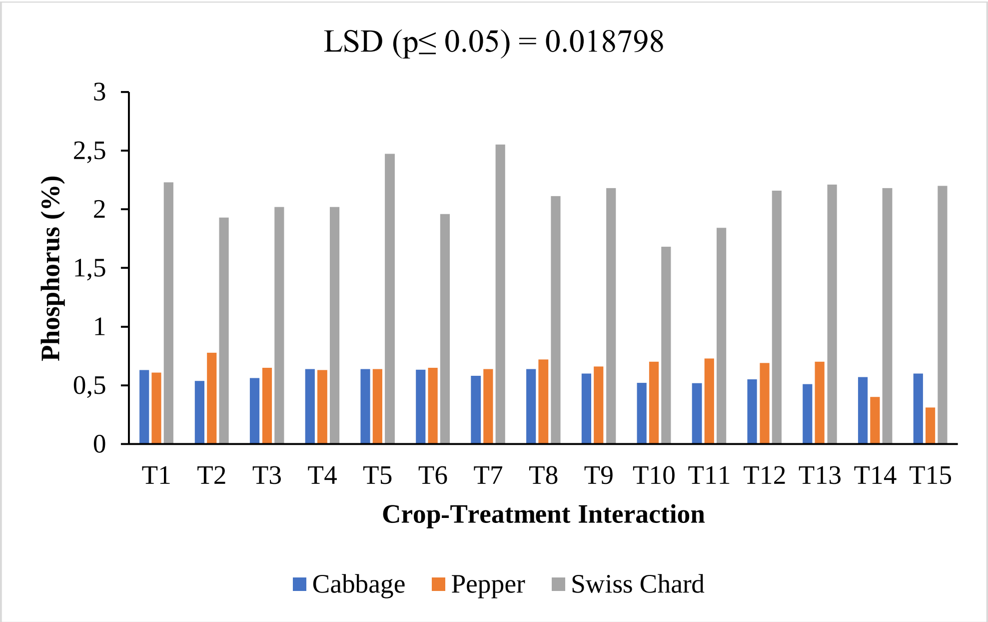

Figure 5.4: Overall comparison of phosphorus uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

(c) Potassium (K) and Boron (B)

Figure 5.5 and 5.6 showed a balanced K uptake by three crop types, however Swiss Chard had the highest K uptake than cabbage by about a percentage. This indicated a good movement of solutes through the plant, from the substrate (growing media) throughout the plant cells. Boron showed the same uptake as potassium (Figure 5.7 and 5.8).

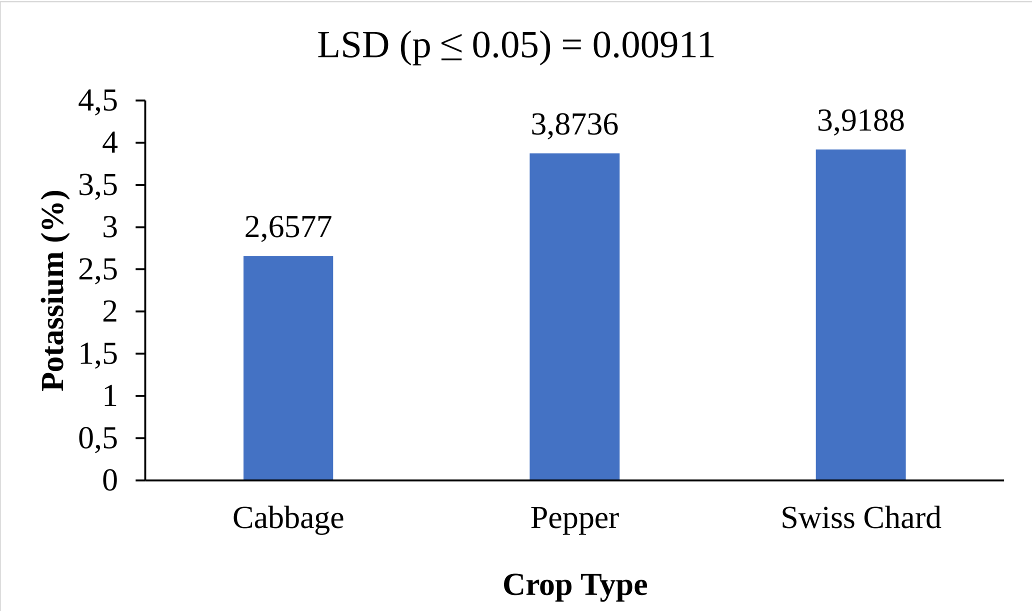

Figure 5.5: Overall comparison of potassium uptake of three crop types. Data presented as mean (n=20)

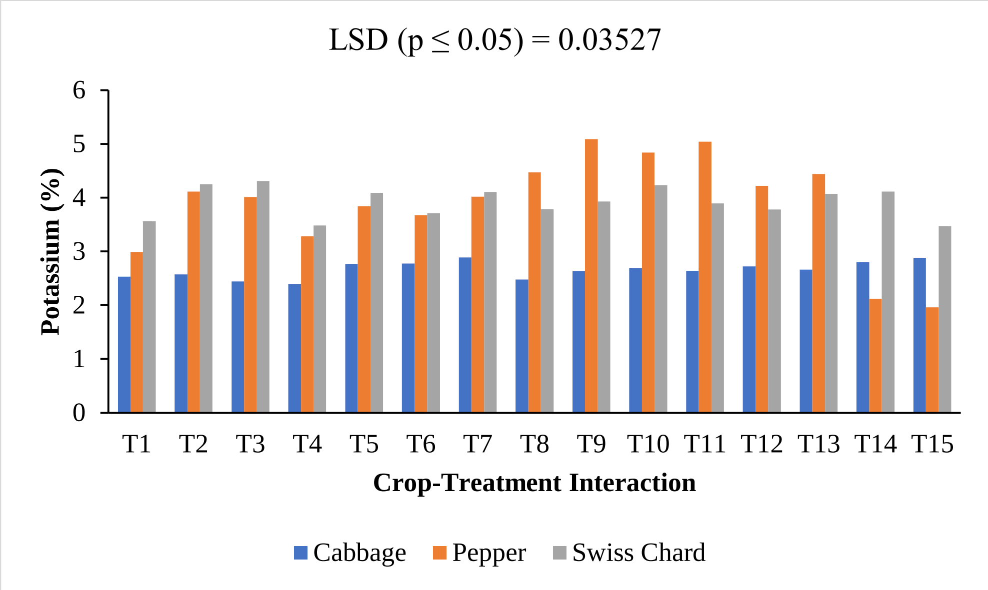

Figure 5.6: Overall comparison of potassium uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

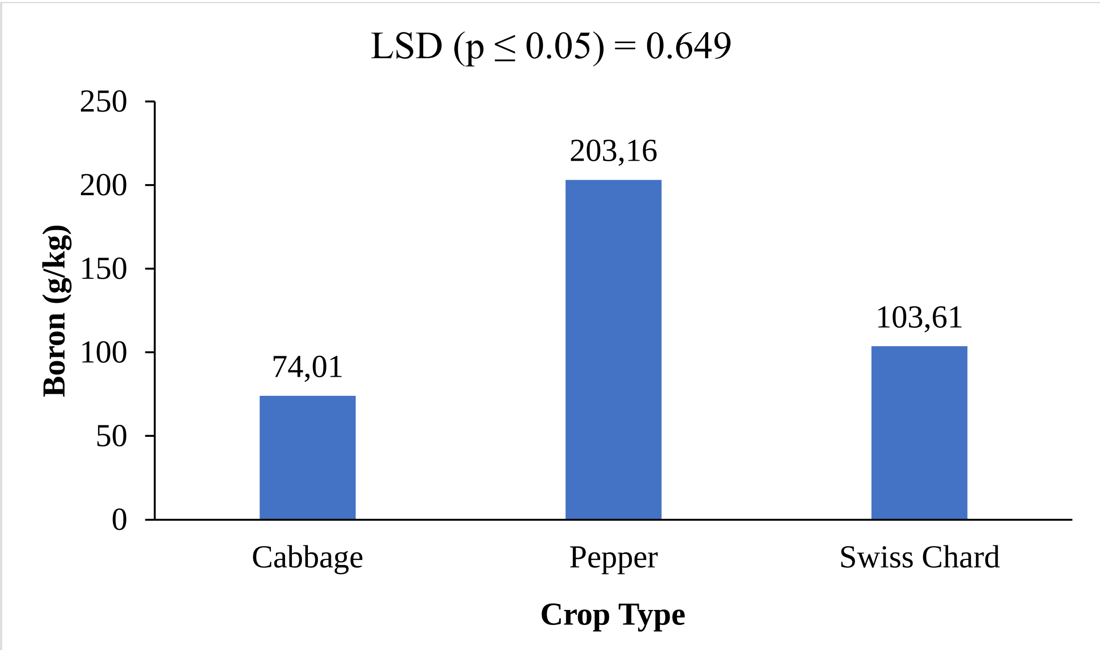

Figure 5.7: Overall comparison of boron uptake of three crop types. Data presented as mean (n=20)

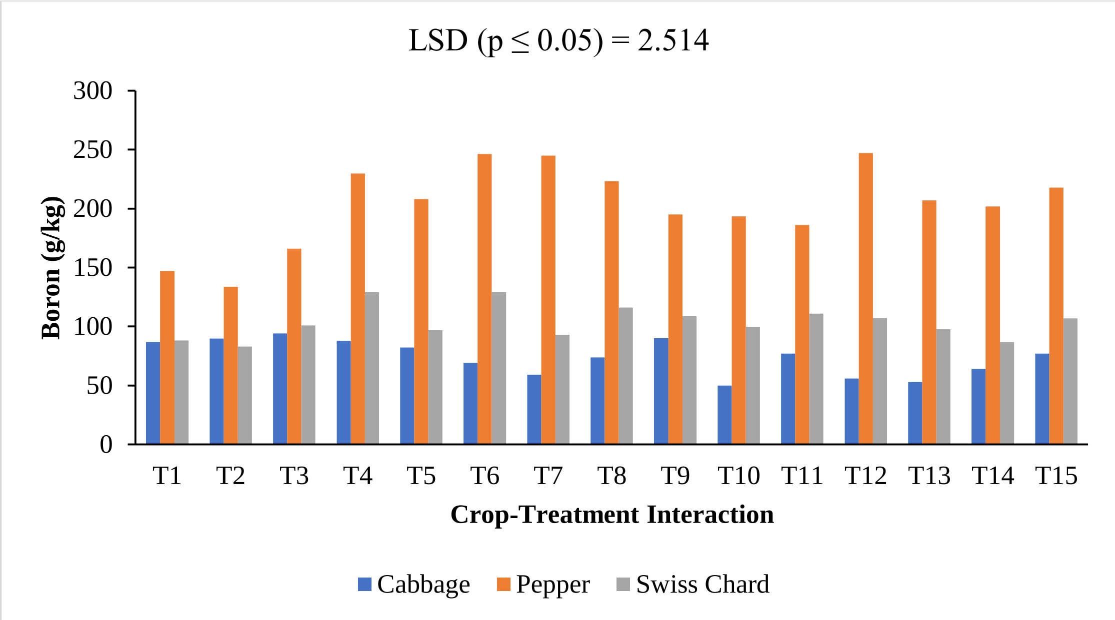

Figure 5.8: Overall comparison of boron uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

(d) Calcium (Ca) and Sulphur (S)

Handreck and Black, 2005 highlighted the main function of calcium as to strengthen the cell walls of the entire plant. This study showed that the leafy crops, the *Brassica oleracea var. capitate* and *Beta vulgaris* have a higher calcium and Sulphur uptake than fruiting crops; *Capsium annum* (Figure 5.9 to 5.12). The calcium uptake per crop, treatment, and the interactions have all showed the highest and balanced levels of Ca uptake compared to the other nutrients, which indicated the good balance of cations and anions in the growing media (Handreck and Black, 2005). The effect of vermicompost as per its different levels of pre-enrichment showed no significant effect in a pattern form in a varying pattern of Ca and S uptake levels per treatment.

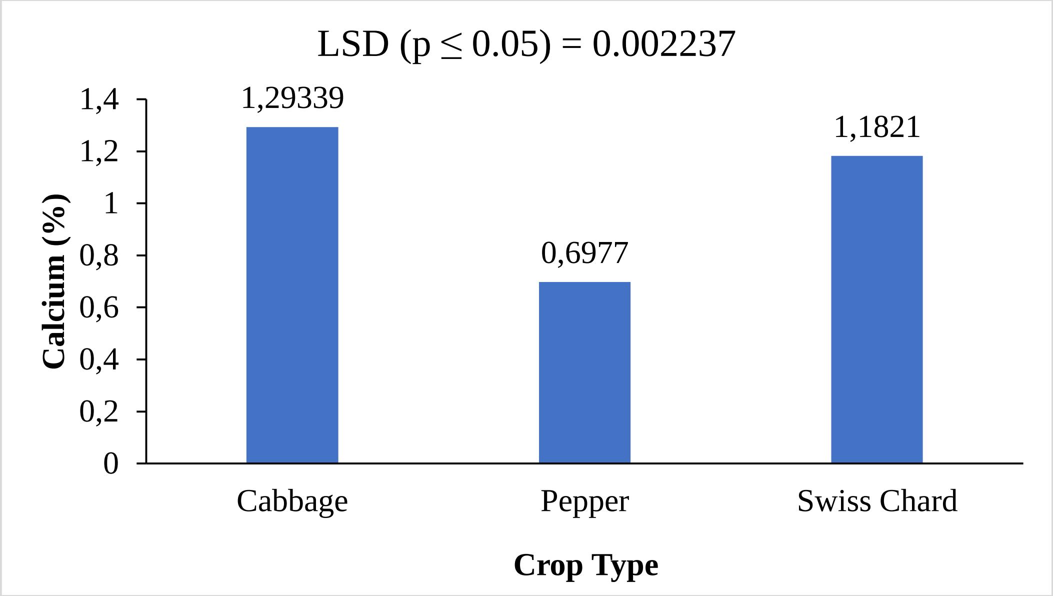

Figure 5.9: Overall comparison of calcium uptake of three crop types. Data presented as mean (n=20)

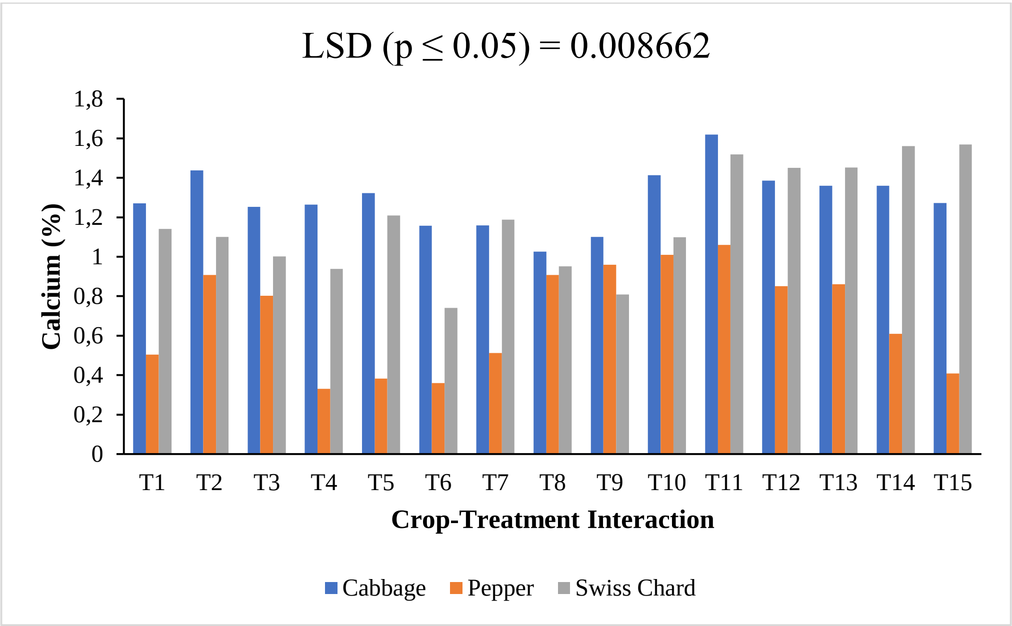

Figure 5.10: Overall comparison of calcium uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

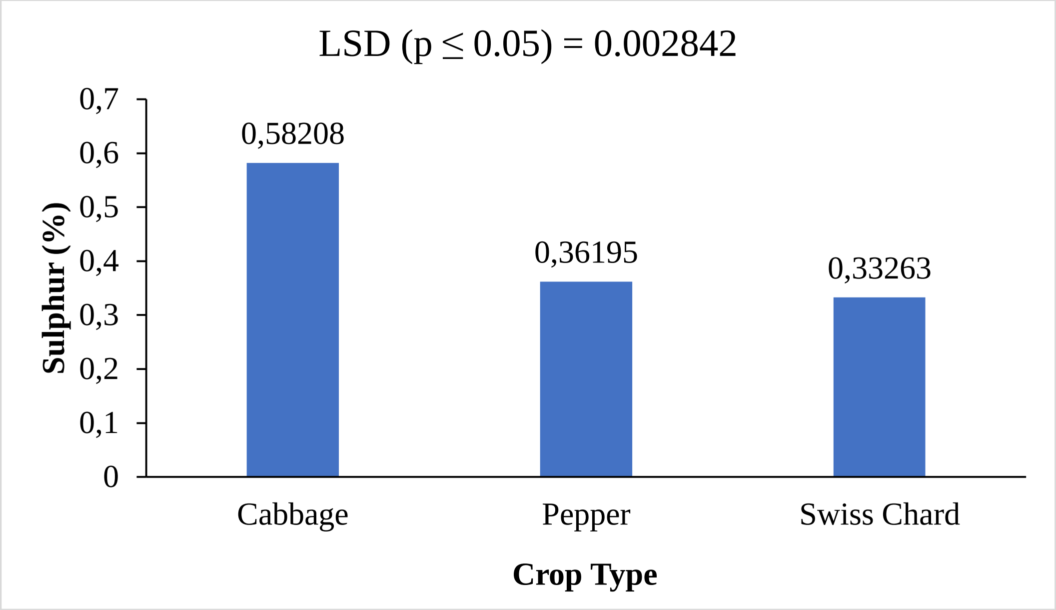

Figure 5.11: Overall comparison of sulphur uptake of three crop types. Data presented as mean (n=20)

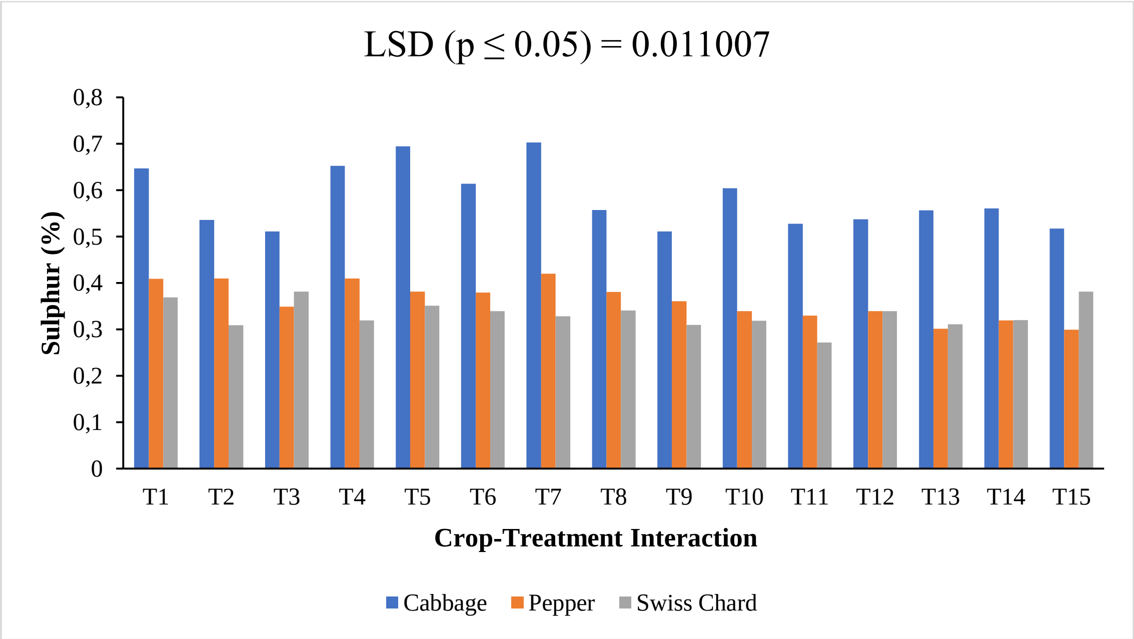

Figure 5.12: Overall comparison of sulphur uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

(e) Iron (Fe), Magnesium (Mg) and Aluminium (Al)

The three elements (Iron, Magnesium, and Aluminium) showed a very similar form of uptakes by all the seedlings. the Swiss Chard showed a significantly high uptake, followed by pepper, then cabbage. Taking into consideration that Swiss Chard is a leafy vegetable, maturing earlier than pepper and cabbage, it physiologically takes up the required elements as early as the seedling stage due to its straight leaf form, unlike the cabbage that need to form its head after developing enough leaves, and pepper that flowers and form fruits after the vegetative phase.

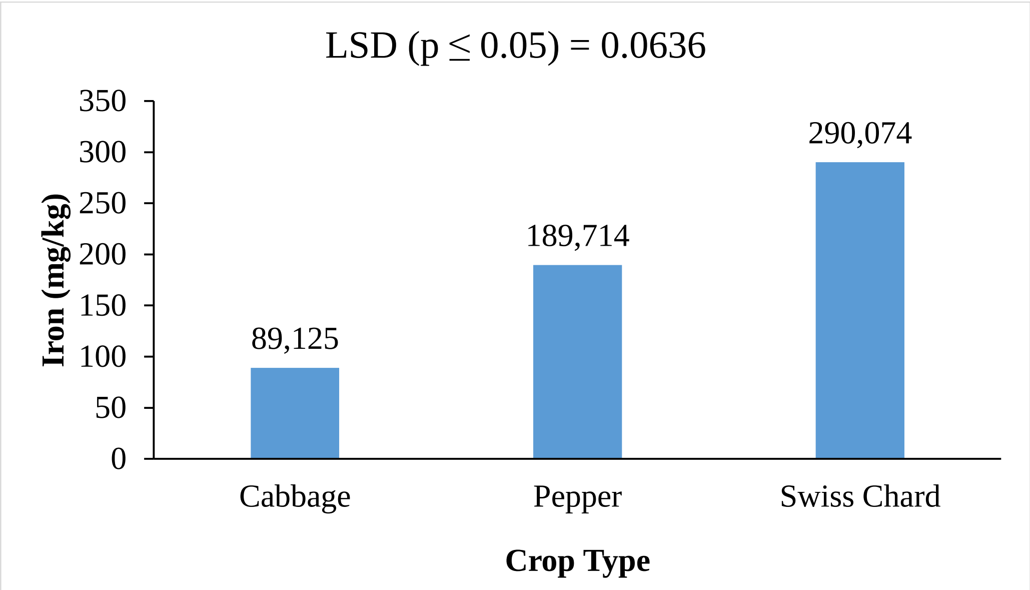

Figure 5.13: Overall comparison of iron uptake of three crop types. Data presented as mean (n=20)

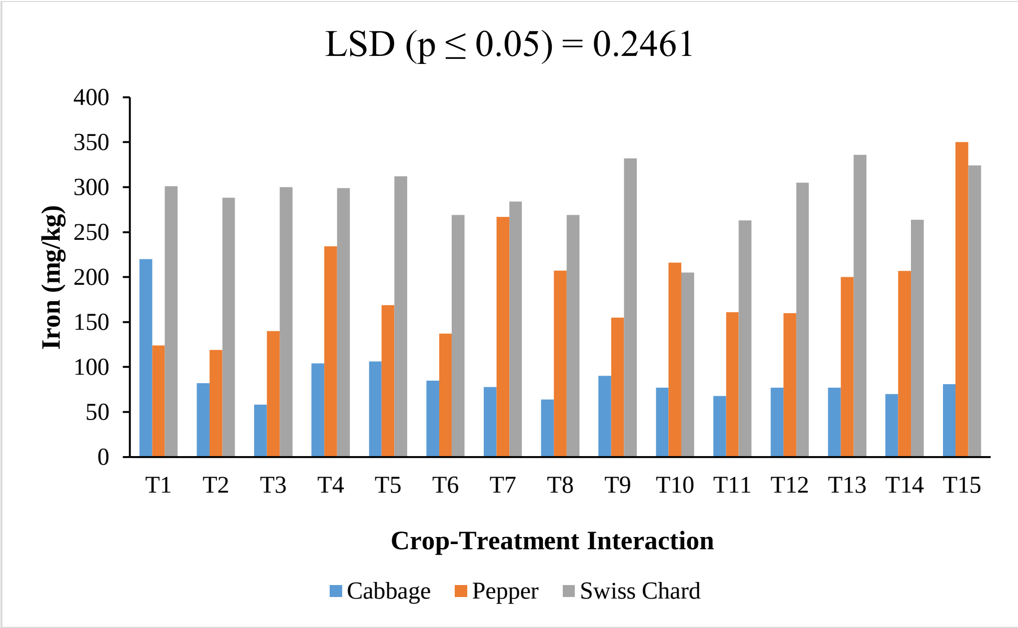

Figure 5.14: Overall comparison of iron uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

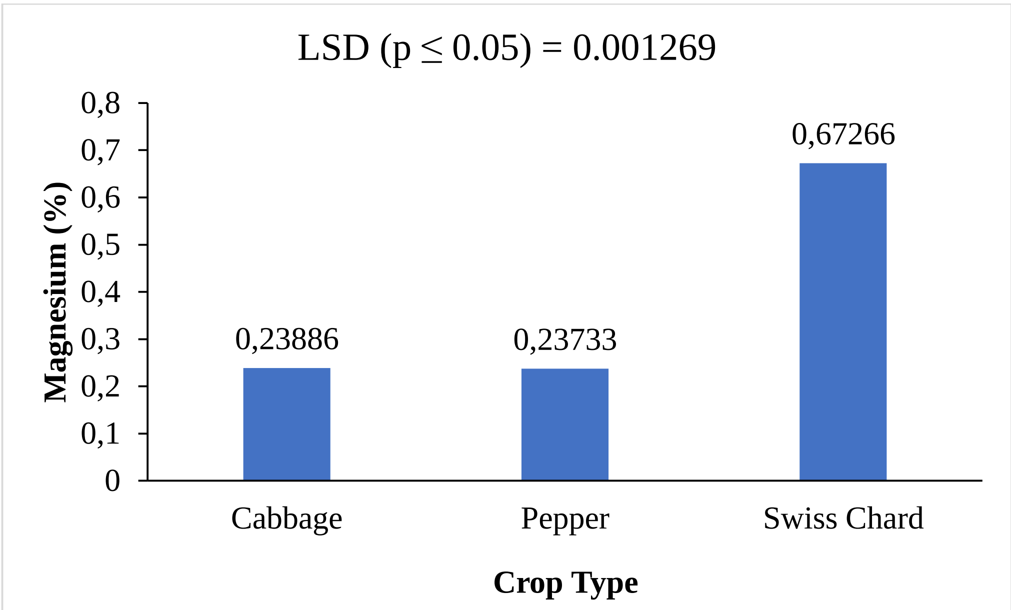

Figure 5.15: Overall comparison of magnesium uptake of three crop types. Data presented as mean (n=20)

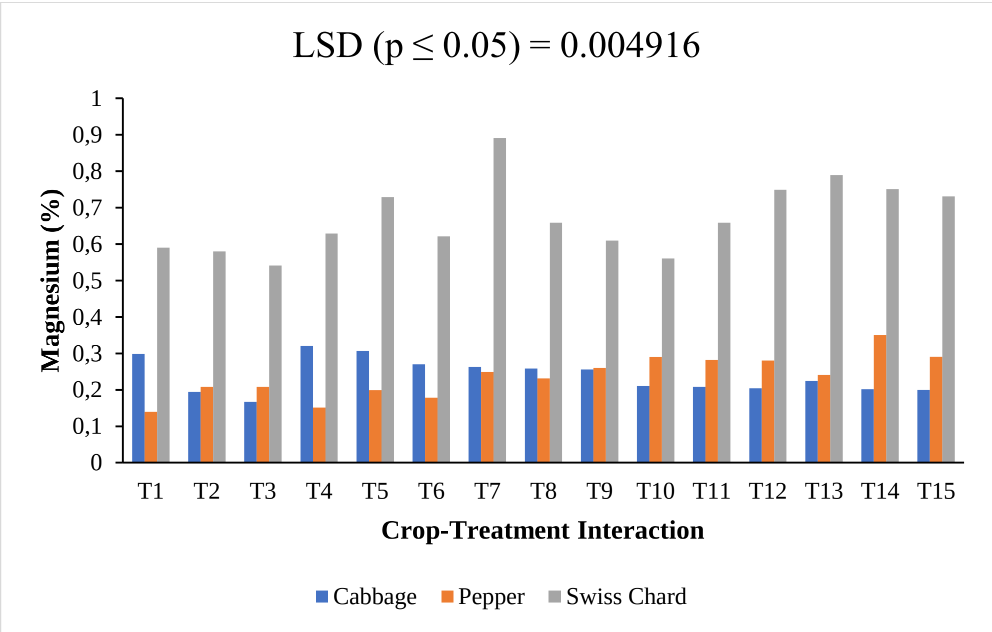

Figure 5.16: Overall comparison of magnesium uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

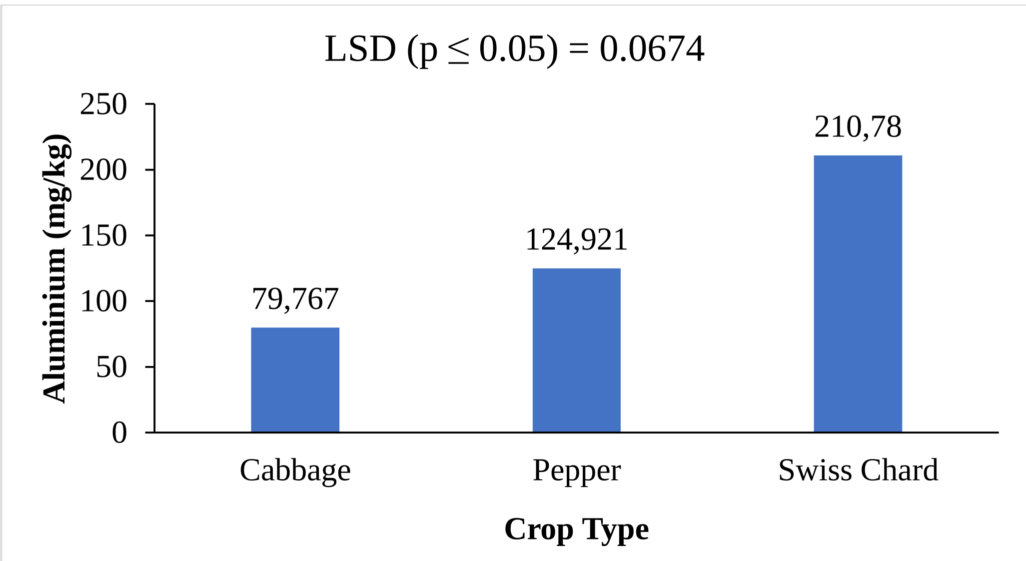

Figure 5.17: Overall comparison of aluminium uptake of three crop types. Data presented as mean (n=20)

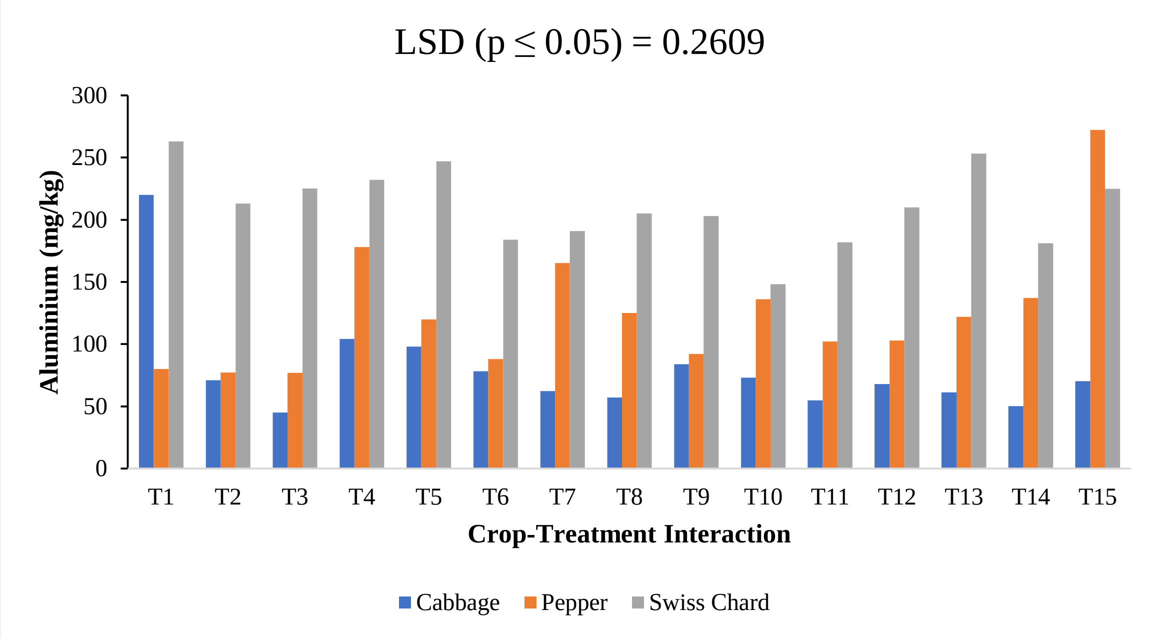

Figure 5.18: Overall comparison of aluminium uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

(f) Sodium (Na)

The statistical analysis for Sodium did not show any significant difference amongst all the three crops and the treatments.

(g) Zinc (Zn) and Manganese (Mn)

These two elements are mainly responsible for the production of the chlorophyll in order to facilitate the photosynthetic process within the plant's leaves. The statistical analysis for these elements showed that Swiss Chard had a highest Zn and Mn uptake than cabbage and pepper (Figure 5.19 to 5.22). This was influenced by the physiological factors of Swiss Chard, being a leafy vegetable crop, not undergoing heading, flower formation, and fruiting like cabbage and pepper.

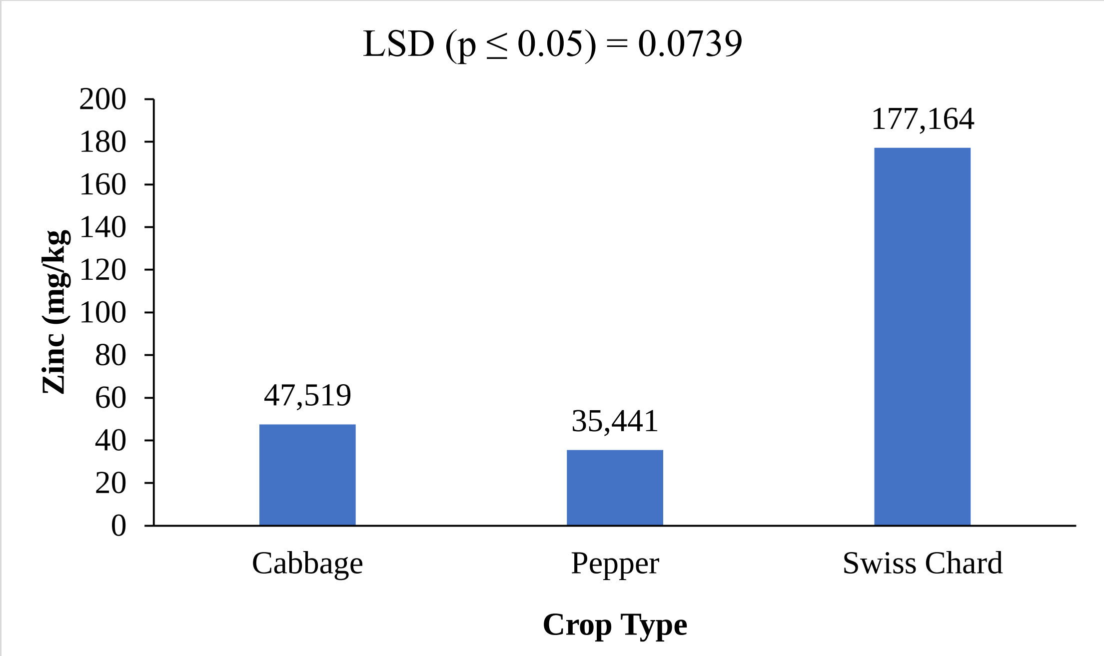

Figure 5.19: Overall comparison of zinc uptake of three crop types. Data presented as mean (n=20)

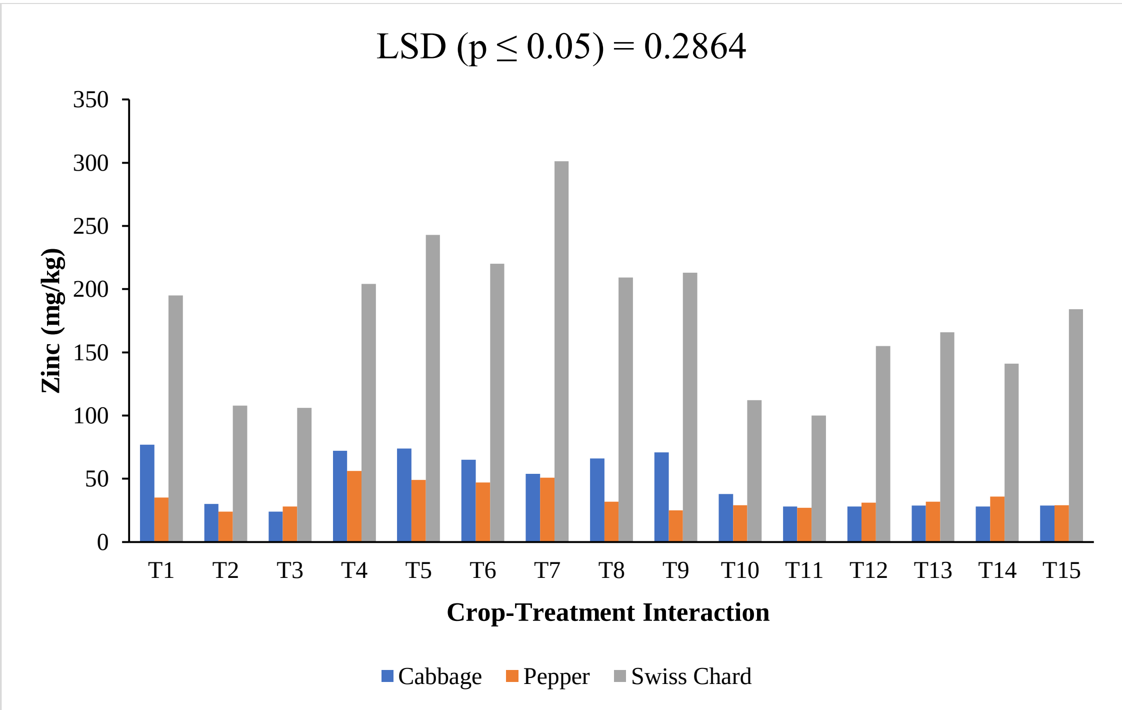

Figure 5.20: Overall comparison of zinc uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

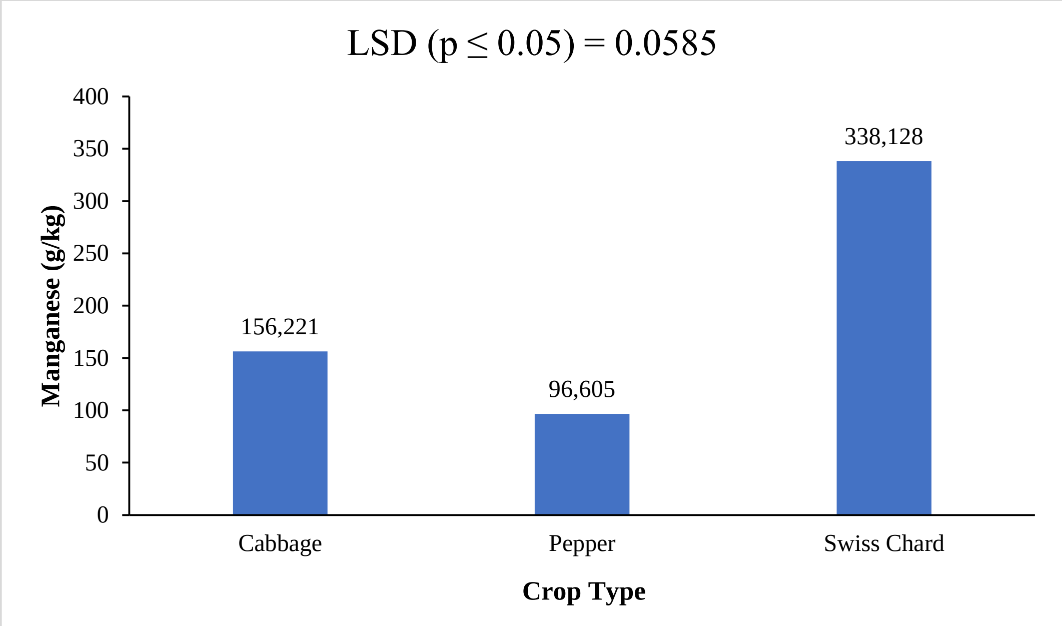

Figure 5.21: Overall comparisons of manganese uptake of three crop types. Data presented as mean (n=20)

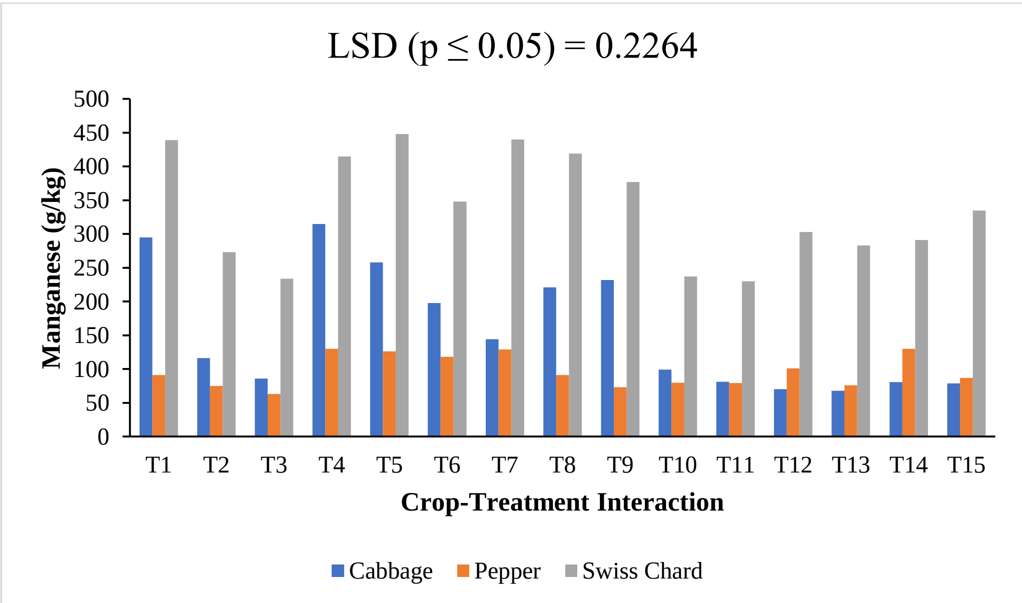

Figure 5.22: Overall comparison of manganese uptake of three crops per treatment (1-15) as outlined in Table 4.1. Data presented as mean (n=60)

5.5.2 Sunshine Seedlings

(a) Nitrogen (N)

Figure 5.23 and 5.24 showed the statistical analysis of the N uptake by seedlings at the Sunshine Seedlings trial where pepper showed a highest uptake than cabbage and Swiss Chard. The statistical analysis of N uptake per treatment showed the decreasing curve as treatment 1 showed the highest uptake, whilst treatment 2 down to 6 showed a decreasing level of uptake by almost 0.5% (Figure 5.24). This implied that the increase in vermicompost pre-enrichment rate resulted into a decline in N uptake. Due to the high possibility of N losses, since the nursery operated by water application, leaching of N might have resulted.

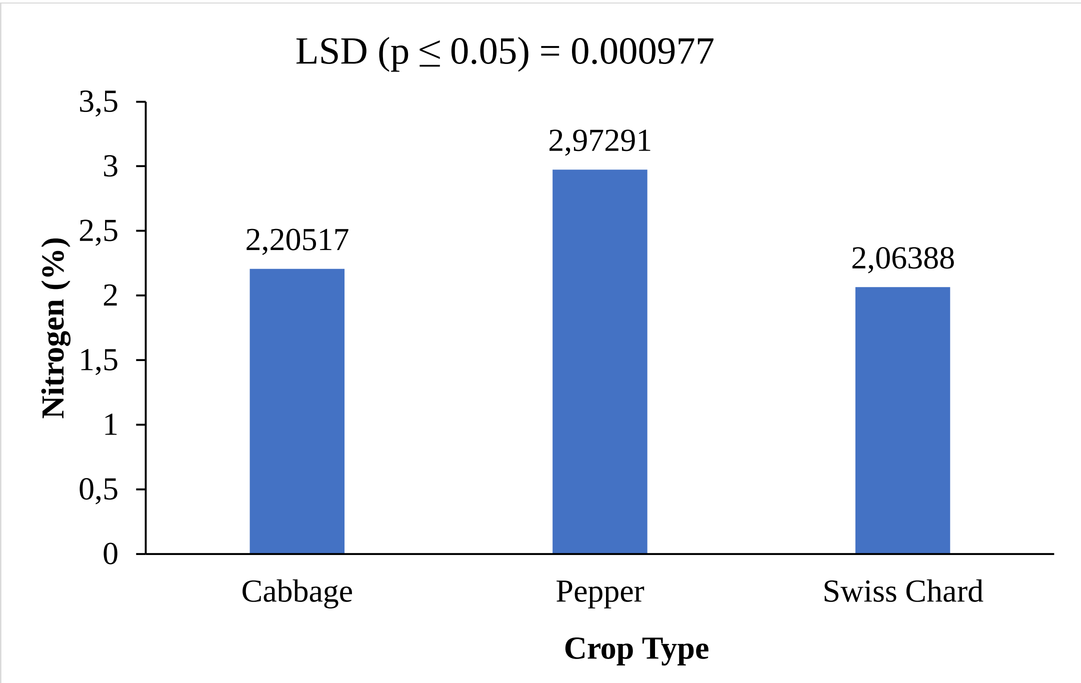

Figure 5.23: Overall comparison of nitrogen uptake of three crop types. Data presented as mean (n=20)

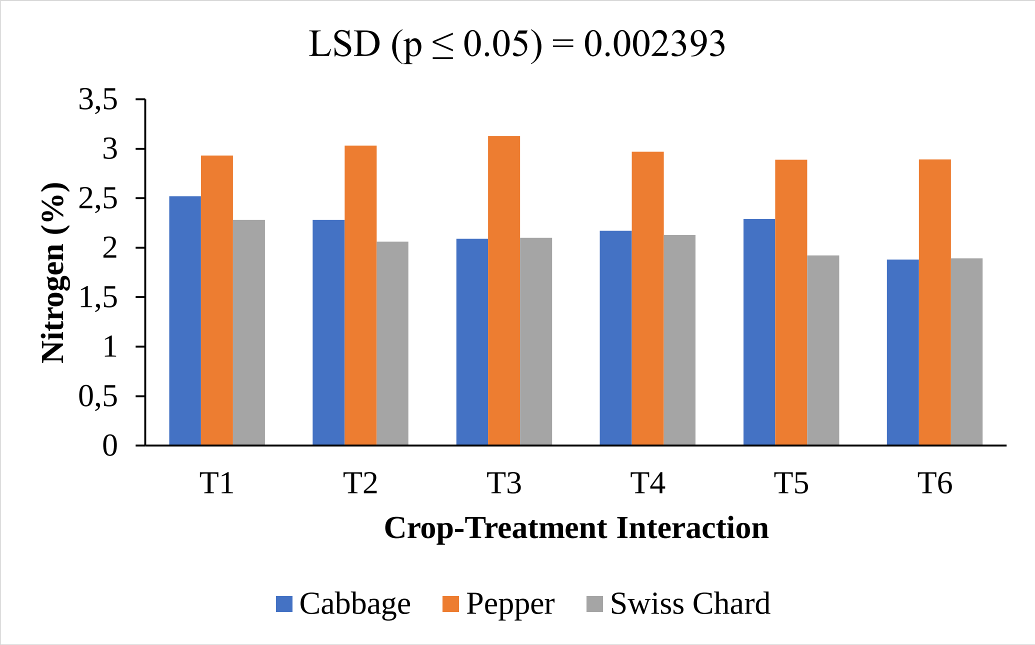

Figure 5.24: Overall comparison of nitrogen uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

(b) Phosphorus (P), Potassium (K), Magnesium (Mg), Aluminium (Al), Zinc (Zn), and Manganese (Mn)

The seedlings uptake of all these elements (P, K, Mg, Al, Zn, and Mn) showed the very similar pattern. The statistical analysis of both the Crop variations and crop-treatment interaction The Swiss Chard showed a highest uptake, followed by pepper, and cabbage. The physiological aspects played a role again in this regard where the cells of the roots, stems and the leaves of the Swiss Chard were able to take up these elements, especially P and K, even when then were slow in solubility. The statistical curve for the treatment variation for all these elements, except for aluminium were almost similar. From the first control (treatment 1), the curve shows a low uptake, increasing with the increase in vermicompost pre-enrichment levels, up to 15% vermicompost (treatment 4), they all showed a decline at 20% (treatment 5), and in all of these curves, the second control (treatment 6) showed the lowest rate of nutrients uptake.

The Al curve showed a high Al uptake by seedlings especially both controls at 0% vermicompost pre-enrichment (treatment 1 and 6) and at 15 to 20% (treatment 4 to 5). This indicate that the vermicompost pre-enrichment of 5 to 10% was ideal for plat growth, especially for the plants like cabbage which showed to be Al sensitive, whilst Swiss Chard and pepper showed to be Al tolerant.

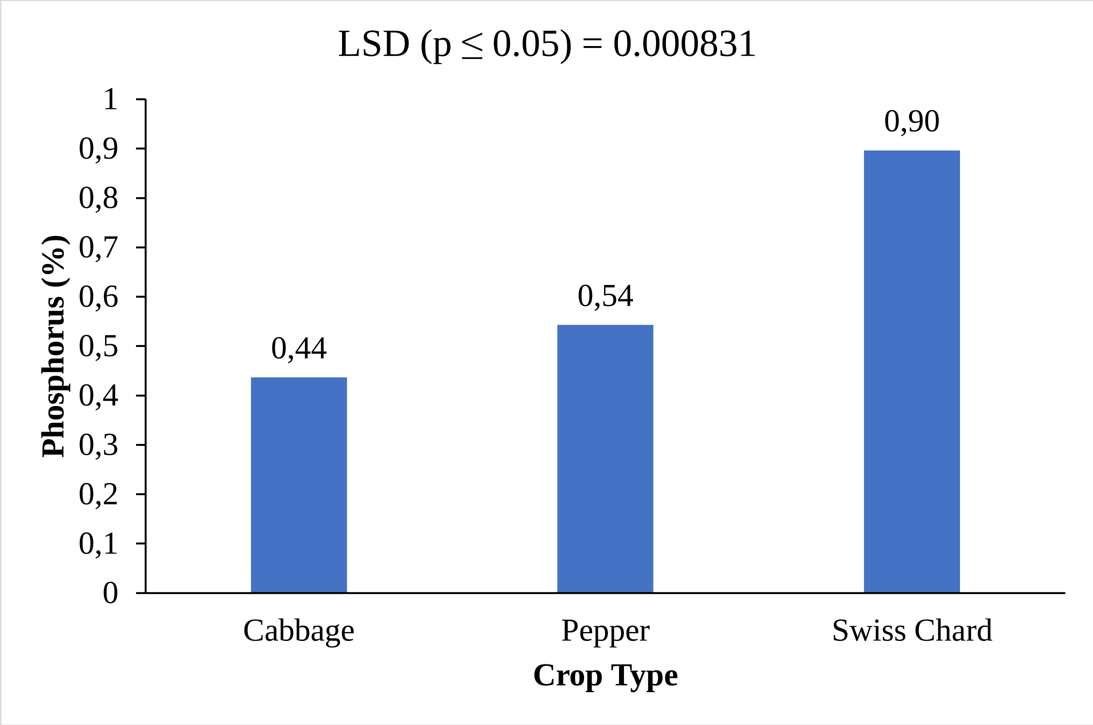

Figure 5.25: Overall comparison of phosphorus uptake of three crop types. Data presented as mean (n=20)

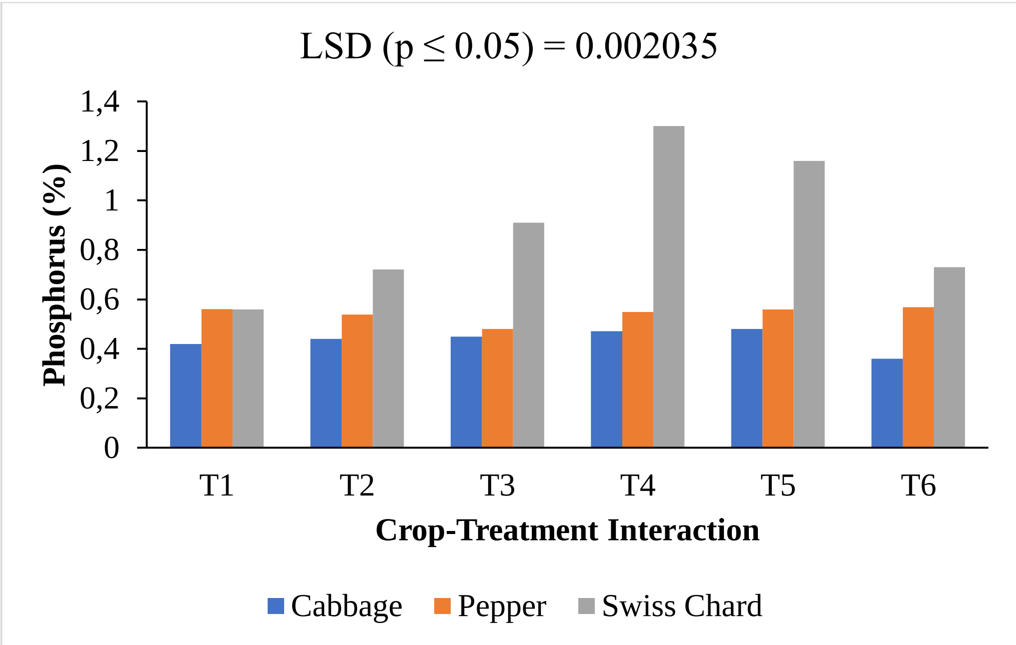

Figure 5.26: Overall comparison of phosphorus uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

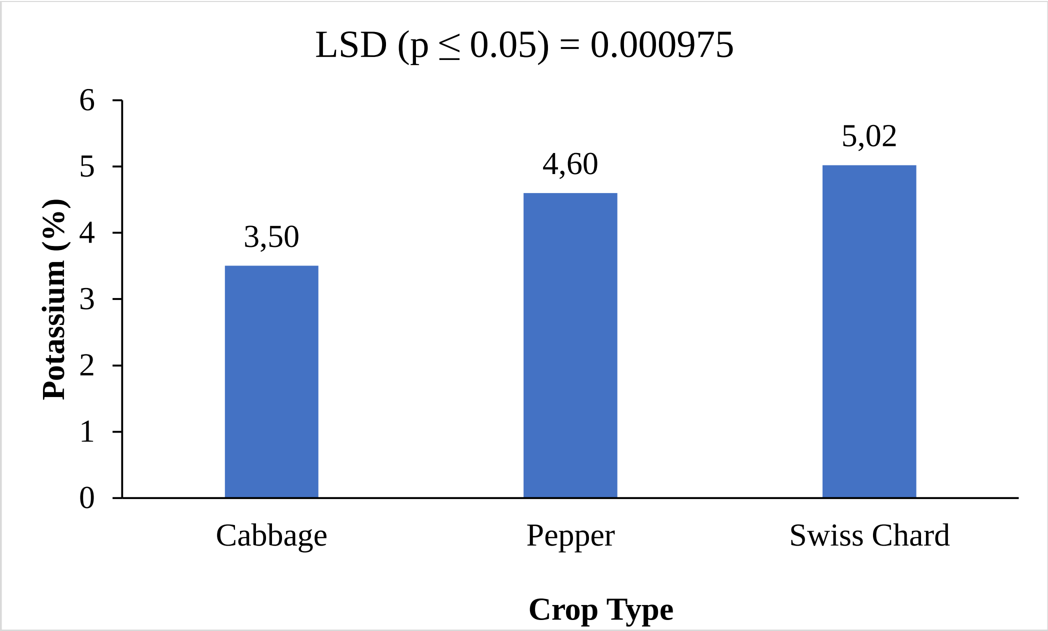

Figure 5.27: Overall comparison of phosphorus uptake of three crop types. Data presented as mean (n=20)

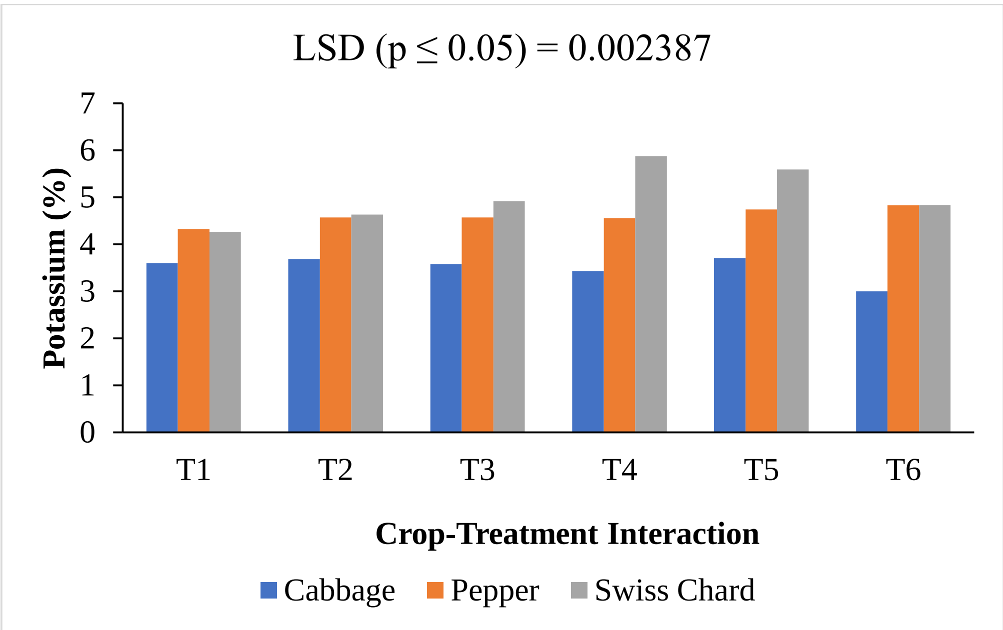

Figure 5.28: Overall comparison of potassium uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

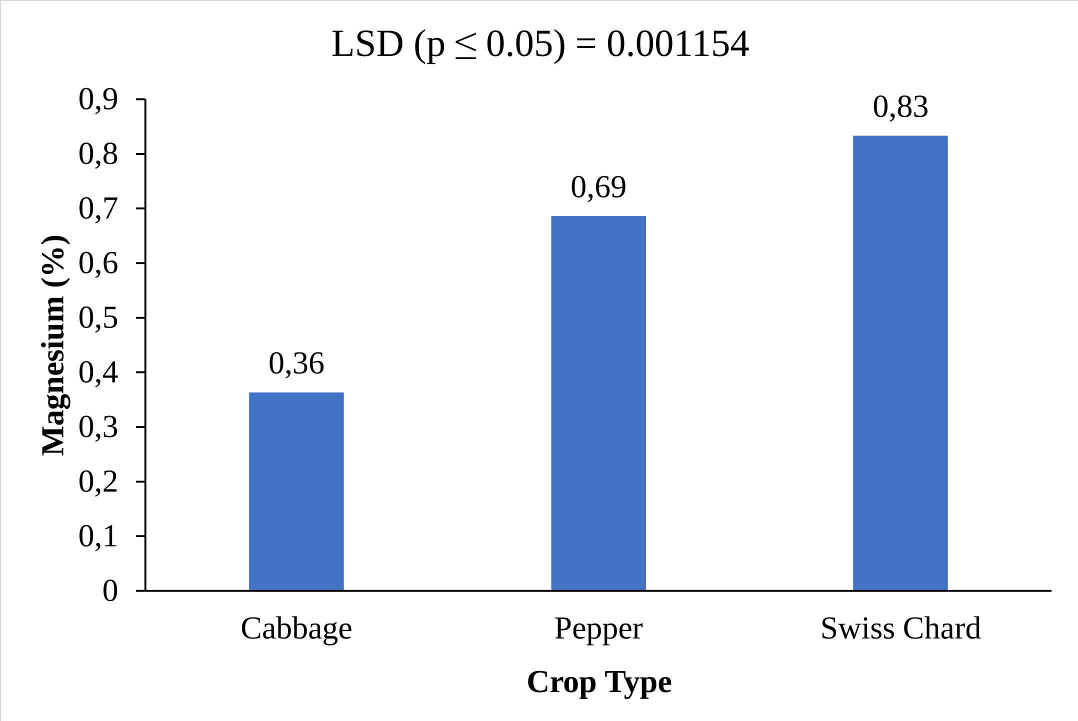

Figure 5.29: Overall comparison of magnesium uptake of three crop types. Data presented as mean (n=20)

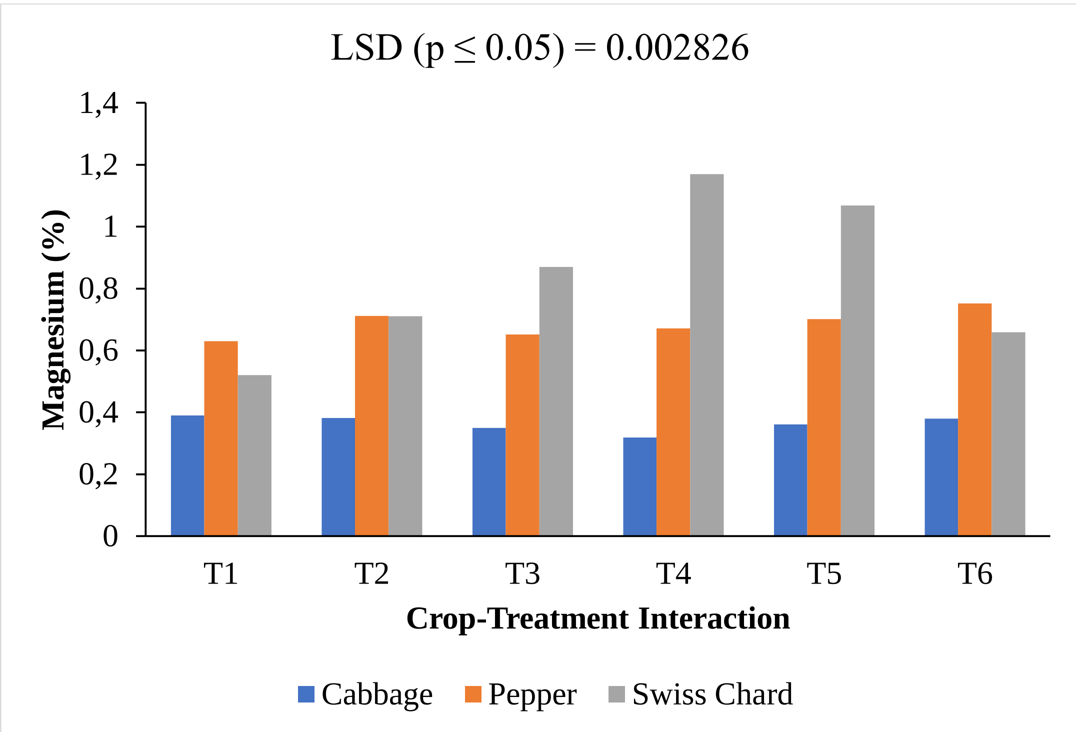

Figure 5.30: Overall comparison of magnesium uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

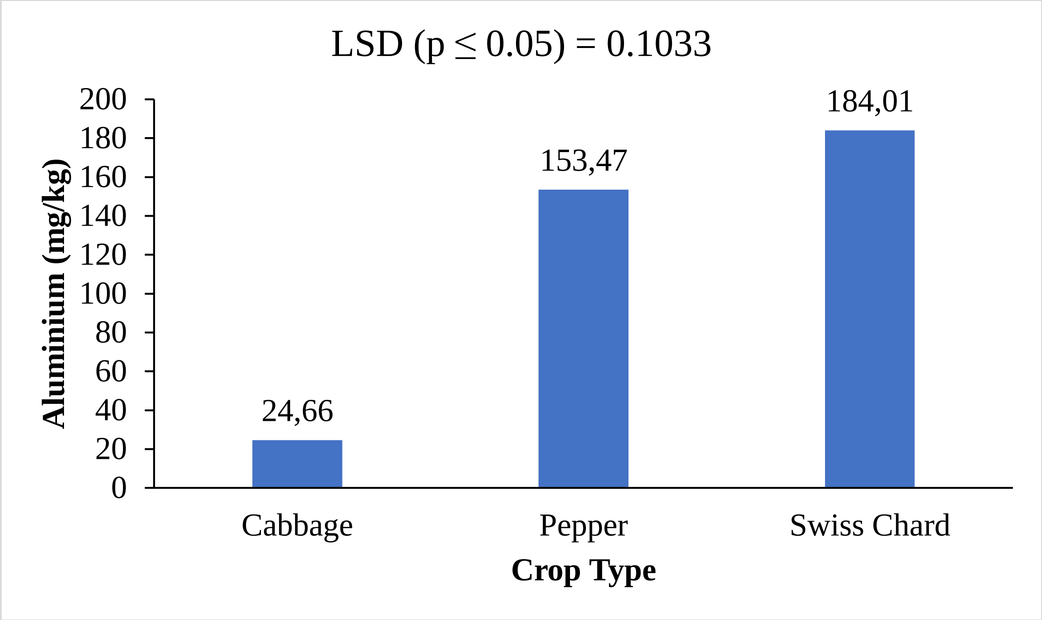

Figure 5.31: Overall comparison of aluminium uptake of three crop types. Data presented as mean (n=20)

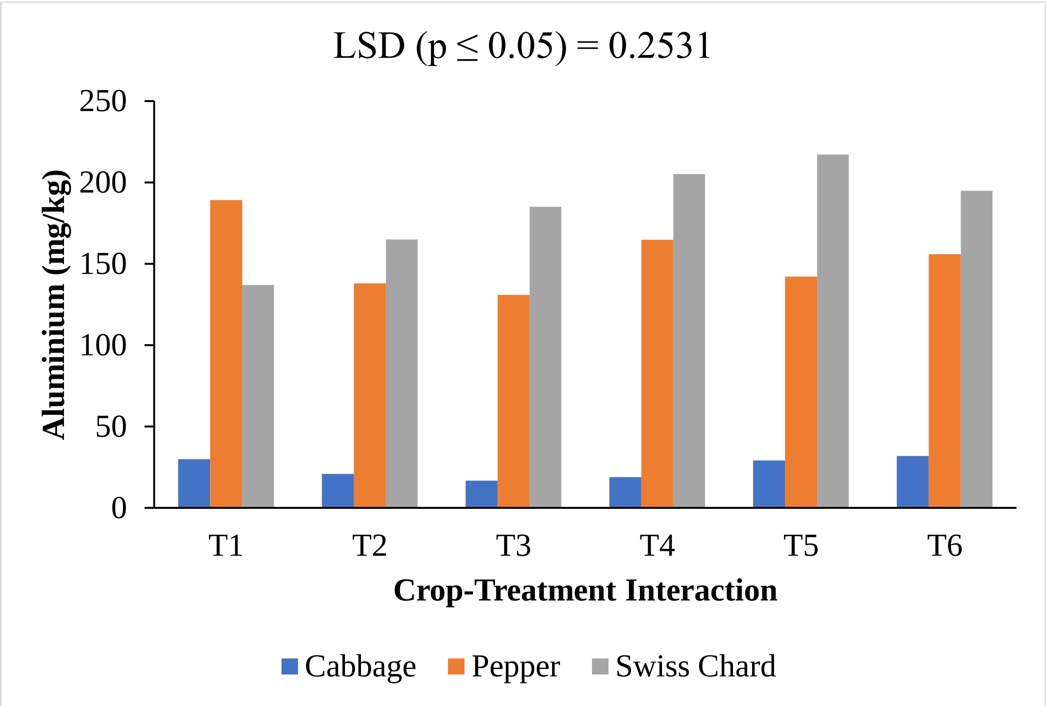

Figure 5.32: Overall comparison of aluminium uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

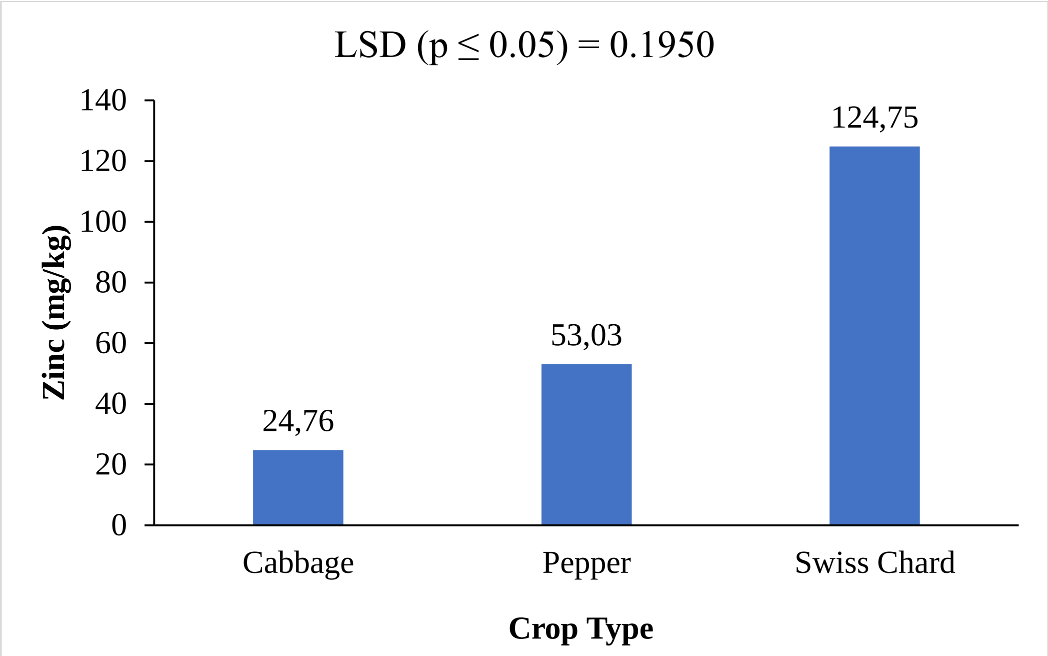

Figure 5.33: Overall comparison of zinc uptake of three crop types. Data presented as mean (n=20)

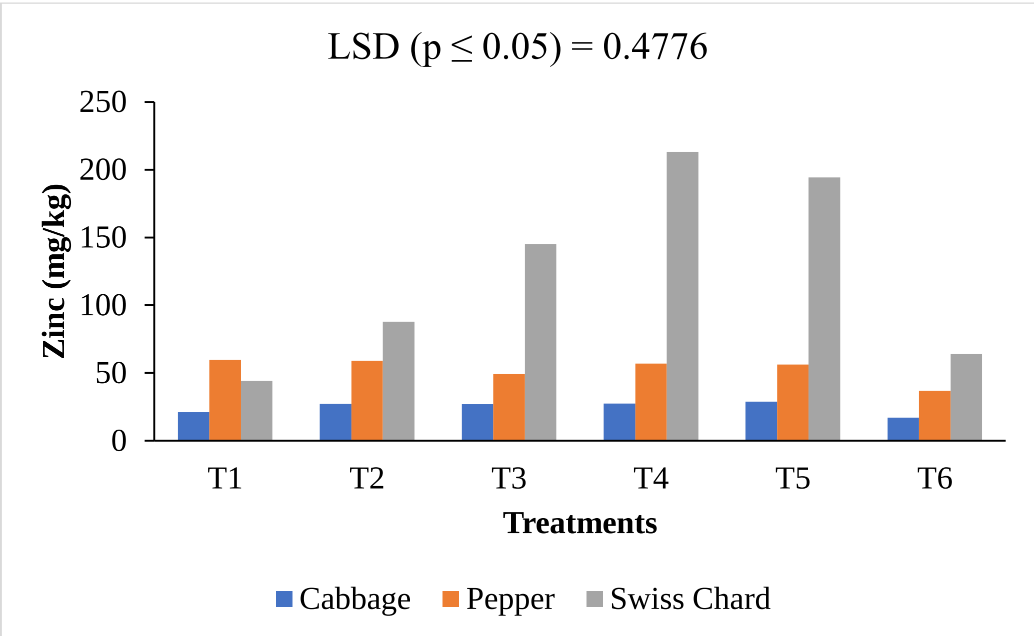

Figure 5.34: Overall comparison of zinc uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

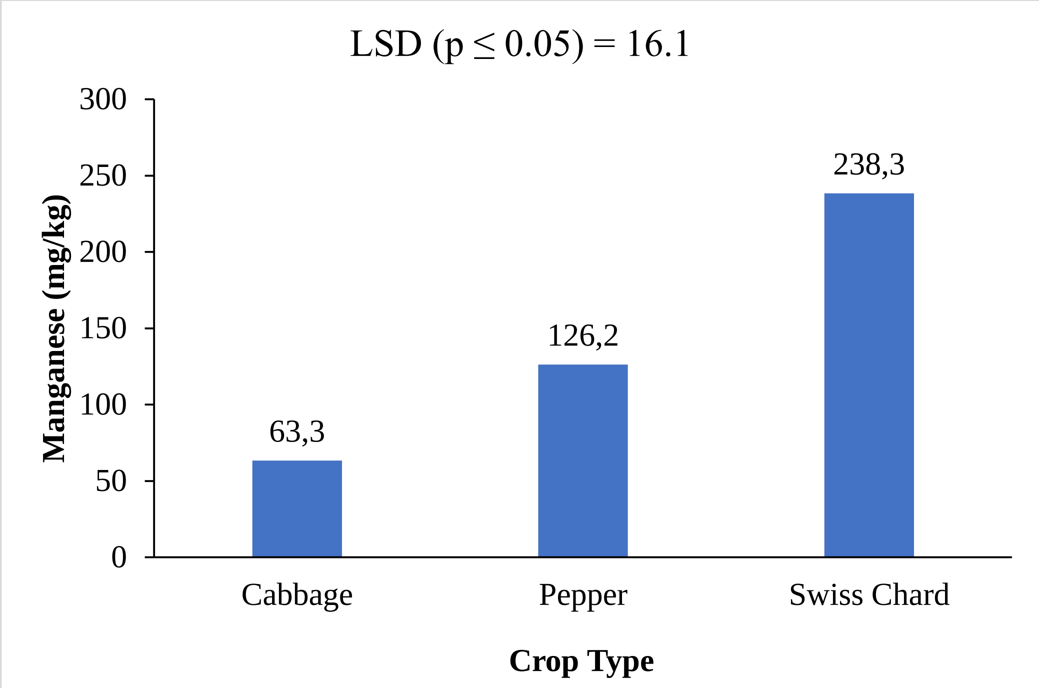

Figure 5.35: Overall comparison of manganese uptake of three crop types. Data presented as mean (n=20)

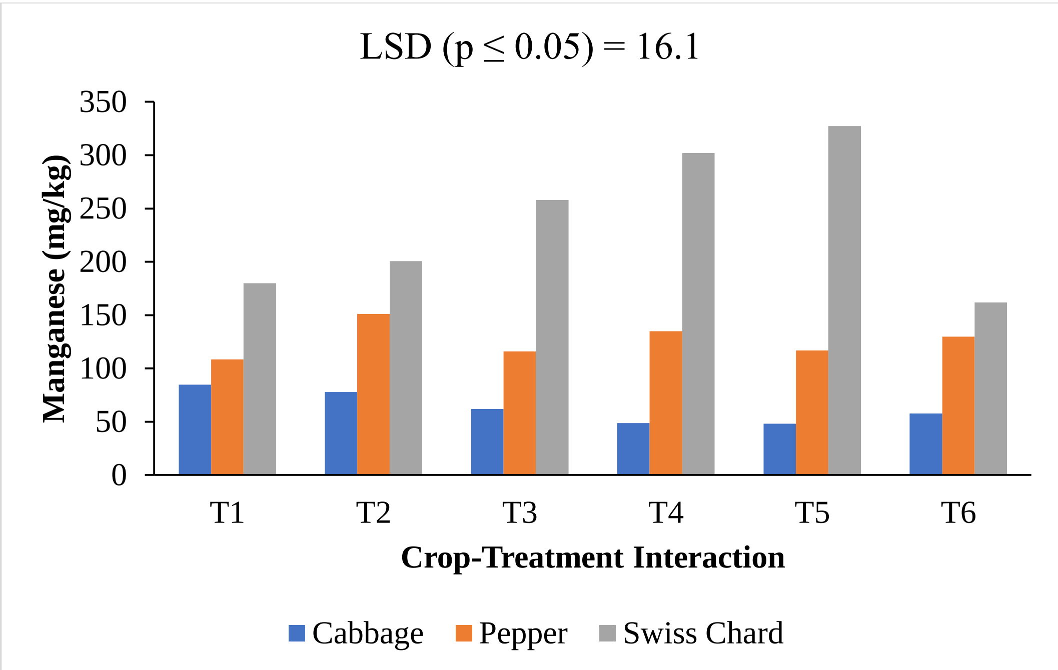

Figure 5.36: Overall comparison of manganese uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

(c) Calcium (Ca)

Cabbage seedlings at Sunshine Seedlings showed to have a lowest overall calcium uptake than Swiss Chard and pepper (Figure 5.37 and 5.38). The statistical analysis curve for treatments showed that the overall calcium uptake increased up to 15% of vermicompost pre-enrichment (treatment 4), of which after that it declined. Physiologically, pepper and Swiss Chard have a very strong and longer stems than cabbages, and the primary function of calcium is strengthening cell walls of the stems, therefore, pepper and Swiss Chard responded earlier than cabbage on calcium application.

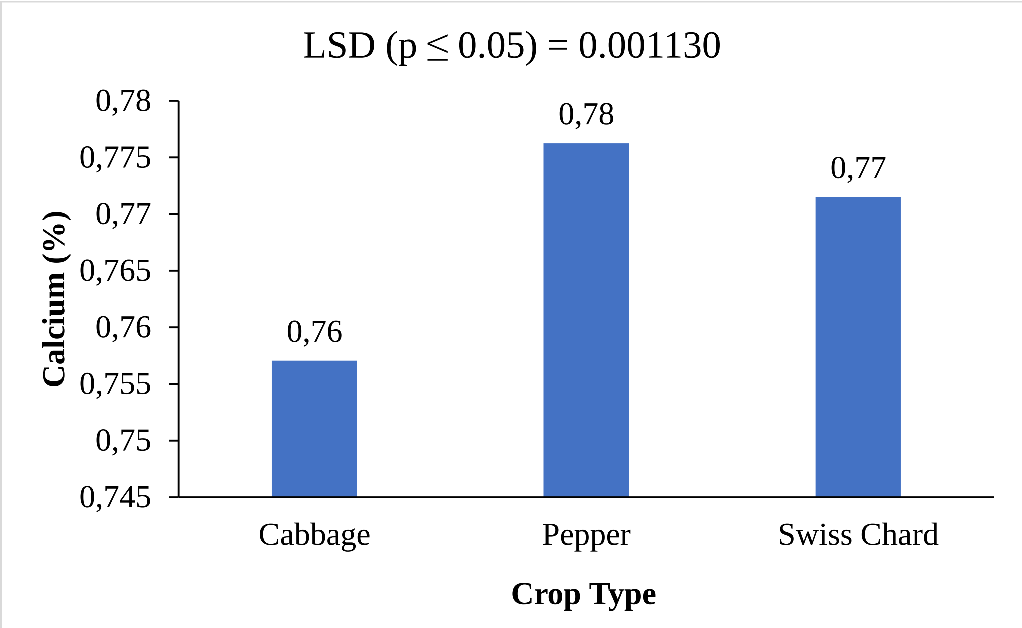

Figure 5.37: Overall comparison of calcium uptake of three crop types. Data presented as mean (n=20)

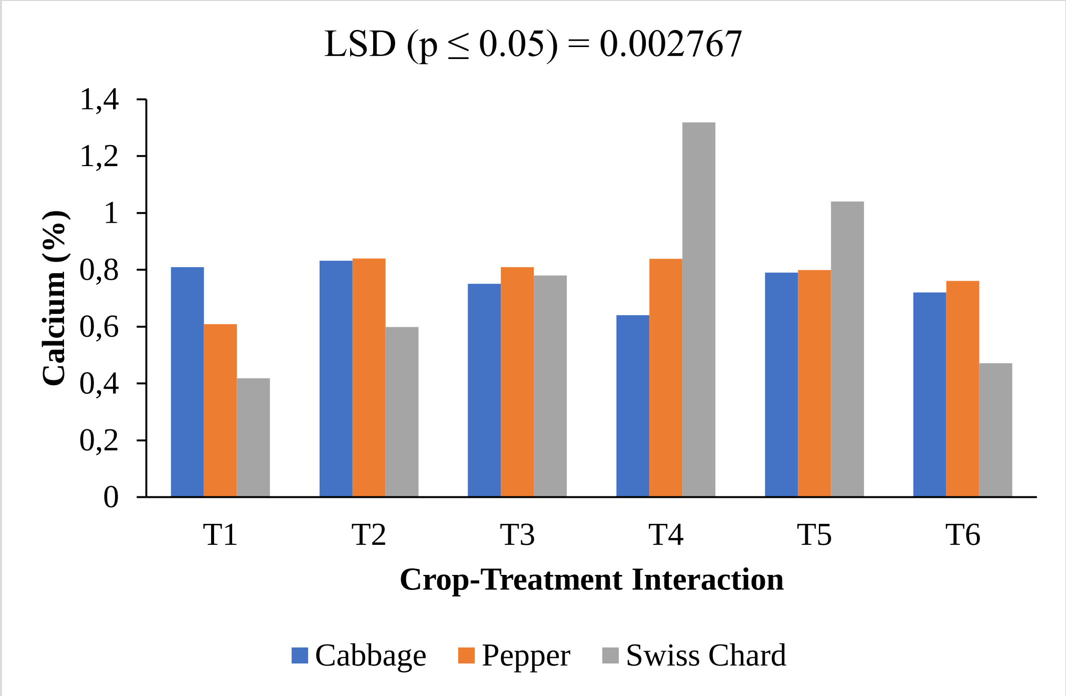

Figure 5.38: Overall comparison of calcium uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

(d) Iron (Fe) and Boron (B)

The statistical analysis of Fe and B showed the similar behaviour in their curves as they showed the first control (treatment 1) having a high nutrients uptake, that declined from 5 to 10% vermicompost pre-enrichment, started increasing again at 15 and 20% (treatment 4 and 5), declining again at treatment 6. When comparing the nutrients uptake for three crops, Swiss Chard had the highest Fe and B uptake, followed by pepper whilst cabbage showed the significantly lowest uptake (Figure 5.39 to 5.42).

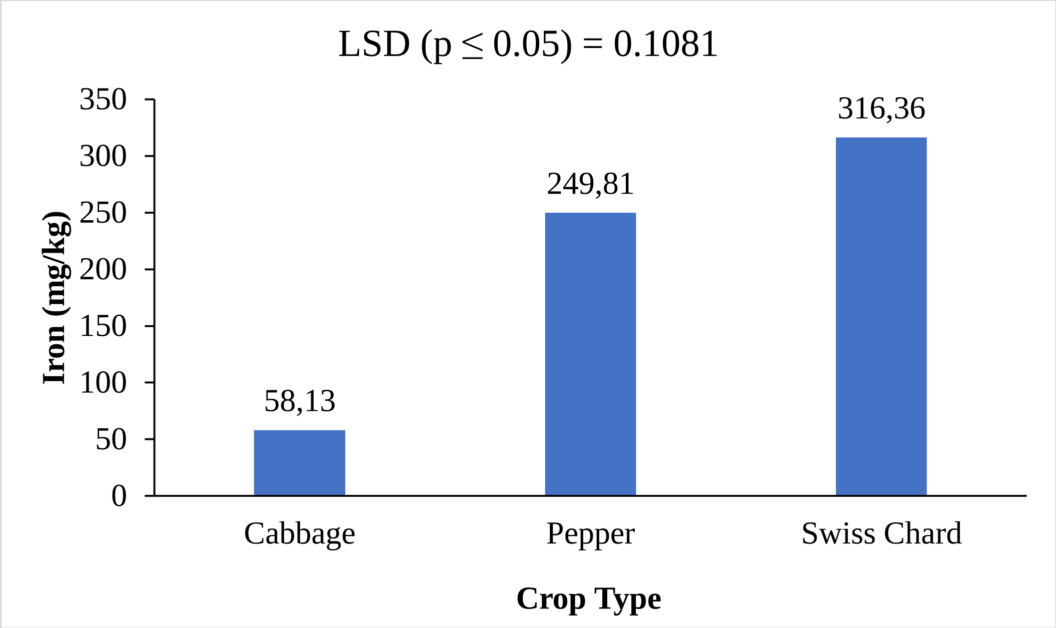

Figure 5.39: Overall comparison of iron uptake of three crop types. Data presented as mean (n=20)

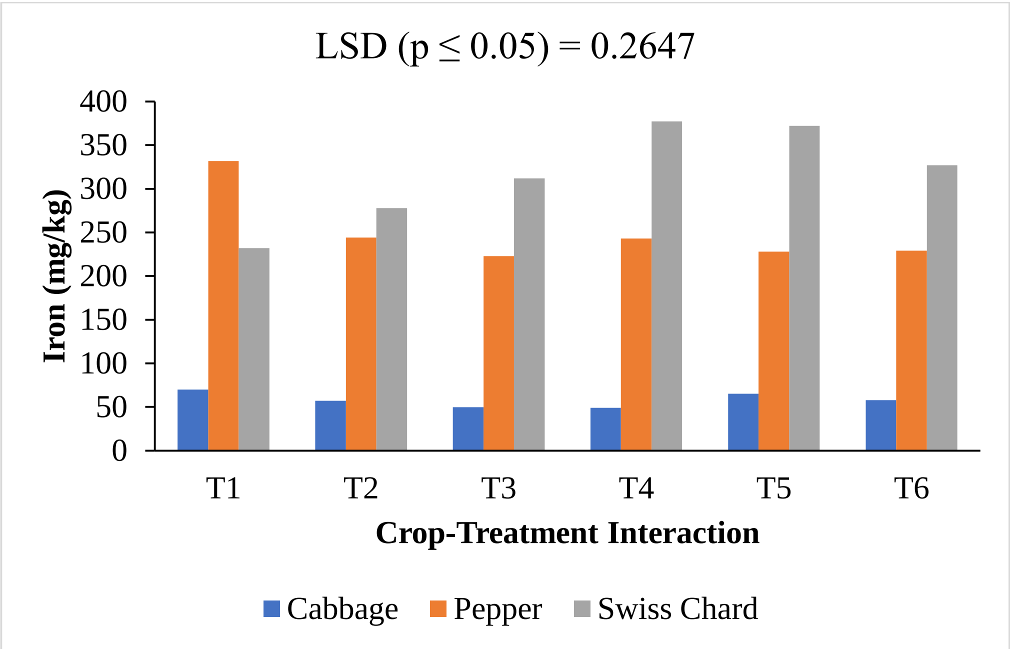

Figure 5.40: Overall comparison of iron uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

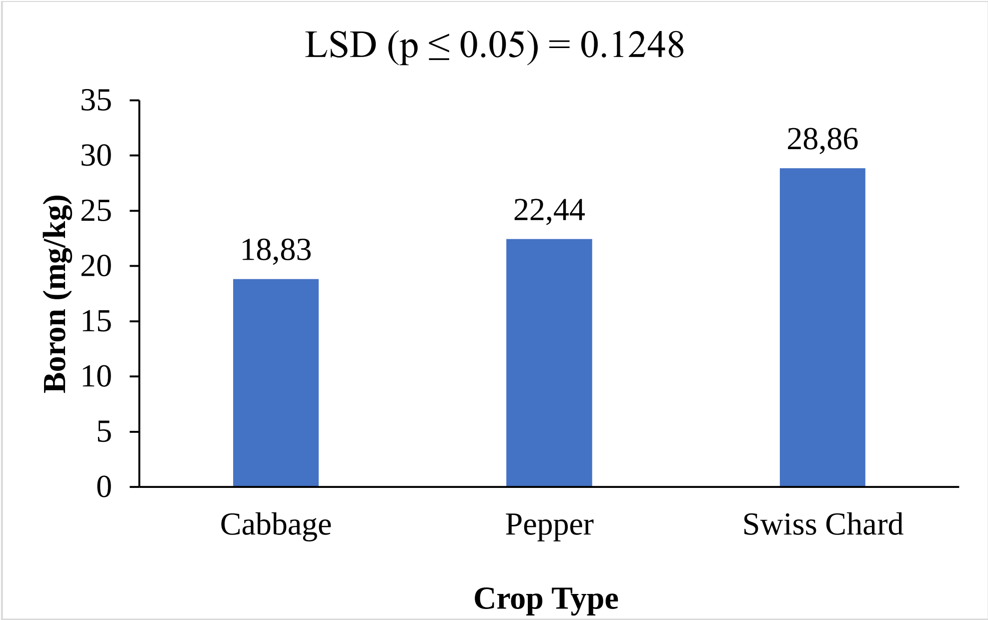

Figure 5.41: Overall comparison of boron uptake of three crop types. Data presented as mean (n=20)

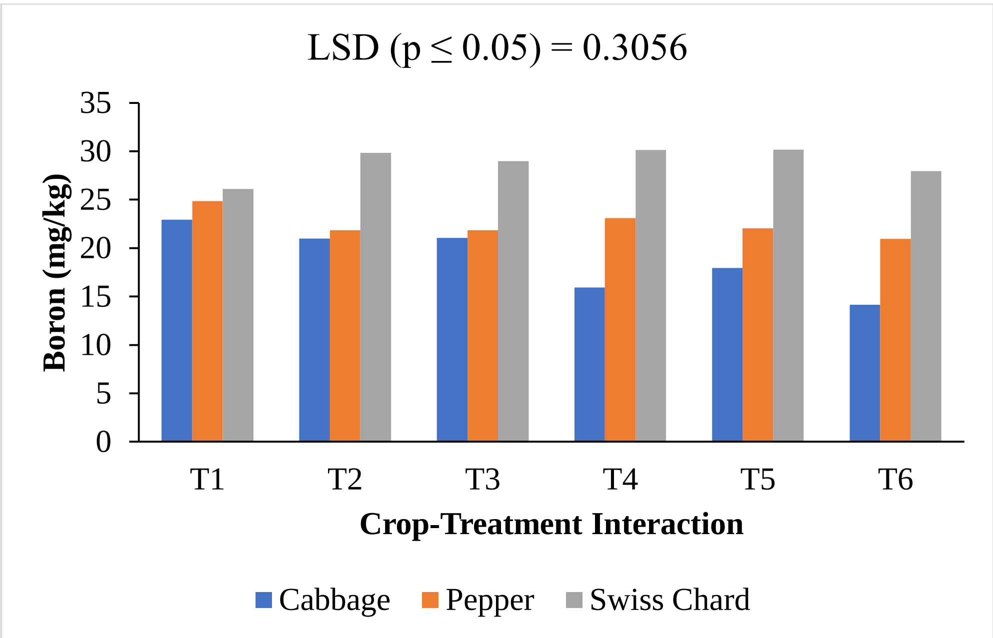

Figure 5.42: Overall comparison of boron uptake of three crops per treatment (1-6) as outlined in Table 4.6. Data presented as mean (n=60)

(e) Sodium (Na)

The statistical analysis of sodium showed no significant difference in all their sources of variation (Appendix: Table 24). Through the osmosis phenomenon, accumulation of sodium will restrict the movement, absorption and uptake of nutrients, and the analysis showed it to be at minimum and below.

(f) Sulphur (S)

Figure 5.43 and 5.44 showed that cabbage had a marginally high sulphur uptake than pepper and Swiss Chard. Handreck and Black, 2005 suggested that sulphur contains the amino acids, the building blocks of proteins and that sulphur is responsible for odour maintenance throughout the plant's growth stages. Since cabbage undergoes the head formation, the folded leaves in forming a head do not photosynthesise easily, therefore the high sulphur uptake at seedling stage assist with the reserves needed by the plant at a later stage. The vermicompost pre-enrichment showed a decline in the sulphur uptake per treatment from 0 to 15% (treatment 1 to 4), slight increase at 20% but decline again at the second control (treatment 6).

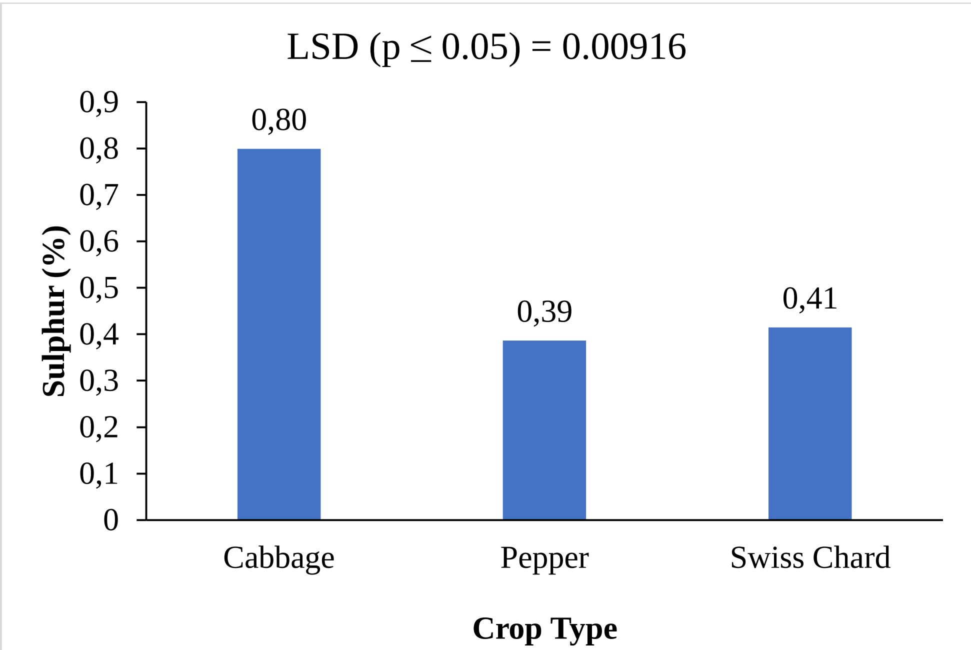

Figure 5.43: Overall comparison of sulphur uptake of three crop types. Data presented as mean (n=20)

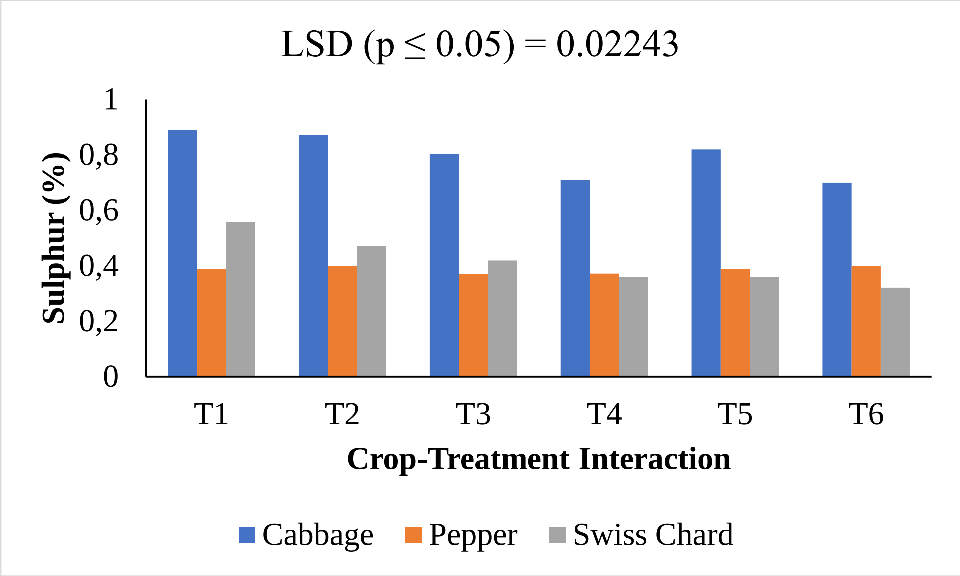

Figure 5.44: Overall comparison of sulphur uptake of three crops per treatment (1-6) as outline in Table 4.6. Data presented as mean (n=60)

Discussion and Conclusion

Nitrogen uptake by all seedlings for both Top Crop and Sunshine Seedlings, pepper showed a highest uptake than cabbage and Swiss Chard. The increase in vermicompost pre-enrichment rate at Top Crop nursery showed a non-constant curve, insignificant effect, no effect to N uptake whilst at Sunshine Seedlings it resulted into a decline in N uptake by all crops.

At Top Crop Nursery, Phosphorus uptake by the seedlings showed that overall, Swiss Chard showed a better P uptake than pepper and cabbage, whereas the crop-treatment interaction showed no relation or direct effect of vermicompost pre-enrichment as the results shows great variation from all treatments, regardless of the percentage of pre-enrichment.

At Sunshine Seedlings, the nutrient uptake of P, K, Mg, Al, Zn, and Mn showed the very similar curve pattern, where the statistical analysis of both the crop variations and crop, treatment interaction, Swiss Chard showed a highest uptake than pepper, and cabbage. The high Al uptake by seedlings especially both controls at treatment 1 and 6 and treatment 4 to 5, giving an indication that the vermicompost pre-enrichment of 5 to 10% is ideal for plant growth, especially for the plants like cabbage which have shown to be Al sensitive, whilst Swiss Chard and pepper showed to be Al tolerant.

At Top Crop Nursery, there was a balanced potassium and boron uptake by three seedling types, however Swiss Chard had a very slight higher K uptake than cabbage by about a percentage. Swiss Chard had a highest Zn and Mn uptake than cabbage and pepper.

At Top Crop Nursery, cabbage and Swiss Chard showed to have a higher calcium and sulphur uptake than pepper. The calcium uptake per crop, treatment, and the interactions have all shown the highest and balanced levels of C uptake compared to the other nutrients, which shows the good balance of cations and anions in the growing media. The effect of vermicompost as per its different levels of pre-enrichment showed no significant effect in a pattern form.

At Top Crop Nursery, iron, magnesium, and aluminium showed a highest uptake by Swiss Chard, followed by pepper, then cabbage.

The statistical analysis for Sodium did not show any significant difference amongst all the three crops at both Top Crop Nursery and Sunshine Seedlings, where their uptake was all slightly acidic, therefore indicating that the pH balance is well maintained as they both use lime in their pre-enrichment.

Cabbage seedlings at Sunshine Seedlings showed to have a lowest overall calcium uptake than Swiss Chard and pepper. An increased uptake was only realized at 15% of vermicompost pre-enrichment, whereas other treatments showed no effect.

At Sunshine Seedlings, Fe and B showed similar uptake as treatment 1, 2, 3, and 6 showed a low nutrient uptake, whilst treatment 4 and 5 showed a high uptake. Overall, Swiss Chard had the highest Fe and B uptake, followed by pepper whilst cabbage showed the significantly lowest uptake.

At Sunshine Seedlings, cabbage had a marginally high sulphur uptake than pepper and Swiss Chard. The vermicompost pre-enrichment in the sulphur uptake on all treatments except for treatment 5, which has a 20% vermicompost pre-enrichment.

The nutrient uptake by seedlings from both nurseries was not significantly different for almost all nutrients tested for. At Sunshine Seedlings®, Swiss chard showed the highest uptake of all the nutrients, except for sulphur, where cabbage had the highest uptake and pepper showed the highest uptake of nitrogen. At Top Crop Nursery, pepper showed the highest nitrogen and boron uptake, cabbage showed the highest uptake of sulphur and calcium, whereas the rest of the nutrients Swiss chard showed the highest uptake of them all.

At Sunshine Seedlings®, the treatments 3, 4, and 5 (10, 15, and 20% vermicompost) have shown the highest nutrient uptake, meaning that the effect of vermicompost was beneficial to the growing media and the three crops, especially the Swiss Chard. At Top Crop Nursery, the uptake of almost all nutrients was mainly achieved by most treatments as well, which does not clearly indicate the significant effect of vermicompost at any varying levels.

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Appendices

Table 1: Raw data (mean values) of days to germination for three crops (15 treatments, 3 replications) at Top Crop Nursery

Treatment	Rep 1-3	Cabbage	Swiss Chard	Pepper
1	1	5	5	12
2	1	5	5	12
3	1	5	5	12
4	1	5	5	12
5	1	5	5	12
6	1	5	5	12
7	1	5	5	12
8	1	5	5	12
9	1	5	5	12
10	1	5	5	12
11	1	5	5	12
12	1	5	5	12
13	1	5	5	12
14	1	5	5	12
15	1	5	5	12

Table 2: Raw data (mean values) leaf numbers for three crops (15 treatments, 3 replications) recorded weekly at Top Crop Nursery

Treatment no.	Rep 1-3	Cabbage						
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
1	1	2	2	3	4	4	6	7
2	1	2	2	3	4	4	6	7

3	1	2	2	3	4	4	6	7
4	1	2	2	3	4	4	6	7
5	1	2	2	3	4	4	6	7
6	1	2	2	3	4	4	6	7
7	1	2	2	3	4	4	6	7
8	1	2	2	3	4	4	6	7
9	1	2	2	3	4	4	6	7
10	1	2	2	3	4	4	6	7
11	1	2	2	3	4	4	6	7
12	1	2	2	3	4	4	6	7
13	1	2	2	3	4	4	6	7
14	1	2	2	3	4	4	6	7
15	1	2	2	3	4	4	6	7
Treatment no.	**Rep 1-3**	**Swiss Chard**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	2	4	4	5	6	6	7
2	1	2	4	4	5	6	6	7
3	1	2	4	4	5	6	6	7
4	1	2	4	4	5	6	6	7
5	1	2	4	4	5	6	6	7
6	1	2	4	4	5	6	6	7
7	1	2	4	4	5	6	6	7
8	1	2	4	4	5	6	6	7
9	1	2	4	4	5	6	6	7
10	1	2	4	4	5	6	6	7
11	1	2	4	4	5	6	6	7
12	1	2	4	4	5	6	6	7
13	1	2	4	4	5	6	6	7
14	1	2	4	4	5	6	6	7
15	1	2	4	4	5	6	6	7

Treatment no.	Rep 1-3	Pepper						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0	2	2	2	3	6	6
2	1	0	2	2	2	3	6	6
3	1	0	2	2	2	3	6	6
4	1	0	2	2	2	3	6	6
5	1	0	2	2	2	3	6	6
6	1	0	2	2	2	3	6	6
7	1	0	2	2	2	3	6	6
8	1	0	2	2	2	3	6	6
9	1	0	2	2	2	3	6	6
10	1	0	2	2	2	3	6	6
11	1	0	2	2	2	3	6	6
12	1	0	2	2	2	3	6	6
13	1	0	2	2	2	3	6	6
14	1	0	2	2	2	3	6	6
15	1	0	2	2	2	3	6	6

Table 3: Raw data (mean values) of seedling height for three crops (15 treatments, 3 replications) recorded weekly at Top Crop Nursery

Treatment no.	Rep 1-3	Cabbage						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	1,4	2,5	2,9	3	5,5	10	16,2
2	1	2	2,7	2,9	4	8	12,5	18
3	1	1,5	2,4	2,9	3,1	5,5	10	16,2

4	1	1,5	2,4	2,9	3	5,5	10	16,2
5	1	2	2,7	2,9	4,1	8	12,5	18
6	1	1,6	2,5	2,9	3,1	5,5	10	16,2
7	1	2	2,7	2,9	4	8	12,5	18
8	1	2	2,7	2,9	4	8	12,5	18
9	1	2	2,7	2,9	4	8	12,5	18
10	1	2	2,7	2,9	4,1	8	12,5	18
11	1	1,5	2,4	2,9	3	5,5	10	16,2
12	1	2	2,7	2,9	4,1	8	12,5	18
13	1	1,4	2,5	2,9	3	5,5	10	16,2
14	1	1,4	2,5	2,9	3	5,5	10	16,2
15	1	2	2,7	2,9	4,1	8	12,5	18
Treatment no.	**Rep 1-3**	**Swiss Chard**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0,5	1,2	3	4,6	5,5	7,6	11,5
2	1	0,5	1,2	3	4,5	5,5	7,6	11,5
3	1	0,5	1,2	2,5	4	5,2	7	8,4
4	1	0,5	1,2	2,5	4	5,2	7	8,4
5	1	0,5	1,2	3	4,6	5,5	7,5	11,5
6	1	0,5	1,2	3	4,5	5,5	7,6	11,5
7	1	0,5	1,2	3	4,5	5,5	7,6	11,5
8	1	0,5	1,2	2,5	4	5,2	7	8,4
9	1	0,5	1,2	3	4,6	5,5	7,5	11,5
10	1	0,5	1,2	3	4,6	5,5	7,5	11,5
11	1	0,5	1,2	2,5	4	5,2	7,6	11,5
12	1	0,5	1,2	2,5	4	5,2	7	8,5
13	1	0,5	1,2	3	4,6	5,5	7,6	11,5
14	1	0,5	1,2	3	4,6	5,5	7,6	11,5
15	1	0,5	1,2	2,5	4	5,2	7	8,5

Treatment no.	Rep 1-3	Pepper						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0,5	1	1,5	2	5	6	7
2	1	0,5	1	1,7	2,9	7,5	11	19
3	1	0,5	1	1,7	2,4	6	11	19
4	1	0,5	1	1,5	2	5	6	7,2
5	1	0,5	1	1,7	2,4	6	11	18,5
6	1	0,5	1	1,5	2	5	6,9	10
7	1	0,5	1	1,7	2,9	7,5	11	18,2
8	1	0,5	1	1,7	2,9	7,5	10,5	18,4
9	1	0,5	1	1,7	2,4	6	8	13,5
10	1	0,5	1	1,7	2,9	7,5	11	18
11	1	0,5	1	1,7	2,9	7,5	11	17,5
12	1	0,5	1	1,7	2,4	6	11,5	19
13	1	0,5	1	1,7	2,9	7,5	11,5	19
14	1	0,5	1	1,7	2,4	6	12	19
15	1	0,5	1	1,7	2,4	6	12	19

Table 4: Raw data (mean values) of root development for three crops (6 treatments, 3 replications) recorded weekly at Top Crop Nursery rated 0-4 where 0 = None, 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent

Treatment no.	Rep 1-3	Cabbage						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0	1	1	1	1	1	1
2	1	0	1	2	2	2	3	3
3	1	0	1	1	1	1	2	3
4	1	0	1	1	1	1	1	1
5	1	0	1	1	1	1	1	1

6	1	0	1	1	1	1	1	1
7	1	0	1	1	1	1	1	2
8	1	0	1	1	1	1	1	1
9	1	0	1	1	2	3	3	4
10	1	0	1	1	2	3	3	4
11	1	0	1	1	1	1	1	1
12	1	0	1	1	2	3	3	3
13	1	0	1	1	2	3	3	3
14	1	0	1	1	1	2	2	2
15	1	0	1	1	2	3	3	3
Treatment no.	**Rep 1-3**	**Swiss Chard**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0	0	1	1	1	1	1
2	1	0	1	1	1	2	2	2
3	1	0	1	1	1	2	2	2
4	1	0	1	1	1	1	1	1
5	1	0	0	1	1	1	1	1
6	1	0	0	1	1	1	1	1
7	1	0	1	1	1	1	2	2
8	1	0	0	1	1	1	1	1
9	1	0	0	1	1	2	2	2
10	1	0	1	1	2	3	4	4
11	1	0	1	1	2	3	3	3
12	1	0	1	1	2	3	3	3
13	1	0	1	1	2	3	3	3
14	1	0	1	1	1	2	3	3
15	1	0	1	1	2	3	4	4
Treatment no.	**Rep 1-3**	**Pepper**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**

1	1	0	1	1	1	1	2	2
2	1	0	1	1	1	1	2	2
3	1	0	1	1	1	1	2	3
4	1	0	1	1	1	1	1	1
5	1	0	1	1	1	1	1	1
6	1	0	1	1	1	1	1	1
7	1	0	1	1	1	1	1	2
8	1	0	1	1	2	3	3	4
9	1	0	1	1	2	3	3	3
10	1	0	1	1	2	3	3	3
11	1	0	1	1	2	3	3	3
12	1	0	1	1	1	2	2	2
13	1	0	1	1	1	2	2	2
14	1	0	1	1	2	2	3	3
15	1	0	1	1	2	2	3	3

Table 5: Analysis of variance of leaf colour at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2		571.3	285.7	2.15	
Rep.*Units* stratum						
Crop	2		508.6	254.3	1.91	0.154
Treatment	14		1693.5	121	0.91	0.552
Crop.Treatment	28		3510.7	125.4	0.94	0.555
Residual	81	-7	10776.2	133		
Total	**127**	**-7**	**17020.7**			

Table 6: Analysis of variance of wet mass at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2		143.88	71.94	1.03	
Rep.*Units* stratum						
Crop	2		20733.79	10366.89	147.74	<.001
Treatment	14		1348.46	96.32	1.37	0.186
Crop.Treatment	28		2555.67	91.27	1.3	0.181
Residual	81	-7	5683.62	70.17		
Total	**127**	**-7**	**29514.25**			

Table 7: Analysis of variance of dry mass at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**(m.v.)**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2		0.9654	0.4827	0.71	
Rep.*Units* stratum						
Crop	2		376.9778	188.4889	276.2	<.001
Treatment	14		24.0564	1.7183	2.52	0.005
Crop.Treatment	28		31.4027	1.1215	1.64	0.044
Residual	81	-7	55.2764	0.6824		
Total	**127**	**-7**	**467.2557**			

Table 8: Raw data (mean values) of days to germination for three crops (6 treatments, 3 replications) at Sunshine Seedlings®

Treatment	Rep 1-3	Cabbage	Swiss Chard	Pepper
1	1	5	5	12
2	1	5	5	12
3	1	5	5	12
4	1	5	5	12
5	1	5	5	12
6	1	5	5	12

Table 9: Raw data (mean values) of leaf numbers for three crops (6 treatments, 3 replications) recorded weekly at Sunshine Seedlings®

Treatment no.	Rep 1-3	Cabbage						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	2	3	4	5	6	6	7
2	1	2	3	4	5	6	6	7
3	1	2	3	4	5	6	6	7
4	1	2	3	4	5	6	6	7
5	1	2	3	4	5	6	6	7
6	1	2	3	4	5	6	6	7
Treatment no.	**Rep 1-3**	**Swiss Chard**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	2	4	4	5	6	6	7
2	1	2	4	4	5	6	6	7
3	1	2	4	4	5	6	6	7
4	1	2	4	4	5	6	6	7

5	1	2	4	4	5	6	6	7
6	1	2	4	4	5	6	6	7
Treatment no.	**Rep 1-3**	**Pepper**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0	2	2	2	3	7	9
2	1	0	2	2	2	3	7	9
3	1	0	2	2	2	3	7	9
4	1	0	2	2	2	3	7	9
5	1	0	2	2	2	3	7	9
6	1	0	2	2	2	3	7	9

Table 10: Raw data (mean values) of seedling height (cm) for three crops (6 treatments, 3 replications) recorded weekly at Sunshine Seedlings®

Treatment no.	**Rep 1-3**	**Cabbage**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0,5	2,6	4,5	10	15	16,2	17
2	1	0,5	2,6	4,5	10	15	16,2	17
3	1	0,5	2,6	4,5	10	15	16,2	17
4	1	0,5	2,6	4,5	10	15	16,2	17
5	1	0,5	2,6	4,5	10	15	16,2	17
6	1	0,5	2,6	4,5	10	15	16,2	17
Treatment no.	**Rep 1-3**	**Swiss Chard**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	1,5	4,5	5	6,5	7,1	9	11,8
2	1	1,5	4,5	5	6,5	7,1	9	11,8
3	1	1,5	4,5	5	6,5	7,1	9	11,8

4	1	1,5	4,5	5	6,5	7,1	9	11,8
5	1	1,5	4,5	5	6,5	7,1	9	11,8
6	1	1,5	4,5	5	6,5	7,1	9	11,8
Treatment no.	**Rep 1-3**	**Pepper**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0,5	1	1,8	3	4	7	10,5
2	1	0,5	1	1,8	3	4	7	10,5
3	1	0,5	1	1,8	3	4	7	10,5
4	1	0,5	1	1,8	3	4	7	10,5
5	1	0,5	1	1,8	3	4	7	10,5
6	1	0,5	1	1,8	3	4	7	10,5

Table 11: Raw data (mean values) of root development for three crops (6 treatments, 3 replications) recorded weekly at Sunshine Seedlings® rated 0-4 where 0 = None, 1 = Poor, 2 = Fair, 3 = Good, and 4 = Excellent.

Treatment no.	**Rep 1-3**	**Cabbage**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0	1	2	3	4	4	4
2	1	0	1	2	3	4	4	4
3	1	0	1	2	3	4	4	4
4	1	0	1	2	3	4	4	4
5	1	0	1	2	3	4	4	4
6	1	0	0	1	1	2	2	2
Treatment no.	**Repl. No.**	**Swiss Chard**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**

1	1	0	1	2	3	3	3	3
2	1	0	1	2	3	3	3	3
3	1	0	1	2	3	3	3	3
4	1	0	1	2	3	3	3	3
5	1	0	1	2	3	3	3	3
6	1	0	0	1	1	1	2	2
Treatment no.	**Repl. No.**	**Pepper**						
		Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
1	1	0	1	2	3	3	3	3
2	1	0	1	2	3	3	3	3
3	1	0	1	1	1	2	2	2
4	1	0	1	1	1	2	2	2
5	1	0	1	1	1	2	2	2
6	1	0	1	1	1	2	2	2

Table 12: Analysis of variance of leaf colour at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.2937	0.1469	0.19	
Rep.*Units* stratum					
Crop	2	17.4448	8.7224	11.55	<.001
Treatment	5	14.3765	2.8753	3.81	0.008
Crop.Treatment	10	27.8241	2.7824	3.68	0.002
Residual	34	25.673	0.7551		
Total	**53**	**85.612**			

Table 13: Analysis of variance of wet mass at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	64.25	32.12	0.44	
Rep.*Units* stratum					
Crop	2	17524.98	8762.49	119.17	<.001
Treatment	5	4935.68	987.14	13.43	<.001
Crop.Treatment	10	1240.58	124.06	1.69	0.124
Residual	34	2499.9	73.53		
Total	**53**	**26265.38**			

Table 14: Analysis of variance of dry mass at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	2.9554	1.4777	1.77	
Rep.*Units* stratum					
Crop	2	413.5826	206.7913	247.21	<.001
Treatment	5	72.1026	14.4205	17.24	<.001
Crop.Treatment	10	20.6219	2.0622	2.47	0.024
Residual	34	28.4407	0.8365		
Total	**53**	**537.7033**			

Table 15: Analysis of variance of Nitrogen (N) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**P value**
Rep stratum	2	0.000769	0.000385	0.51	
Rep.*Units* stratum					
Crop	2	82.53576	41.26788	54315.33	<.001
Treatment	14	3.402709	0.243051	319.89	<.001
Crop.Treatment	28	11.05692	0.39489	519.74	<.001
Residual	88	0.066861	0.00076		
Total	**134**	**97.06302**			

Table 16: Analysis of variance of Phosphorus (P) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.0004545	0.0002272	1.69	
Rep.*Units* stratum					
Crop	2	68.3226720	34.16134	2.55E+05	<.001
Treatment	14	0.785104	0.056079	417.84	<.001
Crop.Treatment	28	2.035818	0.072708	541.74	<.001
Residual	88	0.011811	0.000134		
Total	**134**	**71.15586**			

Table 17: Analysis of variance of Potassium (K) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.001044	0.000522	1.1	

Rep.*Units* stratum					
Crop	2	46.06479	23.0324	48745.38	<.001
Treatment	14	16.01653	1.144038	2421.22	<.001
Crop.Treatment	28	25.93109	0.92611	1960	<.001
Residual	88	0.04158	0.000473		
Total	**134**	**88.05503**			

Table 18: Analysis of variance of Boron (B) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	5.809	2.904	1.21	
Rep.*Units* stratum					
Crop	2	411980.8	205990.4	85823.42	<.001
Treatment	14	23338.08	1667.006	694.54	<.001
Crop.Treatment	28	44021.36	1572.191	655.03	<.001
Residual	88	211.215	2.4		
Total	**134**	**479557.3**			

Table 19: Analysis of variance of Calcium (Ca) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	3.73E-05	1.86E-05	0.65	
Rep.*Units* stratum					
Crop	2	9.03E+00	4.51E+00	1.58E+05	<.001
Treatment	14	3.56E+00	2.54E-01	8915.57	<.001
Crop.Treatment	28	3.38E+00	1.21E-01	4230.86	<.001

Residual	88	2.51E-03	2.85E-05		
Total	**134**	**1.60E+01**			

Table 20: Statistical analysis of variance of Sulphur (S) levels Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	1.94E-05	9.71E-06	0.21	
Rep.*Units* stratum					
Crop	2	1.673119	0.836559	18180.32	<.001
Treatment	14	0.149817	0.010701	232.56	<.001
Crop.Treatment	28	0.139663	0.004988	108.4	<.001
Residual	88	0.004049	4.6E-05		
Total	**134**	**1.966667**			

Table 21: Analysis of variance of Iron (Fe) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	4.34E-02	2.17E-02	0.94	
Rep.*Units* stratum					
Crop	2	9.09E+05	4.54E+05	1.97E+07	<.001
Treatment	14	8.18E+04	5.84E+03	2.54E+05	<.001
Crop.Treatment	28	1.86E+05	6.65E+03	2.89E+05	<.001
Residual	88	2.03E+00	2.30E-02		
Total	**134**	**1.18E+06**			

Table 22: Statistical analysis of variance of Magnesium (Mg) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	3.83E-05	1.92E-05	2.09	
Rep.*Units* stratum					
Crop	2	5.67E+00	2.83E+00	3.09E+05	<.001
Treatment	14	2.32E-01	1.66E-02	1806.51	<.001
Crop.Treatment	28	4.01E-01	1.43E-02	1559.29	<.001
Residual	88	8.08E-04	9.18E-06		
Total	**134**	**6.30E+00**			

Table 23: Analysis of variance of Aluminium (Al) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	1.58E-02	7.89E-03	0.31	
Rep.*Units* stratum					
Crop	2	3.99E+05	1.99E+05	7.71E+06	<.001
Treatment	14	8.40E+04	6.00E+03	2.32E+05	<.001
Crop.Treatment	28	1.40E+05	5.02E+03	1.94E+05	<.001
Residual	88	2.28E+00	2.59E-02		
Total	**134**	**6.23E+05**			

Table 24: Analysis of variance of Sodium (Na) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0	0		
Rep.*Units* stratum					
Crop	2	3.48E+08	1.74E+08		
Treatment	14	16136662	1152619		
Crop.Treatment	28	24109177	861042		
Residual	88	0	0		
Total	**134**	**3.88E+08**			

Table 25: Statistical analysis of variance of Zinc (Zn) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	2.49E-02	1.25E-02	0.4	
Rep.*Units* stratum					
Crop	2	5.56E+05	2.78E+05	8.92E+06	<.001
Treatment	14	9.38E+04	6.70E+03	2.15E+05	<.001
Crop.Treatment	28	6.98E+04	2.49E+03	79986.42	<.001
Residual	88	2.74E+00	3.12E-02		
Total	**134**	**7.19E+05**			

Table 26: Statistical analysis of variance of Manganese (Mn) levels at Top Crop Nursery at a 5% level of significance.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.42E-01	7.12E-02	3.66	
Rep.*Units* stratum					
Crop	2	1.43E+06	7.12E+05	3.66E+07	<.001
Treatment	14	4.20E+05	3.00E+04	1.54E+06	<.001
Crop.Treatment	28	2.01E+05	7.18E+03	3.69E+05	<.001
Residual	88	1.71E+00	1.95E-02		
Total	**134**	**2.05E+06**			

Table 27: Statistical analysis of variance of Nitrogen (Na) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.03E-05	5.16E-06	2.48	
Rep.*Units* stratum					
Crop	2	8.61E+00	4.31E+00	2.07E+06	<.001
Treatment	5	6.21E-01	1.24E-01	59718.26	<.001
Crop.Treatment	10	5.17E-01	5.17E-02	24864.61	<.001
Residual	34	7.07E-05	2.08E-06		
Total	**53**	**9.75E+00**			

Table 28: Analysis of variance of Phosphorus (P) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	2.05E-06	1.03E-06	0.68	
Rep.*Units* stratum					
Crop	2	2.09E+00	1.04E+00	6.94E+05	<.001
Treatment	5	4.94E-01	9.89E-02	65758.2	<.001
Crop.Treatment	10	7.65E-01	7.65E-02	50874.21	<.001
Residual	34	5.11E-05	1.50E-06		
Total	**53**	**3.35E+00**			

Table 29: Statistical analysis of variance of Potassium (K) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	5.97E-07	2.99E-07	0.14	
Rep.*Units* stratum					
Crop	2	2.22E+01	1.11E+01	5.35E+06	<.001
Treatment	5	2.52E+00	5.03E-01	2.43E+05	<.001
Crop.Treatment	10	4.45E+00	4.45E-01	2.15E+05	<.001
Residual	34	7.04E-05	2.07E-06		
Total	**53**	**2.91E+01**			

Table 30: Statistical analysis of variance of Magnesium (Mg) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	5.82E-06	2.91E-06	1	
Rep.*Units* stratum					
Crop	2	2.08E+00	1.04E+00	3.58E+05	<.001
Treatment	5	2.71E-01	5.41E-02	18653.09	<.001
Crop.Treatment	10	7.10E-01	7.10E-02	24477.12	<.001
Residual	34	9.86E-05	2.90E-06		
Total	**53**	**3.06E+00**			

Table 31: Statistical analysis of variance of Aluminium (Al) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	3.58E-02	1.79E-02	0.77	
Rep.*Units* stratum					
Crop	2	2.58E+05	1.29E+05	5.54E+06	<.001
Treatment	5	4.18E+03	8.35E+02	35910.97	<.001
Crop.Treatment	10	1.59E+04	1.59E+03	68478.47	<.001
Residual	34	7.91E-01	2.33E-02		
Total	**53**	**2.78E+05**			

Table 32: Statistical analysis of variance of Zinc (Zn) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	2.42E-02	1.21E-02	0.15	
Rep.*Units* stratum					
Crop	2	9.57E+04	4.78E+04	5.77E+05	<.001
Treatment	5	2.92E+04	5.84E+03	70531.25	<.001
Crop.Treatment	10	4.60E+04	4.60E+03	55549.09	<.001
Residual	34	2.82E+00	8.28E-02		
Total	**53**	**1.71E+05**			

Table 33: Analysis of variance of Manganese (Mn) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	61.4	30.7	0.05	
Rep.*Units* stratum					
Crop	2	282833.3	141416.7	243.9	<.001
Treatment	5	16731.8	3346.4	5.77	<.001
Crop.Treatment	10	59452.6	5945.3	10.25	<.001
Residual	34	19713.9	579.8		
Total	**53**	**378793**			

Table 34: Statistical analysis of variance of Calcium (Ca) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	2.34E-07	1.17E-07	0.04	
Rep.*Units* stratum					
Crop	2	3.61E-03	1.80E-03	648.37	<.001
Treatment	5	6.95E-01	1.39E-01	49985.59	<.001
Crop.Treatment	10	1.34E+00	1.34E-01	48264.59	<.001
Residual	34	9.46E-05	2.78E-06		
Total	**53**	**2.04E+00**			

Table 35: Analysis of variance of Iron (Fe) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	2.70E-02	1.35E-02	0.53	
Rep.*Units* stratum					
Crop	2	6.47E+05	3.24E+05	1.27E+07	<.001
Treatment	5	7.46E+03	1.49E+03	58620.81	<.001
Crop.Treatment	10	6.54E+04	6.54E+03	2.57E+05	<.001
Residual	34	8.66E-01	2.55E-02		
Total	**53**	**7.20E+05**			

Table 36: Statistical analysis of variance of Boron (B) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.03071	0.01536	0.45	
Rep.*Units* stratum					
Crop	2	928.6835	464.3418	13689.89	<.001
Treatment	5	74.23776	14.84755	437.74	<.001
Crop.Treatment	10	164.579	16.4579	485.22	<.001
Residual	34	1.15323	0.03392		
Total	**53**	**1168.684**			

Table 37: Analysis of variance of Sodium (Na) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0	0		
Rep.*Units* stratum					
Crop	2	3.11E+08	1.56E+08		
Treatment	5	590839	118168		
Crop.Treatment	10	2350833	235083		
Residual	34	0	0		
Total	**53**	**3.14E+08**			

Table 38: Statistical analysis of variance of Sulphur (S) levels at Sunshine Seedlings® at a 5% level of significance.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rep stratum	2	0.000389	0.000195	1.07	
Rep.*Units* stratum					
Crop	2	1.914222	0.957111	5239.77	<.001
Treatment	5	0.134854	0.026971	147.65	<.001
Crop.Treatment	10	0.079282	0.007928	43.4	<.001
Residual	34	0.006211	0.000183		
Total	**53**	**2.134957**			

Figure 1: Stack of sieves used during the Sieve Test Analysis

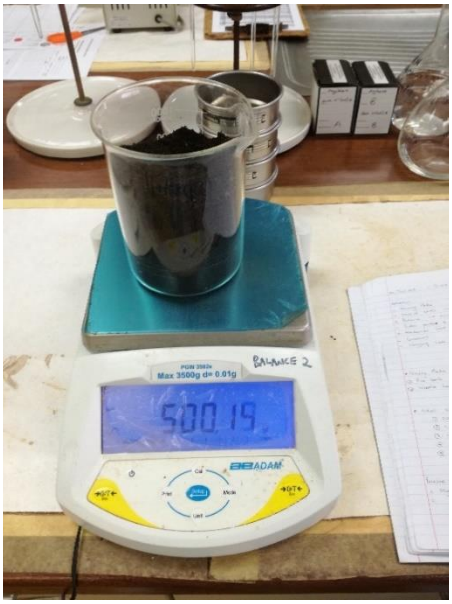

Figure 2: Wattle bark weighed before pouring onto the stack of sieves

Figure 3: Stack of sieves mounted on the shaker for 10 to 15 minutes.

Figure 4: Different sieves showing the different particle sizes retained on each sieve after shaking

Figure 5: Samples from each sieve size ready for nutritional analysis, each with a different particle size

Figure 6: Labelling the seedling trays at Top Crop Nursery before filling in with treatments.

Figure 7: Hand mixing vermicompost pre-mix into the growing medium at Top Crop Nursery.

Figure 8: Manual filling seedling trays with various treatments (1-15) at Top Crop Nursery

Figure 9: Algae formed due to capping of growing media, resulting into stunted growth of seedlings on Treatment 12and 14 at Top Crop Nursery.

Figure 10: Comparison of cabbage seedlings uniformity at week 4 (left) and at week 7 (right) at Top Crop Nursery.

Figure 11: Comparison of Swiss Chard seedlings uniformity at Top Crop Nursery at week 4 (left) and at week 7 (right).

Figure 12: Comparison of pepper seedlings uniformity at Top Crop Nursery at week 4 (left) and at week 7 (right).

Figure 13: At Top Crop Nursery, treatment 5 of cabbage showed the downy mildew at week 7.

Figure 14: The Chlorophyll meter used to check for chlorophyll in seedlings at week 7.

Figure 15: Biomass sampling at Top Crop Nursery for wet (fresh) and dry mass.

Figure 16: A bunch of randomly sampled fresh biomass for cabbage seedlings.

Figure 17: Top Crop on-site weighing and recording of the fresh biomass for a wet (fresh) mass.

Figure 18: Filling up the seedling trays at Sunshine Seedlings® with various treatments (1-6) after mixing using the concrete mixer

Figure 19: Seedling trays filled with various treatments (1-6), lined up for sowing at Sunshine Seedlings®.

Figure 20: Putting seedling trays filled with growing media on the sowing machine and Sunshine Seedlings®.

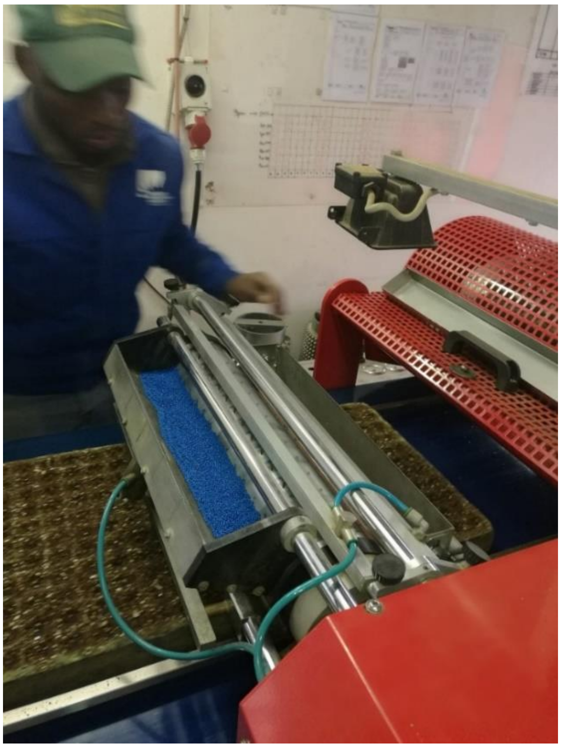

Figure 21: "URBANAT" sowing machine performing the sowing operation of pepper seeds at Sunshine Seedlings®.

Figure: 22: Comparison of seedling sizes at Sunshine Seedlings®, Cabbage, Swiss Chard, and Pepper (left to right) at week 6.

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Figure 23: Root development for cabbage seedlings at Sunshine Seedlings® at harvest (week 7).

Figure 24: Sunshine Seedlings® root development for Swiss Chard seedlings at harvest (week 7)

Figure 25: Sunshine Seedlings® Root development for pepper seedlings at harvest (week 7)

Figure 26: Uniform growth and general appearance of seedlings at Sunshine Seedlings® at week 3 (left) and week 7 (right)

Figure 27: Cabbage seedlings leaves at Sunshine Seedlings® showing chlorosis and downy mildew due to overcrowding.