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Production and effect of vermiwash singly and in combination with vermicompost on the growth, development and productivity of tomato (*Lycopersicon esculentum* Mill.) in Suriname

by

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A thesis submitted to the Anton de Kom University of Suriname, Faculty of Technology, Suriname, in fulfillment of the requirements for the degree of Master of Science (MSc) in Sustainable Management of Natural Resources

Supervisor:

Dr. Lydia Ori

Date: April 30, 2019

Paramaribo, Suriname

Preface

To complete the Master of Science degree in Sustainable Management of Natural Resources at the Anton the Kom University of Suriname, I have done a main part of my research investigation at the greenhouse and vermicompost unit at the Campus of Suriname. The research was conducted in the period March to August 2018 under supervision of Dr. Lydia Ori (Supervisor) and Dr. Riad Nurmohamed (Project coordinator). This final thesis was titled as follows: Production and effect of vermiwash on the growth, development and yield of tomato (*Lycopersicon Esculentum Mill*.) in comparison to vermicompost. During this research investigation, I gained lots of experience and insight in the research subject.

My gratitude goes to the Belgian Directorate-General for Development Cooperation (DGDC) and the Flemish Interuniversity Council (VLIR-UOS) for establishing the Master of Science Programme in Sustainable Management of Natural Resources (MSc. in SMNR) at the Anton de Kom University of Suriname (AdeKUS). Dr. Lydia Ori and Prof. Dr. A. Ansari for their supervision, guidance, continuous encouragement, support and valuable comments throughout the progress of my research and the writing of this thesis. Lecturers, fellow students of SMNR, my family, friends and colleagues for their motivation and support.

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Vijantie R.R. Awadhpersad
Paramribo, April 30 2019

Table of contents

Table of Figures

Table of Tables

List of abbreviations

%	-	Percent
	-	Grade Celsius
C	-	Blanco treatment
C	-	Carbon
C/N	-	Carbon/Nitrogen
Ca	-	Calcium
CEC	-	Cation Exchangeable Capacity
cm	-	Centimeters
EC	-	Electrical conductivity
F	-	Field
Fe	-	Iron
Fig.	-	Figure
G	-	Greenhouse
g.	-	Gram
h	-	Hours
K	-	Potassium
Mg	-	Magnesium
mm	-	Millimeter
N	-	Nitrogen
Na	-	Sodium
P	-	Phosphorus
P-bray	-	Available Phosphorus
pH	-	Acidity
ppm	-	Parts per million
resp.	-	Respectively
S	-	Sulphur
V	-	Plants fertilized with vermicompost
VW	-	Plants fertilized with vermicompost and vermiwash
W	-	Plants fertilized with vermiwash
Zn	-	Zinc

Executive summary

Vermiwash is an organic liquid fertilizer obtained from the units of vermicompost as an extract which is rich in macro- and micro nutrients, enzymes, plant growth hormones and microbes, and in combination with vermicompost it may have the potential to improve the sustainability of tomato production by improving the yield and quality. Therefore, the purpose of this study was to provide an insight in how to produce vermiwash and vermicompost using organic waste material and study the effect on the growth, development, and yield of tomato plants (*Lycopersicon esculentum* Mill.) in the greenhouse and in the field. The experiment was carried out in two phases, the production of vermicompost followed by vermiwash using *Eisenia foetida* earthworms and the cultivation of tomato plants. The first phase, production of vermicompost, consisted of three feed types (dry grass clippings, dry neem leaves and a combination of dry grass clippings and dry neem leaves) with three replications. Vermiwash was collected at day 60 and 90 and the physicochemical properties were analyzed. The second phase consisted of a Randomized Block Design (RBD) with four treatments and three replications in the greenhouse and field. The treatments were control (C), vermicompost (V), vermiwash (W) and a combination of vermicompost and vermiwash (VW). The growth parameters were measured for plant height, stem thickness, number of branches, root length and yield in terms of number of fruits and fruit weight. Data was statistically analyzed using a one-way ANOVA test, followed by the LSD test. The results revealed that the produced vermicompost had a dark color, finely divided peat-like material, with desirable soil odor and a fine smooth texture and an adequate nutritional value, which confirms that the vermicompost was of good quality. The produced vermiwash from the different vermicomposting bins was a brownish colored liquid and had all the essential macro and micro plant nutrients, which indicates the achievement of an environmental friendly enriched nutrient liquid fertilizer for sustainable agriculture. Vermicompost, vermiwash and the combination of vermicompost and vermiwash as a bio-fertilizer had a positive effect on the plant growth parameters and production of the tomato plants. The combination of vermicompost and vermiwash (50 g + 50 ml) significantly ($p < 0.05$) resulted in the highest yielding plants, followed by vermiwash (100 ml) and vermicompost (100 g).

Keywords: earthworms, vermiwash, vermicompost, bio-fertilizer, organic tomato

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.) belongs to the Solanaceae family and is a popular vegetable widely grown in the tropics, including Suriname. According to the statistical data of the Ministry of Agriculture, Animal Husbandry and Fisheries (LVV), the total tomato production area in 2017 was approximately 119 ha. with a total production of 1.442 ton tomato fruits, which makes tomato one of the most cultivated crops in Suriname. This crop is an excellent source of minerals and vitamins, including iron, phosphorus, vitamin A and C (Bhowmik et al. 2012).

In Suriname, agricultural practices largely rely on high inputs of synthetic fertilizers and pesticides to achieve high yield and to protect the crops against pathogens and pests. Excessive use of fertilizers and pesticides leads to gradual degradation of soil fertility and microbiological diversity (Samadhiya et al. 2013). This decline in soil quality further leads to water and land pollution, thereby lowering the lands worth.

Due to the massive application of the pesticide and synthetic fertilizers, the chemical residue limits in fruits are also exceeded. Although, tomato is mostly consumed fresh, high chemical levels in the fruits are bad for the human health. Consumers are now more aware of the food they consume, therefore much attention needs to be paid to organic cultivation and the use of bio-fertilizers as a supplement for chemical fertilizers.

Presently, there is a strong interest in alternative strategies to ensure competitive yields, protection of crops, environment and the health of humankind. Sustainable agriculture seeks to introduce agricultural practices that are environmentally sound, economically viable, and socially supportive. In this context, alternative sources such as microbial inoculants and composted products are considered to meet the nutrient requirements of crops.

Earthworms are known to decompose organic waste into nutrient rich vermicasts through the combined action with microorganisms. The produced vermicompost is reported to be rich in nitrogen (N), phosphorus (P), potassium (K) and micronutrients, with a greater rate of microbial and enzymatic activities. Several researchers found that vermicompost has a positive effect on the growth, development, flowering and yield of plants. It is also been noted that vermicompost increase the root apparatus and the biomass production of the plants and improve the soil fertility (Manyuchi et al. 2013; Zaefarian and Rezvani 2016).

The by-product from the vermicomposting process, which is termed vermiwash is a brownish colored substance that is formed due to the movement of water in the vermicomposting units through the burrows formed by the earthworms.

This liquid is reported to be rich in NPK components, micronutrients, plant growth hormones, microbes, and enzymes. It is used as a foliar spray that can be easily absorbed by plants (Manyuchi et al. 2013; Kaur et al. 2015). The foliar application of vermiwash is also reported to have pesticide effect, plants show less or no incidence of diseases and pests (Verma et al. 2018).

Both the vermicompost and vermiwash are used as bio-fertilizers in the practices of sustainable agriculture. It is reported that the combined use of vermiwash and vermicompost have the highest yielding plants with more branches, higher number of capsules, higher plant dry weight, improve root growth parameters, improve the physicochemical, biological and microbiological properties of the soil (Makkar et al. 2017). Improving the growing conditions with vermiwash and vermicompost enhance the quality of the crop, by increasing their nutrition status which also improves the sustainability of commercial agriculture in a less tangible, but equally important way, since the main goal of agriculture is to grow food for the wellbeing of the population.

1.1. Problem description

Farmers in Suriname generally cultivate in poor soils. Therefore, for improvement in crop productivity, in Suriname and most other countries massive application of pesticides and synthetic fertilizers are used. These result in gradual depletion of soil fertility and microbial diversity. Conventionally managed soils are found to exhibit a poorer micro-flora and a lower biological activity then organically managed soils. The use of chemical fertilizers can result in poor soil health, reduction in production and increase in incidences of pest and diseases and environmental pollution. Recently much attention is paid to organic cultivation and the use of bio-fertilizers as a supplement for chemical fertilizers. In the scope of good agricultural practices, the aim is to substitute chemical fertilizers with environmental friendly and effective biological fertilizers. In Suriname, vermiwash is a new method of liquid fertilizer. Therefore, this research aims to provide an insight in how to produce vermiwash out of organic waste material and its effect on crop production singly and in combination with vermicompost.

1.2. Purpose of the study

The purpose of this study was to provide an insight in how to produce vermiwash using organic waste material and to study the effect singly and in combination with vermicompost on the growth, development, and yield of tomato plants in the field and greenhouse.

1.3. Research questions

The research questions of this study are:

1. Did the vermiwash result in a good nutrient quantity?
2. What will be the effect of vermiwash on the plant growth parameters of tomato plants when compared to vermicompost?
3. What will be the effect of vermiwash singly and in combination with vermicompost on the productivity of tomato plants?

1.4. Method of the research

This research study was carried out from March 2018 to August 2018 at the Anton the Kom University of Suriname. The experiment was carried out in two phases, the production of vermicompost followed by vermiwash using Eisenia foetida earthworms and the cultivation of tomato plants. The first phase, production of vermicompost, consisted of three feed types (dry grass clippings, dry neem leaves and a combination of dry grass clippings and dry neem leaves) with three replications. Vermiwash was collected at day 60 and 90 and the physico-chemical properties were analyzed. The second phase consisted of a Randomized Block Design (RBD) with four treatments and three replications in the greenhouse and field. The treatments were control (C), vermicompost (V), vermiwash (W) and a combination of vermicompost and vermiwash (VW). The growth parameters were measured for plant height, stem thickness, number of branches, root length and yield in terms of number of fruits and fruit weight. Data was statistically analyzed using a one-way ANOVA test, followed by the LSD test.

1.5. Outline of the research

This study consists of five chapters. Chapter one is the introduction that contains the background information from which the problem is formulated and its objectives relative to the research questions. Chapter two provides literature information to support the research on the following aspects: production of vermicompost and vermiwash using *Eisenia foetida* earthworms, the effect of vermicompost and vermiwash on the soil properties, plant growth and yield of crops and tomato growth stages and plant nutrition requirements. Chapter three describes the methodology that is used to conduct the research. The results and discussion are described in chapter four. At last chapter five includes specific finding and conclusions of the research. In chapter five the recommendations are also included.

2. Literature review

2.1. Vermicompost and vermiwash

During the vermicomposting process there are two main products produced, as follows:

- Vermicompost that contains vermicast
- Vermiwash

The vermicompost and vermiwash are used as bio-fertilizers. The earthworms are used to maintain the vermicomposting process.

2.1.1. Earthworms

There are about 4400 species of earthworms in the world, which are adapted to a range of environments (Rajendran and Thivyatharsan 2013). Earthworms belong to the phylum Annelida and subclass Oligochaeta (Ansari and Ismail 2012). According to their feeding and burrowing strategies, earthworms can be classified in three groups: epigeics (they live in the surface litter and feed on decaying organic matter. These “decomposers” are the type of worm used in vermicomposting)), anecic (they drag organic matter and mineral soil in their burrows at night and feed on them) and endogeics (feed the organic matter that is already in the soil and make small burrows) (Ansari and Ismail 2012; Nair 2019).

There have been various earthworms used in the vermicomposting with different quantities and different organic wastes. However, in the vermitechnology, the earthworms of the Lumbricidae family, *Eisenia Foetida* species is commonly used (Manyuchi 2016). This earthworm (Fig. 2.1) is known as the ‘red wiggler worm’ (Nair 2019). It is segmented, containing groups of bristles (setae) on each segment that help the worm move. It has a sensory lobe in front of the mouth (prostomium) and an anus at the end of the body (Jim 2017). The red wiggler is hermaphrodites (Shahnawaz, Andleeb and Ali 2011). They reproduce by joining clitella, wide bands that are visible when they are fertile. Both worms then secrete cocoons, which contains several eggs. The cocoons are lemon-shaped and are pale yellow at first, becoming more brownish as the worms inside become mature (Ansari and Ismail 2012).

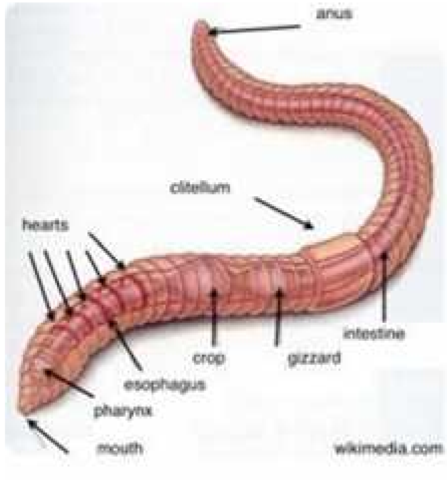

Figure 2.1. Earthworm (Jim 2017)

Eisenia foetida species is most commonly used for vermicomposting, because of the worldwide distribution, short life cycle, naturally colonization of organic substances, wide temperature, and moisture tolerance range and they are resilient earthworms that can be easily handled (Ansari and Ismail 2012). The characteristics of the species are summarized in Table 2.1 (Ramnarain et al. 2019).

Table 2.1. Characteristics of *Eisenia foetida* species (Ramnarain et al. 2019)

	Characteristics
Color	Red
Size of the adult earthworms	4-8mm x 50-100mm
Mean weight of adults	0.55g
Time to maturity (days)	28-30
Number of cocoons per day	0.35-0.5
Mean size of cocoons	4.85mm x 2.82mm
Incubation time (days)	18-26
Hatching viability (%)	73-80
Number of worms per cocoon	2.5-3.8
Self -fertilization	+
Life cycle (days)	45-51
Limits and optimal temperature	25°C (0°C-35°C)
Limits and optimal moisture	85% (70%-90%)
pH	5-9
Average life span	594 days at 18°C (in controlled conditions)
Average life span	589 days at 28°C
Maximum life expectancy	between 4.5 and 5 years
Food consumption	These worms are able to consume waste organics equivalent to its own body weight every day

2.1.2. Vermicompost

Earthworms are known to decompose organic waste into nutrient rich vermicasts through the combined action with microorganisms, either free-living or associated with their guts. Earthworms are the crucial drivers of the process, they aerate condition and fragment the substrate, thereby drastically increase the microbial activity. Earthworms can be seen as mechanical blenders, they modify the organic matters physical and chemical status, by gradually reducing the C:N ratio and increasing the surface area that is exposed to microorganisms for bio-chemical degradation. Based on this, there are two phases that can be distinguished (Dominguez and Edwards 2011):

a. A phase where the earthworms process the waste, modify its physical state and microbiological composition, also called the active phase.
b. A mature-like phase where the earthworms transfer towards the fresher layers of undigested waste, where the microorganisms take over in the decomposition of the waste.

The characteristics of vermicomposting are presented in Table 2.2 (Dominguez and Edwards 2011).

Table 2.2. Characteristics of vermicomposting (Dominguez and Edwards 2011)

Process Factor	Values
C:N ratio of wastes	25:1 to 30:1
Initial particle size	10-20mm (0.4-0.8 in)(higher values slow down the process)
Moisture content	80-85% (limits 60-90%)
Oxygen	Earthworms maintain aerobic conditions
Temperature	15 -25 (limits 4 -30)
pH	>5 and <9
Ammonia content of wastes	Low: < 0.5 $mg.g^{-1}$
Salt content	Low: < 0.5%
Windrow size	Any length and width 50 cm high (higher values slow down the process or can even stop it long)
Reactor size	40 m long x 2.4 m wide x 1 m deep. Wastes should be added in thin layers 5 -10 cm
Human pathogens	Killed after 70 days of vermicomposting
Time taken	From 4 to 12 months in the windrows to 30 – 60 days in the continuous reactor systems.

All types of biodegradable waste such as farm waste, kitchen waste, market waste, bio-waste of agro based industries, live- stock waste etc. can be used for the production of vermicompost. The earthworms consume these type of waste and hereby reduce the volume for 40 – 60%.

Each earthworm consumes waste equivalent to its body weight (0.5 – 0.6 g) and the cast produced is equivalent to about 50% of the waste consumed in a day. The castings have a moisture content of about 32 – 66% and a pH of around natural (7.0) (Adhikary 2012).

Several researchers found that vermicompost contains an average of 1.5% - 2.2% N, 1.8% - 2.2% P and 1.0% - 1.5% K with an organic carbon range from 9.15 to 17.98. It also contains micronutrients like Sodium (Na), Calcium (Ca), Zinc (Zn), Sulphur (S), Magnesium (Mg) and Iron (Fe) (Adhikary 2012) (Anasri and Sukhraj 2010). Besides the nutrients, it also contains hormones like auxins and cytokinins, enzymes, vitamins and useful microorganisms like bacteria, Actinomycetes, Nitrosomonas, Azotobacter, protozoans and fungi that play an important role in transforming the raw organic material to humus like sweet smelling fine composted material (Jaikisun et al. 2014).

2.1.3. Environmental factors affecting the production and quality of vermicompost

For the consistent productivity of vermicompost, it is essential to maintain control on the matching feed rates, population, and environmental parameters. Environmental factors such as moisture, temperature, and pH in growing medium must be maintained to ensure healthy growing worm populations and vermicompost of good quality (Amarvathi and Reddy 2015).

1. **Moisture**

Moisture is one of the crucial factors for the breeding of the worm population. The worms breathe through their skin, and therefore need a moist environment to live. If the moisture is not enough (below 50%) and the skin dries out and the worm will die.

The ideal moisture content range for vermicomposting or vermiculture processes is between 70-90%. According to Dominguez and Edwards (1997), the moisture should be between 80%-90%, with an optimal moisture of 85% for a rapid growth of *Eisenia foetida*. Nova Scotia researchers reported that the best growth and reproductive response is found at a moisture content between 75 - 80%. Moisture level is a significant factor in the set-up of a vermicomposting unit, water constitutes to 75-90% of earthworms body weight (Edwards and Bohlen 1996).

2. **Temperature**

The activity, metabolism, growth, respiration, reproduction, fecundity, and growth period from hatching to sexual maturity of earthworms are greatly influenced by temperature. The temperature range for setting vermicomposting units with *Eisenia foetida* species should be between 20 – 35 . It is reported that the optimum temperature for *Eisenia foetida* species activity is 25 (Pandit et al. 2012).

3. **pH**

According to researchers, the pH of a vermicomposting unit varies between 5 - 9. When the compost is ready to harvest the pH reaches near natural. Depending on the food source used, the pH of the vermicomposting bed can drop over time. If the food source is alkaline, the pH will be neutral or slightly alkaline. If the food source is acid, the pH will drop below seven (Edwards and Bohlen 1996).

2.1.4. Vermiwash

The by-product from the vermicomposting process, which is termed vermiwash, is a brownish colored substance that is formed due to the movement of water in the vermicomposting units through the burrows formed by the earthworms. The vermiwash is ready to be harvest when the liquid turns pale or brownish compared to the first collect (Prabina et al. 2018). This liquid is reported to be a collection of excretory products and mucus secretion of earthworms along with micronutrients from the soil organic molecules. It is rich in NPK components, micronutrients, plant growth hormones, microbes, and essential enzymes (Manyuchi, et al. 2013; Prabina et al. 2018; Verma, et al. 2018). It contains a mixture of various enzymes of protease, amylase, unease and phosphatase that are beneficial for the growth and development of the plant and stimulate the yield and productivity of crops. Microbial studies of vermiwash found that it contains nitrogen fixing bacteria like *Azetobacter*, *Agrobacterium* and *Rhizobium* and phosphate solubilizing bacteria that are responsible for the improvement of the soil health (Kaur et al. 2015).

2.2. Effect of vermicompost and vermiwash on soil properties

There is reported that the combination of vermicompost and vermiwash has a significant influence on the biochemical characteristics of the soil. There is a marked improvement in soil micronutrients and the physical and chemical properties of the soil (Anasri and Sukhraj 2010; Tharmaraj et al. 2011). It is noted that the nutrients in the vermicompost are readily available and enhances the nutrient uptake of plants. The vermicompost has enzymes like amylase, lipase, cellulase and chitinase, which can break down the organic matter in the soil to release the nutrients and make it available to the plant roots (Adhikary 2012). The vermicompost when applied to the soil rejuvenates the depleted soil fertility, increases the water holding capacity, maintains the soil quality, and enriches the nutrient composition and biological resources (Prabina et al. 2018). Besides the vermicompost, the application of vermiwash to the soil also increases the soil nutrient status and microbiological activity. Mostly the vermiwash is used as a foliar spray.

2.3. Effect of vermicompost and vermiwash on plant growth and yield of crops

Many researchers suggest that vermicompost and vermiwash can induce excellent plant growth, root development and yield. Vermicompost and vermiwash is reported to be rich in nitrogen (N), phosphorus (P), potassium (K) and micronutrients, with a greater rate of microbial and enzymatic activities (Manyuchi 2016; Zaefarian & Rezvani, 2016). They also contain plant growth hormones like auxins, cytokinis and gibberellins and humic acids (Gopal et al. 2012; Bhardwaj and Sharma 2016). Humic acids are known to enhance the root growth and nutrient uptake by increasing the root cell membrane permeability (Makkar et al. 2017).

Researches with brinjal (Sundararasu and Jeyasankar 2014), pepper (Lujan-Hidalgo, et al. 2016) tomato (Kaur et al. 2015) and gladiolus (Tamrakan, et al. 2018) found that vermicompost and vermiwash significantly enhance the plant growth parameters and yield. They also result in early flowering and fruiting (Makkar et al. 2017), which is beneficial for the farmers. The production is also uniform and the fruits also ripen uniform (Makkar et al. 2017).

In contrast, it is also reported that high doses of vermicompost show relatively poor growth, due to the excessive nutrient absorption and humic acids which are toxic for the plants (Makkar et al. 2017).

Studies in comparison with chemical fertilizers showed that the best plant growth and production were reported for the chemical fertilizer, but the organic fertilizer (vermicompost or vermiwash or combination) had significant results (Bhardwaj and Sharma 2016).

The plants with vermicompost and vermiwash had also less pest and disease incidence in comparison to the chemical fertilizer. In some studies it is reported that there were no pest and insects observed, which mains that the organic fertilizers (depending on the feed used) have bio - pesticide effect (Samadhiya et al. 2013; Verma et al. 2018).

There is also suggested that the fruits or crops obtained from the organic fertilizers (vermiwash and vermicompost) have a better quality and nutritional value with a longer shelf life (Verma et al. 2018).

2.4. Tomato (*Lycopersicon esculentum* Mill.)

Tomato belongs to the nightshade family, *Solanaceae* and is one of the most popular vegetables in the world. This crop is known for its different varieties, round, oval, ‘cherry’ but all have the same nutritional characteristics. It is an excellent source of minerals and vitamins, including iron, phosphorus, vitamin A and C (Bhowmik et al. 2012).

Over the year’s hybrid tomato varieties have been developed, for better quality and higher production, resistance for diseases and pest. Hybrid tomato varieties have many advantages compared to open-pollinated varieties. They generally mature earlier and more uniformly (Opena et al. 2011).

The tomato hybrids are categorized in two main types, determinant and indeterminate. Determinant tomato plants usually produce a more uniform crop and ripen earlier. The tomato plants do not continue to grow in size and are much smaller than the indeterminate plants. Because the plants do not continue to grow, when the first flush of fruits is harvested, the plants begin to diminish and set little or no fruits. This type of tomato plants is used when a large amount of tomato fruits is needed at once, for example a tomato paste processing factory.

On the other hand, indeterminate plants continue growing throughout the growing season and continue to produce flowers and fruits until they die. These type of tomato plants should be suckered in order to bear good quality and larger fruits (Ibsen and Dagma 2019).

The growth of tomato plants are described in five growth stages. The growth stages are illustrated graphically in Fig. 2.2, as germination and early growth with initial leafs (25-30 days), vegetative growth (20-25 days), flowering or bloom initiated (20-30 days), fruit formation (20 -30 days) and mature fruiting (15-20 days).

Depending on the varieties and other environmental factors, such as temperature, humidity, soil conditions and nutrients the exact days within each stage may differ (Shamshiri et al. 2018). Jones 2013 reported that the number of days from seeding to harvesting of the first fruits varies from 45 to 100 days, depending on the maturity level of the cultivar (Shamshiri et al. 2018). In Fig. 2.2 there is also an illustration of the ripening stages of the tomato fruit. The tomato fruits are harvested when the mature green stage is reached after which it is stored to get its orange red color (fully ripe).

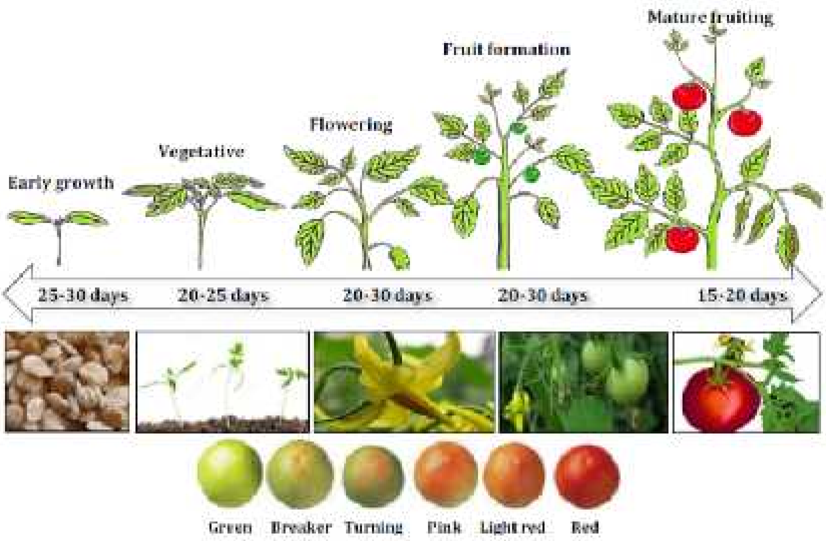

Figure 2.2. The five different growth stages for tomato plants, and the different levels of fruit ripeness (Shamshiri et al. 2018)

Tomatoes can be produced across a wide range of soils as long as the drainage and physical soil structure, incl. organic matter are good. The ideal soil pH for tomato plants ranges from 6.0 – 6.6, but they are mostly grown in soils with a low pH (Advisary committee on vegetable crops n.d.).

The influence of soil pH on nutrient availability is shown in Fig. 2.3, when the pH is acid, the important nutrients such as N, P, K, and Ca become unavailable.

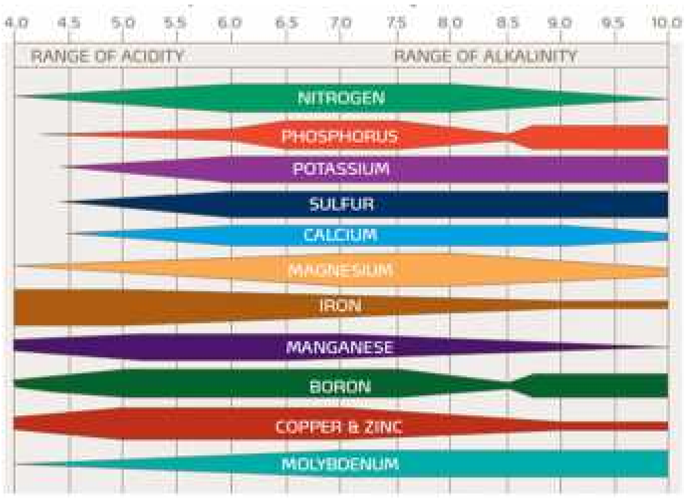

Figure 2.3. The influence of soil pH on nutrient availability (Tomato Agronomic Principles n.d.)

3. Methodology

3.1. General

This research study was carried out from March 2018 to August 2018 at the Anton the Kom University of Suriname. The experiment consisted of two phases. The first phase was the production of vermiwash and vermicompost using three types of feed (dry grass clippings and neem leaves). After 60 days the vermiwash was collected and analyzed. In the second phase the obtained vermiwash with the highest nutrient content from the first phase was used for the cultivation of tomato plants (*Lycopersicon exculentum* Mill.) in the greenhouse and field (Fig. 3.1).

Figure 3.1. Greenhouse and field experiment at the Anton de Kom University of Suriname

3.2. Production of vermiwash

3.2.1. Collection of earthworms

The *Eisenia foetida* earthworms (Fig. 3.2) were collected from the vermicomposting station at the Anton the Kom University of Suriname. Initially the earthworms were imported from the University of Guyana in 2014 by Ramnarain. For the experiment a total of 450 earthworms were collected of different age groups of juvenile, non-clittelate and clittelate earthworms (Fig. 3.3).

3.2.2. Construction of vermiwash units and extraction

Vermiwash units were adapted with a few modifications based on the design from Ramnarain in 2017. Plastic barrels of 20 liters were used and a hole was made at the bottom side, to fit a tap, to regulate the water supply (Fig. 3.5).

The culture bed was prepared, as follows (Fig. 3.4 & Appendix B):

1st layer (basal layer): Broken bricks/pebbles (4.5 cm), on top of this a layer coarse sand was set up 4.5 cm to ensure proper drainage.

2nd layer: on top of the basal layer a layer loamy soil (8 cm) was set and moistened. On this layer 50 earthworms were introduced per bucket.

3th layer: The feed consisted of fresh/dry cattle dung that was scattered up to a thickness of 4.5 cm and dry grass clippings or dry neem leaves or a combination of both.

The tap was kept open for the next 60 days and the unit was kept moist. On day 60 the tap was closed and on top of the barrel a bottle was hanged as a sprinkler of water (Fig. 3.5). About 1 liter of water (the volume of water is 1/20 of the size of the barrel) was poured in the bucket and allowed to gradually sprinkle on the barrel overnight. The tap of the unit was opened the next day and vermiwash was collected. Afterwards vermiwash was collected when needed.

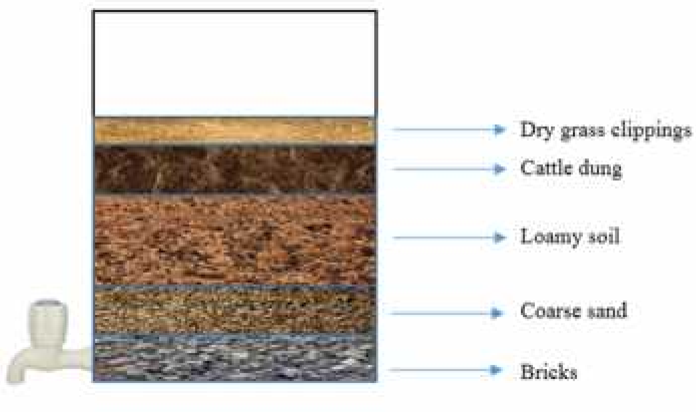

Figure 3.4. Culture bed of a vermiwash bucket


Figure 3.5. Vermiwash bucket with sprinkler

3.2.3. Experimental design

The experiment was conducted in the vermicomposting unit at the AdeKUS University behind building 7 at the Leysweg, Paramaribo. The experiment consisted of three treatments and three replications, set up in 9 buckets (Fig. 3.6), as follows:

- Treatment 1: dry grass clippings
- Treatment 2: dry neem leaves
- Treatment 3: dry grass clippings and dry neem leaves

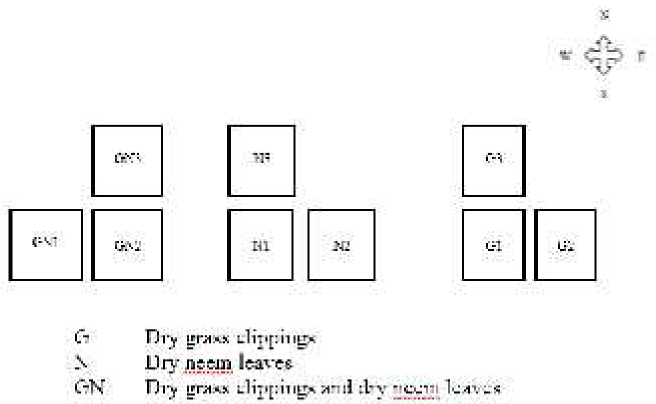

Figure 3.6. Schematic overview of the experimental design of vermiwash units

The earthworms were fed twice a week with cattle dung and according to the treatment with grass or neem or both. The vermiwash units were watered every two days.

3.2.4. Observation and measurements

On a weekly basis, during the process of vermicomposting, till day 90, the temperature, pH and moisture content of the units were measured. The temperature was measured with a thermometer as shown in Fig. 3.7.

The moisture content was measured with a moisture meter as show in Fig. 3.8. The moisture ranges were as follows: 10-40% (dry); 40-80% (moist); 80-100% (wet). The pH was measured with a soil pH-meter as shown in Fig. 3.9. After 30 days the color change of the vermiwash was observed and registered till day 90.

Figure 3.7. Thermometer

Figure 3.8. Soil moisture meter

Figure 3.9. Soil pH meter

3.2.5. Physicochemical analysis

The chemical analyses were conducted for the obtained vermiwash at 60 and 90 days, the vermicompost obtained from the different treatments and the vermicompost of rice straw collected from the existing vermicompost unit. The following parameters were analyzed using the methods described according to the laboratory prescription of the soil laboratory of the Anton de Kom University of Suriname:

- pH-H_2O
- CEC
- Electrical conductivity (EC)
- Organic Carbon
- Total nitrogen
- Total and exch. phosphorus
- Total and exch. potassium
- Total and exch. micro-nutrients: Magnesium, Calcium and Sodium

3.3. Cultivation of tomato plants

3.3.1. Experimental design

The second experiment, the cultivation of tomato plants, was carried out from April 2018 - July 2018 as two experiments:

1. Greenhouse experiment in pots (G)

2. Field experiment in pots (F)

The experiments were set up as two separate Randomized Block Designs (RBD) with four treatments and three replications as shown in Appendix C. Each block consisted of four rows with seven plants per row. The treatments were as follows:

- Control treatment (C)
- Plants fertilized with 100 gr. vermicompost (V)
- Plants fertilized with 100 ml. vermiwash (W)
- Plants fertilized with 50 gr. vermicompost and 50 ml. vermiwash (VW)

3.3.2. Sowing to transplanting

The tomato seeds of the variety Delhi 501 were sown in seed trays in potting soil. The germination rate was 96%. Three weeks after germination, on the 01 May 2018, the seedlings (Fig. 3.10) were transplanted for the implementation of the experiment.

The medium used for the experiment was a mixture of shells and compost (1:1). This mixture was analyzed at the beginning and the end of the experiment on the variables pH, CEC, organic C, tot. N, tot. P, exch. P, tot. K, exch. K, tot. Na, tot. Mg, exch. Mg, tot. Ca, exch. Ca.

Before transplanting the plant pots were irrigated and plant holes were made. For the vermicompost treatment due to the amount of compost needed, vermicompost of rice straw obtained from the existing vermicompost unit was used. After the analyses of the vermiwash it revealed that the vermiwash obtained from the grass and neem treatment had the highest nutrient content and was used for this the experiment.

The experiment was carried out as follows:

1. The plants of the control treatment were transplanted in the soil mixture.
2. In the plant pots of the vermicompost treatment, 100 gr. of vermicompost (Fig. 3.11) was placed in the plant holes after which the tomato plants were transplanted.

3. In the plant pots of the vermiwash treatment, 100 ml of vermiwash (Fig. 3.12) was poured after which the tomato plants were transplanted.
4. In the plant pots of vermicompost and vermiwash treatment, 50 g. of vermicompost and 50 ml of vermiwash were poured in the plant holes after which the tomato plants were transplanted.

Figure 3.10. Seedlings

Figure 3.12. Measurement of e 3.11. Measurement of
100 g. of vermicompost)0 ml. of vermiwash

3.3.3. Fertilization

As mentioned in paragraph 3.3.2., the tomato plants were fertilized at transplanting. Afterwards, the tomato plants were fertilized at an interval of two weeks. According to the treatment, the plants were fertilized with 100 g. of vermicompost per plant or 100 ml of vermiwash per plant or combination of vermicompost and vermiwash in the ratio of 50:50. Due to the fact that 100 ml of vermiwash was much to give the plant in one time, the amount was spread over three times, within the two weeks period. The vermiwash was used as a foliar spray. In total the tomato plants were fertilized 4 times during the cultivation period. The total amount fertilizer added per plant is shown in Table 3.1.

Table 3.1. Total amount fertilizer added per plant

Symbols	**Treatment**	**Total amount added per plant**
C	Control (soil)	0
V	Vermicompost	400 g

W	Vermiwash	400 ml
VW	Vermicompost and vermiwash	200 g + 200 ml

3.3.4. Observations and measurements

The temperature and relative humidity in the greenhouse was measured with a temperature and relative humidity data logger. The climatic parameters for the field experiment was collected from the metrological service Suriname.

During the cultivation of the tomato plants, measurements were done once a week, until the second harvest. The parameters that were recorded included:

- Number of branches
- Plant height (Fig. 3.13): the highest point of the plant to the ground
- Stem thickness (Fig. 3.14): the width halfway between the stem portion from the ground to the first branches
- Root length at the end of the experiment (Fig. 3.15)

At the end of the experiment the biomass was determined, in particular, wet and dry weight of the shoots and roots.

To measure if the vermiwash had influence on the production, the following was recorded:

a. Number of fruits per plant

b. Weight of fruits per plant

Fruits were harvested when a slight color change was observed from green to yellow.

Figure 3.13. Measurement of the plant height, using a tapeline

Figure 3.14. Measurement of the stem thickness, using a caliper

Figure 3.15. Measurement of the root length, using a tapeline

3.4. Statistical analyses

For the statistical analyses of the data the SPSS software was used. The data of the greenhouse and field experiment were separately processed using a one – way ANOVA test, with a significance level of 0.05. Treatments which were significant different, were analyzed with LSD Multiple range test.

4. Results and discussion

The results of phase 1 and phase 2 of the experiment are presented in the following sections.

4.1. Production of vermiwash

4.1.1. Analysis of the environmental factors

4.1.1.1. Temperature

The average temperature measured in the vermicompost bins during the twelve weeks of composting is shown in Figure 4.1. The average temperature and the fluctuation for the treatments was recorded to be 27.3 ± 0.5 ℃ for grass, followed by 27.1 ± 0.4 ℃ for neem and 27.2 ± 0.3 ℃ for grass and neem. According to Pandit et al. 2012 the temperature was in the range of the optimal temperature, 25 – 30℃ for growth of earthworms.

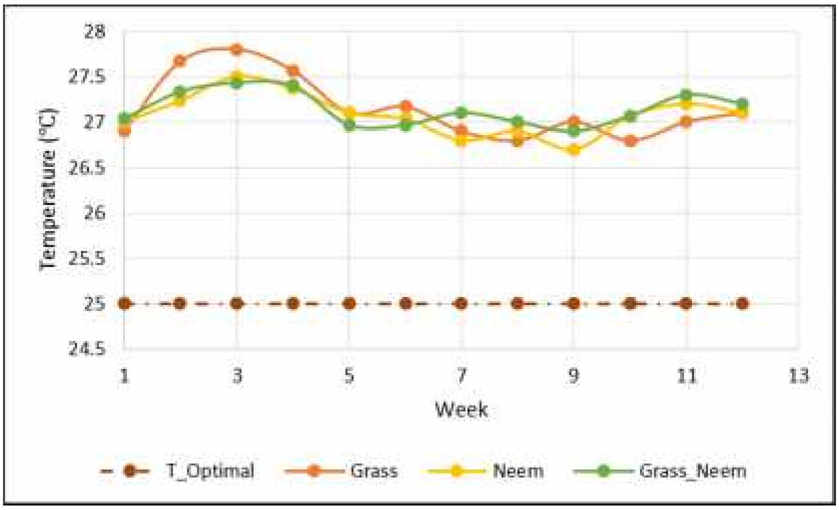

Figure 4.1. Average temperature in the vermicompost bins during twelve weeks of composting

4.1.1.2. pH

The average pH measured in the vermicompost bins during the twelve weeks of composting is shown in Figure 4.2. The pH for all the three treatments varied from 5.3 – 7.0 until it was almost neutral. Several researchers found that worms can survive in a pH range of 5-9 and that the worms prefer a pH of 7 or slightly higher (Adhikary 2012).

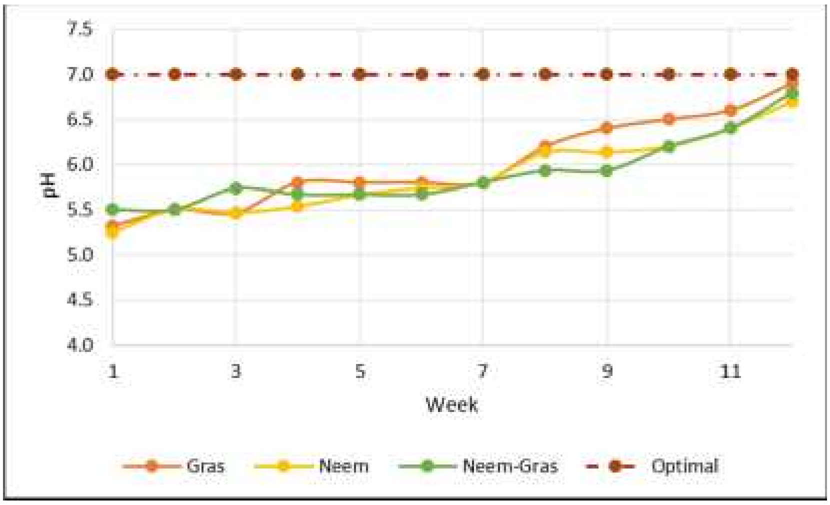

Figure 4.2. Average pH in the vermicompost bins during the twelve weeks of composting

4.1.1.3. Moisture

The average moisture content measured in the vermicompost bins during the twelve weeks of composting is shown in Figure 4.3. The moisture content for the three treatments varied form 80 - 97%. According to Edward and Bohlen in 1996, the ideal moisture content range is from 70-90%, with an optimum moisture content of 85%. The moisture content was in the range with the literature, until approximately week 6, when the bins were watered to harvest vermiwash.

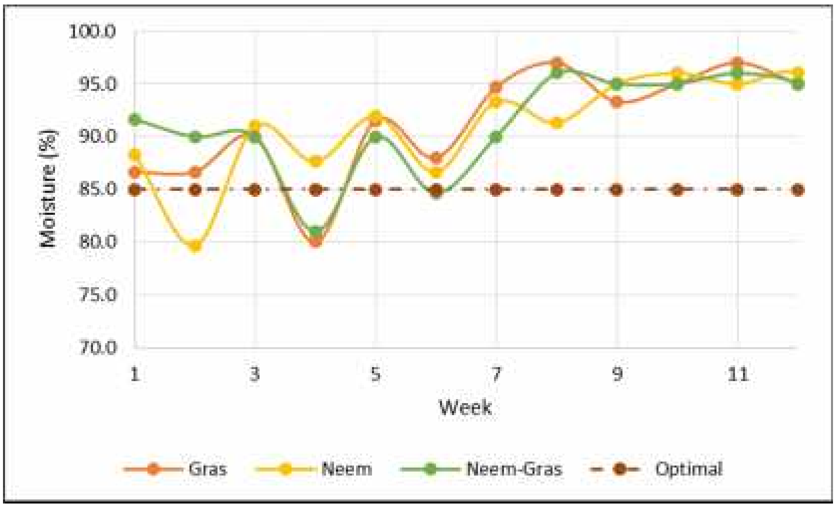

Figure 4.3. Average moisture content in the vermicompost bins during the twelve weeks of composting

4.1.2. Vermicompost physicochemical properties

As shown in Fig. 4.4 & 4.5, the obtained vermicompost is a finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture holding capacity (Maheswari et al. 2016; Ansari and Ismail 2012). The vermicompost was dark colored, with a desirable soil odour and a fine smooth texture. There were also cocoons (Fig. 4.6) seen in the composting bins.

Figure 4.4. Vermicompost of the bins fed with neem

Figure 4.5. Vermicompost of the bins fed with grass

Figure 4.6. Cocoons during the vermicomposting process

In Table 4.1, the physicochemical properties of vermicompost obtained from the vermiwash units and the exciting compost unit (rice straw) is shown. According to the results the highest and lowest quantity of pH were 6.50 and 5.90 resp. in the vermicompost produced from neem and rice straw. The observed reduction during the vermicomposting process is in line with the literature review (Ramnarain et al. 2019; Jaikisun et al. 2014). It is also stated that a slightly acidic pH, is characteristic of good quality compost (Jaikisun et al. 2014). Earthworm and microbial decomposition of organic matter during vermicomposting leads to production of high concentrations of CO_2 and organic acids, which regulates and shifts the pH of vermicompost towards neutrality (Kaushik and Grag 2004). Another reason for the pH reduction can be considered the biotic converting of organic matter to different intermediate materials, intensive mineralization of organic nitrogen to nitrate and nitrite and phosphorous to ortho-phosphates. The pH reduction is an important factor for maintenance of nitrogen, because at an alkaline pH the nutrient volatilizes in the form of ammoniac gas (Zarei et al. 2018). Based on the results, the highest EC (9.63 mS) was noted in the vermicompost produced from rice straw and the lowest (4.76 mS) in the vermicompost produced from grass. Electrical conductivity is dependent of freely available minerals and ions, generated during digest and excretion by earthworms, which increases the concentration of available ions (Zarei et al. 2018).

The results showed that, the highest values of organic matter and carbon were related to the vermicompost produced from the combination of grass and neem, which were 57.40 and 28.70% respectively, and the lowest values were measured in vermicompost produced from grass, which were 32.92 and 16.46% resp. Also the highest value of C/N ratio (17.83) was observed in the vermicompost produced from the combination of grass and neem and the lowest value was in the vermicompost produced from grass. All vermicompost showed a reduction of C/N ratio in comparison to the feed used, which is one of the most widely used indicator of organic waste maturity (Dominguez and Edwards 2011). The loss of carbon as carbon dioxide through microbial respiration and simultaneous addition of nitrogen by worms in the form of mucus and nitrogenous excretory material lowered the C/N ratio of the substrate, which is most essential in the humification process (Zarei et al. 2018).
The highest concentrations of N, P, K, exch. P and exch. K (resp. 1.77 %, 0.71%, 0.14%, 0.29%, 11.82 ppm) were observed in the vermicompost produced from neem and the lowest concentration (resp. 1.35%, 0.49%, 0.11% 0.22%, 6.44 ppm) in the vermicompost produced from rice.

The nutritional value is depended and the nature of the organic material used as feed for the vermicomposting process and the quality of the vermicompost (Zarei et al. 2018; Kaur et al. 2015). The results of the vermicompost are in line with the literature review. It has a desirable smell, balances pH, low electrical conductivity, high cation exchange capacity and concentrations of available nutrients (Zarei et al. 2018).

Table 4.1. Physicochemical properties of vermicompost obtained from the different treatments

	Treatment			
Parameters	**Grass**	**Neem**	**Grass + Neem**	**Rice straw**
pH H2O	6.30	6.50	6.30	5.90
EC (mS)	4.76	5.34	5.36	9.63
CEC-unbuffered (meq/100g)	37.67	47.19	42.82	40.51
Org. C (%)	16.46	24.19	28.70	16.85
Org. stof (%)	32.92	48.39	57.40	33.71
Tot. N (%)	1.41	1.77	1.61	1.35
Tot. P (%)	0.61	0.71	0.68	0.49
P-bray (%)	0.13	0.14	0.14	0.11
Tot K (%)	0.26	0.29	0.25	0.22
Exch. K (ppm)	9.94	11.82	11.04	6.44
Tot. Ca (%)	0.57	0.66	0.56	0.78
Exch. Ca (ppm)	11.70	24.58	19.94	31.69
Tot. Mg (%)	0.31	0.27	0.26	0.18
Exch. Mg (ppm)	5.94	11.12	9.48	7.60
Tot. Na (%)	0.04	0.03	0.03	0.04
Exch. Na (ppm)	0.35	0.74	1.38	0.86
C/N ratio	11.67	13.67	17.83	12.48

4.1.3. Vermiwash physicochemical properties

The color change of the obtained liquid from the vermicomposting bins are shown in Fig. 4.7. The color of the liquid changed from transparent to light yellow to brown, were the maximum nutrient value of the vermiwash was found (Prabina et al. 2018).

Figure 4.7. Color change of the obtained vermiwash

The physicochemical properties of vermiwash harvested at 60 and 90 days of composting is shown in Table 4.2. The results of the physicochemical properties at day 60 were approximately the same, except for the total phosphorus (P). The vermiwash harvested from the grass + neem treatment had the highest P value followed by neem treatment and grass treatment, respectively 70, 63 and 35 ppm. Based on these results, the vermiwash harvested from the grass + neem treatment was used for further experiment with tomato plants. The results of the physicochemical properties of the vermiwash harvested at day 90 had approximately the same nutrition value as the vermiwash harvested at day 60. From these results there can be concluded that the nutrition value of the vermiwash was in the same range during the cultivation period.

The analyses of the vermiwash indicated the presence of nutrients in a significant quantity, which is also confirmed by (Anasri and Sukhraj 2010; Kaur et al. 2015). The obtained results of the physicochemical properties of the vermiwash are in agreement with the work done by Anasri and Sukhraj 2010. Although it had to be noted that several researches found different nutritional value for the vermiwash, because the nutritional value is depended on the feed used for the vermicomposting process and quality of the vermicompost (Kaur et al. 2015; Zarei et al. 2018).

Table 4.2. Physicochemical properties of vermiwash harvested at 60 days and 90 days of composting

Physicochemical properties of Vermiwash						
	60 days			90 days		
	Treatment			Treatment		
Parameters	**Grass**	**Neem**	**Grass + Neem**	**Gras**	**Neem**	**Grass + Neem**
pH H2O	7.20	6.90	7.30	7.40	7.50	7.30
EC (mS)	9.09	9.61	8.93	8.69	8.84	8.85
Tot. N (ppm)	212.00	256.00	216.00	246.00	303.00	236.00
Tot. P (ppm)	35.00	63.00	70.00	34.07	64.09	71.80
Tot. K (ppm)	1274.51	1148.87	1327.63	1278.63	1054.97	1056.04
Tot. Ca (ppm)	330.83	271.75	258.17	254.70	292.08	233.01
Tot. Mg (ppm)	362.13	313.00	210.54	306.98	280.22	239.43
Tot. Na (ppm)	376.87	373.58	245.16	343.48	355.35	294.58

4.2. Cultivation of tomato plants

4.2.1. Climatic conditions

The average day and night humidity and temperature in the greenhouse and field are shown in Fig. 4.8, 4.9 & 4.10. According the data of the greenhouse during the day from 7:00 to 18:00 h. the average temperature was always above 29.50 and below 30.61 , while the average temperature during the night from 19:00 to 6:00 h. was above 24.32 and below 24.89 . The maximum average humidity during the day was 77.81% and the minimum 70.97 %, while the maximum average humidity during the night was 94.68% and the minimum 92.09%.

Based on the results of the day temperature in the field, the highest temperature was 27.81 and the lowest 26.87 , while the maximum humidity was 84% and the minimum 74.14%.

The average day temperature in the greenhouse was higher than in the field, while the average day humidity in the field was higher than in the greenhouse.

Jones reported that the optimal day temperature for a good tomato yield is between 21 – 29.5 and night temperature 18.5 - 21 (Shamshiri et al. 2018). According to this, the day and night temperature in the greenhouse was above the ranges, while for the field the day temperature was between the ranges.

The optimal range for relative humidity during the entire growth stages of tomato plants is between 50 - 70%. Some studies showed that a relative humidity around 60% enhanced the tomato pollination. Nevertheless, for greenhouses it is normal to have a relative humidity range of 60 – 90% (Shamshiri et al. 2018). According to this, the relative humidity in the greenhouse and field was above the optimal range, it should be noted that the average relative humidity of Suriname is above 70%.

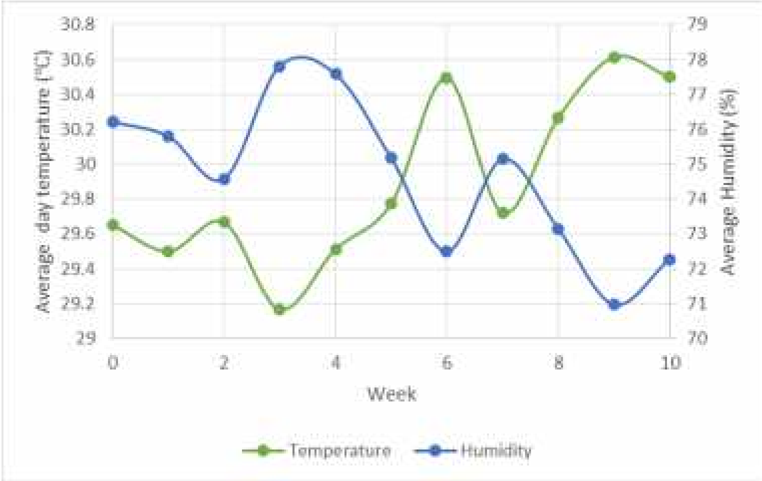

Figure 4.8. Average day temperature and humidity in the greenhouse during the cultivation period

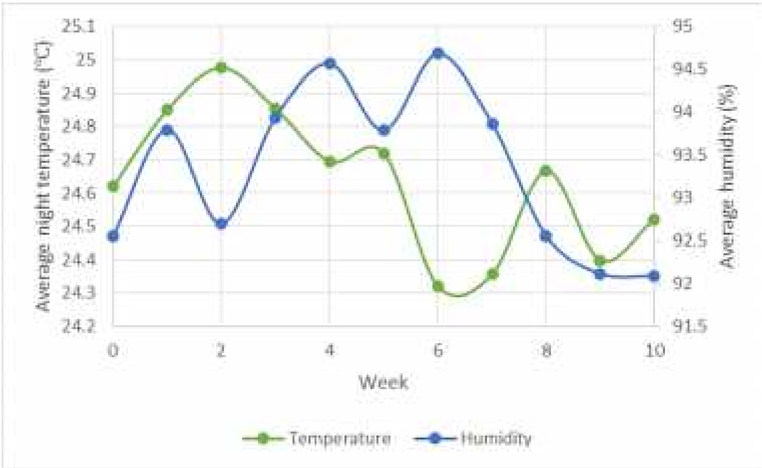

Figure 4.9. Average night temperature and humidity in the greenhouse during the cultivation period

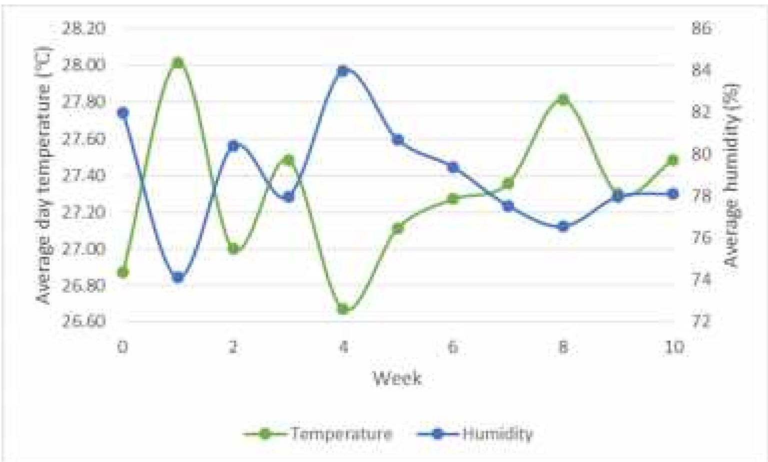

Figure 4.10. Average day temperature and humidity in the field during the cultivation period

4.2.2. Physicochemical properties of the soil

The physicochemical properties of the soil at the beginning and at the end of the experiment are shown in Table 4.3. The soil analysis at the beginning of the experiment showed that the pH was alkaline; this result was obtained due to the fact that for the soil analysis the sample was grinded finely and so the shells in the sample, were the cause that the result was alkaline. Measurement of the sample with the soil pH meter showed that the pH was almost natural. The physicochemical properties of the soil were acceptable for the cultivation of the tomato plants.

At the end of the experiment, a mixed sample was taken from each treatment to determine the nutrient values. Comparison of the soil nutrient at the beginning and at the end of the experiment shows that there was no difference (Table 4.3). At the end of the experiment, the nutrient values of the treated soils for Exchangeable P, K, Ca and Mg in the greenhouse were slightly higher than the nutrient value of the soil at the beginning of the experiment. The overall highest value is seen for the GVW treatment. Approximately similar results are also seen for the field experiment, but there has to be taken in consideration that in the field, the nutrient leaching was high due to rain fall. As reported by researchers, the combination of vermicompost and vermiwash has a positive effect on the biochemical characteristics of the soil, there is marked an improvement in soil micronutrients, physical and chemical properties (Anasri and Sukhraj 2010; Tharmaraj et al. 2011).

It is also reported that vermicompost has enzymes that breakdown the organic matter in soil to release the nutrients, so it rejuvenates the depleted soil fertility, increases the water holding capacity, maintains the soil quality and enriches the nutrient composition (Adhikary 2012; Prabina et al. 2018).

Table 4.3. Physicochemical properties of the soil at the beginning and end of the experiment

Parameters	Begin	End of the experiment							
		Treatment							
		GC	GV	GW	GVW	FC	FV	FW	FVW
pH H2O	8.10	8.30	8.00	7.90	7.90	8.30	8.10	8.20	8.00
EC (mS)	2.40	2.13	3.02	2.63	3.08	2.34	2.98	2.72	3.11
CEC-unbuffered (meq/100g)	8.48	10.40	8.89	9.30	9.45	9.65	9.49	9.23	9.90
Org. C (%)	4.29	4.21	3.66	4.46	3.87	3.89	3.99	3.76	4.10
Org. stof (%)	8.57	8.42	7.32	8.92	7.74	7.78	7.99	7.53	8.20
Tot. N (%)	0.24	0.18	0.22	0.19	0.21	0.22	0.22	0.21	0.24
Tot. P (%)	0.01	0.02	0.03	0.04	0.04	0.02	0.04	0.03	0.05
P-bray (ppm)	6.50	2.00	38.00	64.00	83.00	5.00	32.00	52.00	88.00
Tot K (%)	0.05	0.07	0.07	0.09	0.09	0.07	0.09	0.09	0.07
Exch. K (ppm)	0.13	0.10	0.26	0.30	0.34	0.08	0.11	0.11	0.26
Tot. Ca (%)	6.21	7.55	7.38	8.82	9.00	6.26	8.97	7.84	6.37
Exch Ca (ppm)	11.66	10.41	13.14	11.92	13.50	9.42	9.84	9.82	8.39
Tot. Mg (%)	0.18	0.18	0.17	0.19	0.21	0.15	0.20	0.16	0.15
Exch. Mg (ppm)	3.66	2.80	4.20	4.25	5.23	2.57	2.96	3.03	2.60
Tot. Na (%)	0.36	0.31	0.38	0.41	0.42	0.31	0.33	0.27	0.27

4.2.3. Greenhouse experiment

4.2.3.1. Plant height

According to the results of the greenhouse at the time of harvest, the tallest (112.62 ± 4.33 cm) and shortest (85.38 ± 7.37 cm) plants were observed for resp. VW and C plants (Fig. 4.11 & Table 4.4), which also had the maximum (98.69 cm) and minimum (73.98 cm) increase in height (Table 4.4). The photo collage of the difference in plant growth throughout the cultivation period is displayed in appendix D-a.

The LSD test showed that there was a significant difference between the treated and the control plants ($p < 0.05$) (Table 4.4). There was also a significant difference between the V and VW plants ($p = 0.005$). There was no significant difference between the V and W plants ($p = 0.175$) and the W and VW plants ($p = 0.148$) (Table 4.4).

As shown in Fig. 4-11, the VW plants were taller than the V plants. As for the W plants during the first four weeks of cultivation, the plants were shorter than the V plants, after which the W plants increased in height. From week 1 until week 10 the W plants had an increase of 96.02 cm, while the V plants 88.19 cm (Table 4.4).

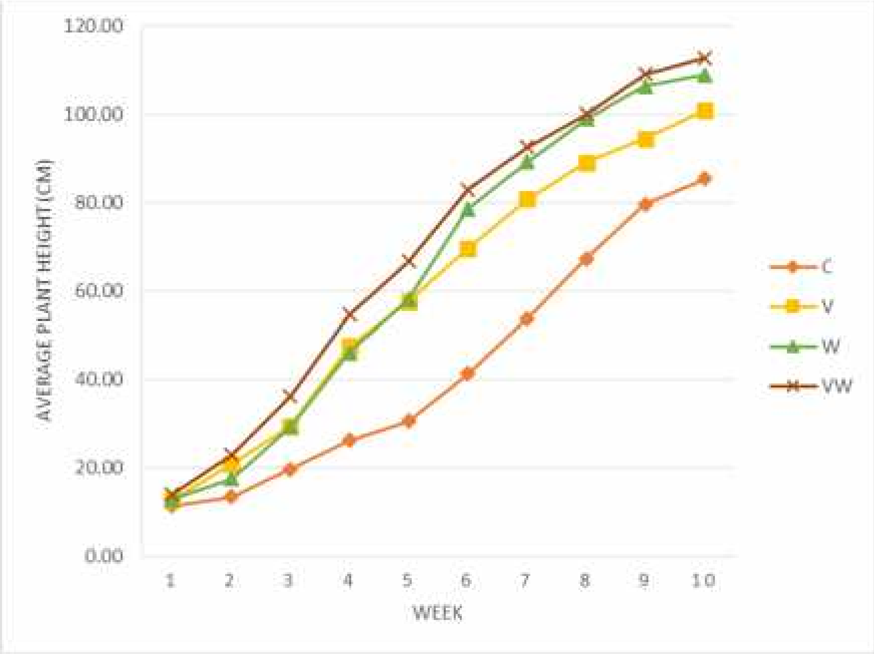

Figure 4.11. Average plant height of the plants (cm) in the greenhouse during the cultivation period

Table 4.4. Plant height (Mean ± SEM) and % increase in the greenhouse

	Treatments			
Week	**C**	**V**	**W**	**VW**
1	11.40 ± 1.87	12.71 ± 1.76	12.79 ± 1.70	13.93 ± 1.33
2	13.42 ± 2.11	20.88 ± 2.45	17.48 ± 2.21	22.93 ± 1.62
3	19.69 ± 2.73	29.40 ± 6.76	29.26 ± 5.19	36.21 ± 3.62
4	26.17 ± 3.88	47.48 ± 9.70	46.10 ± 7.93	54.67 ± 4.32
5	30.57 ± 6.27	57.59 ± 9.72	58.17 ± 8.05	66.67 ± 6.42
6	41.36 ± 7.89	69.69 ± 5.25	78.62 ± 6.63	82.90 ± 3.52
7	53.81 ± 8.03	80.80 ± 8.19	89.29 ± 7.58	92.52 ± 4.07
8	67.38 ± 6.87	89.14 ± 9.54	98.95 ± 7.74	100.00 ± 7.31
9	79.62 ± 6.79	94.43 ± 11.90	106.33 ± 8.64	108.90 ± 5.51
10	85.38 ± 7.37	100.90 ± 11.69	108.81 ± 11.16	112.62 ± 4.33
Increase (cm)	73.98	88.19	96.02	98.69
Increase (%)	87.00	87.00	88.00	88.00
Ranking	a	b	bc	c

Note: The different letters of the ranking are significant different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

4.2.3.2. Stem thickness

Based on the results of the greenhouse experiment at the harvest time, the thickest stem plants were observed for VW plants (1.03 ± 0.09 cm) and the thinnest for C plants (0.77 ± 0.07 cm) (Fig. 4.13 & Table 4.6), which resp. also had the maximum (0.68 cm) and minimum (0.47 cm) increase (Table 4.5).

The LSD test showed that there was a significant difference among the treated plants and the control plants (p = 0.000) (Table 4.5). There was also a significant difference between the W and the VW plants (p = 0.003), the W and V plants (p = 0.021). There was no significant difference between the V and VW plants (p = 0.520) (Table 4.5). As seen in Fig. 4.12, the VW and V plants had approximately the same thickness, and were thicker than the W plants.

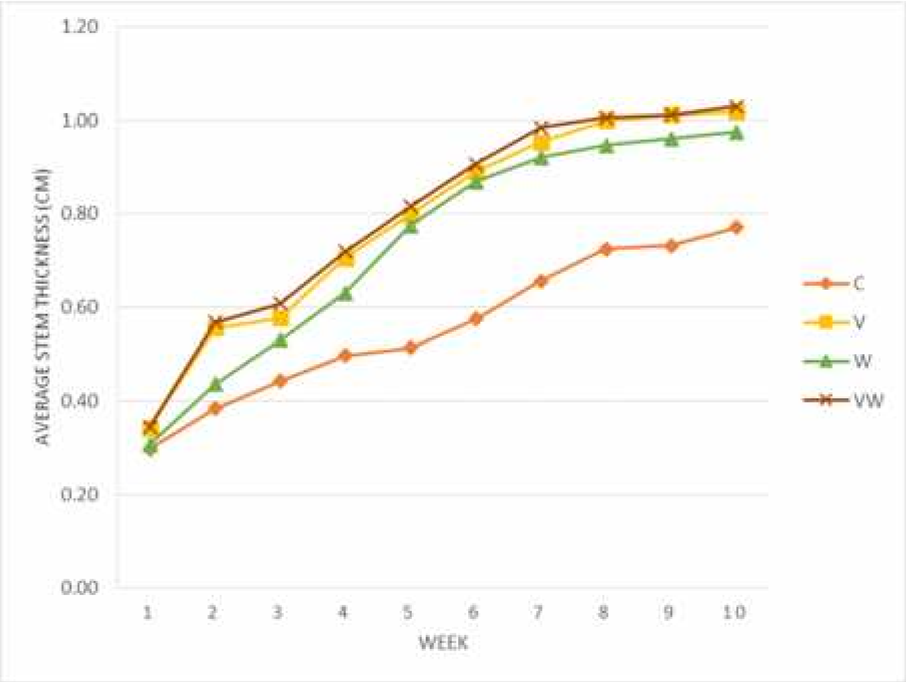

Figure 4.12. Average stem thickness of the plants in the greenhouse

Table 4.5. Stem thickness (Mean ± SEM) and % increase in cm in the greenhouse

	Treatments			
Week	**C**	**V**	**W**	**VW**
1	0.30 ± 0.03	0.34 ± 0.06	0.31 ± 0.04	0.34 ± 0.04
2	0.38 ± 0.05	0.56 ± 0.06	0.44 ± 0.05	0.57 ± 0.10
3	0.44 ± 0.06	0.58 ± 0.11	0.53 ± 0.09	0.61 ± 0.07
4	0.50 ± 0.07	0.71 ± 0.11	0.63 ± 0.09	0.72 ± 0.10
5	0.51 ± 0.05	0.80 ± 0.11	0.77 ± 0.10	0.82 ± 0.08
6	0.57 ± 0.07	0.89 ± 0.10	0.87 ± 0.08	0.91 ± 0.11
7	0.66 ± 0.05	0.95 ± 0.09	0.92 ± 0.08	0.98 ± 0.08
8	0.72 ± 0.07	1.00 ± 0.05	0.95 ± 0.08	1.01 ± 0.09
9	0.73 ± 0.06	1.01 ± 0.06	0.96 ± 0.09	1.01 ± 0.09
10	0.77 ± 0.07	1.02 ± 0.06	0.97 ± 0.08	1.03 ± 0.09
Increase (cm)	0.47	0.68	0.67	0.68
Increase (%)	61.00	66.00	68.00	66.00
Ranking	a	b	c	b

Note: The different letters of the ranking are significant different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

4.2.3.3. Branches

According to the results of the greenhouse experiment at harvest time, the maximum number of branches was observed for the W plants (27 ± 3.75), and the minimum for the C plants (12 ± 0.6), which also had the maximum increase of 25 branches and the minimum of 9 branches (Fig. 4.13). The photo collage of the difference in plant growth throughout the cultivation period is displayed in appendix D-a.

The LSD test showed that there was a significant difference between the treated and control plants ($p = 0.000$) (Table 4.6). There was no significant difference between the treated plants ($p > 0.05$) (Table 4.6). During the cultivation period, the VW plants had the most branches and a more bushier appearance then the V plants (Fig. D.3).

It also should be taken in consideration that at harvest time the old branches were removed to prevent fungal growth (Fig. D.4), which could be the reason for the obtained maximum branches for the W plants.

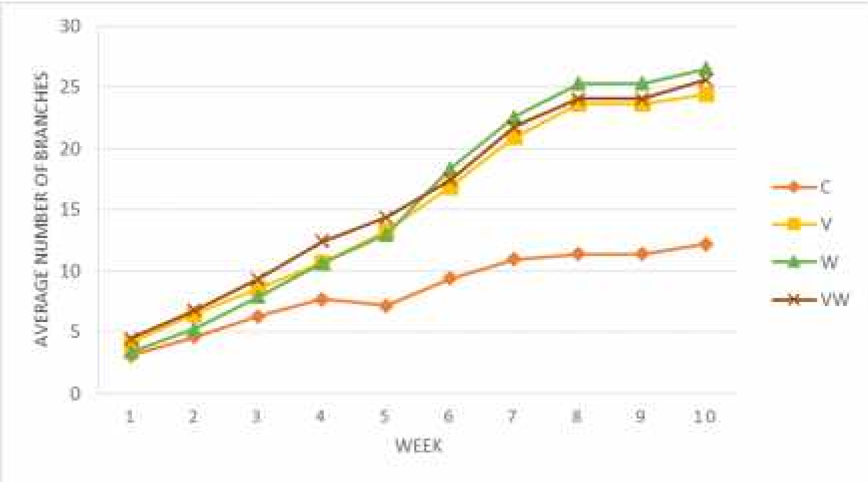

Figure 4.13. Average number of branches of the plants in the greenhouse

Table 4.6. Average number of branches per plant (Mean ± SEM) in the greenhouse

	Treatment			
Week	**C**	**V**	**W**	**VW**
1	3.01 ± 0.44	4.14 ± 0.48	3.38 ± 0.50	4.48 ± 0.60
2	4.62 ± 0.50	6.48 ± 0.51	5.24 ± 0.44	6.76 ± 0.54
3	6.29 ± 0.64	8.62 ± 1.69	7.90 ± 0.77	9.33 ± 0.86
4	7.71 ± 0.64	10.71 ± 1.55	10.67 ± 1.15	12.43 ± 1.40
5	7.20 ± 0.93	13.29 ± 2.19	13.00 ± 1.61	14.38 ± 1.53
6	9.39 ± 1.24	16.90 ± 2.05	18.38 ± 2.18	17.48 ± 2.44
7	10.95 ± 1.43	20.95 ± 3.01	22.57 ± 3.53	21.81 ± 3.19
8	11.38 ± 1.53	23.67 ± 4.43	25.33 ± 4.52	24.05 ± 4.88
9	11.38 ± 1.53	23.67 ± 4.43	25.33 ± 4.52	24.05 ± 4.88
10	12.24 ± 1.79	24.43 ± 4.30	26.52 ± 3.75	25.62 ± 3.75
Ranking	a	b	b	b

Note: The different letters of the ranking are significant different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

4.2.3.4. Biomass and root length

a. Shoot fresh and dry weight

The LSD test for shoot fresh and dry weight showed that there was a significant difference between the treatments (p = 0.000) (Table 4.7). The highest average shoot fresh and dry weight between the treatments was recorded for the W plants (resp. 1107 ± 0.45 g, 320 ± 0.40 g) and the lowest for the C plants (resp. 160 ± 4.04 g, 83 ± 0.21 g) (Fig. 4.14, Fig. 4.15 & Table 4.7). The moisture content for greenhouse was observed the highest for the V plants (810 g) and the lowest for the C plants (77 g) (Table 4.7), which means that the V plants had more moisture in their tissue.

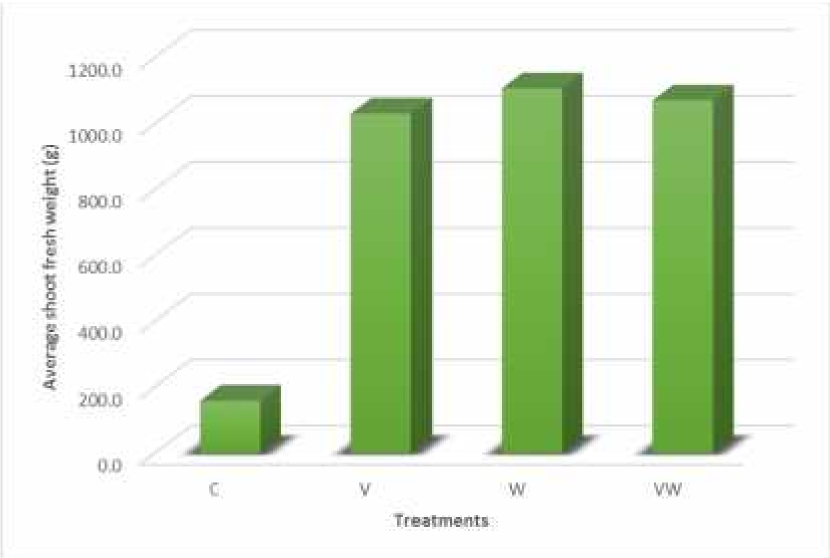

Figure 4.14. Average shoot fresh weight (g) at the end of the experiment in the greenhouse

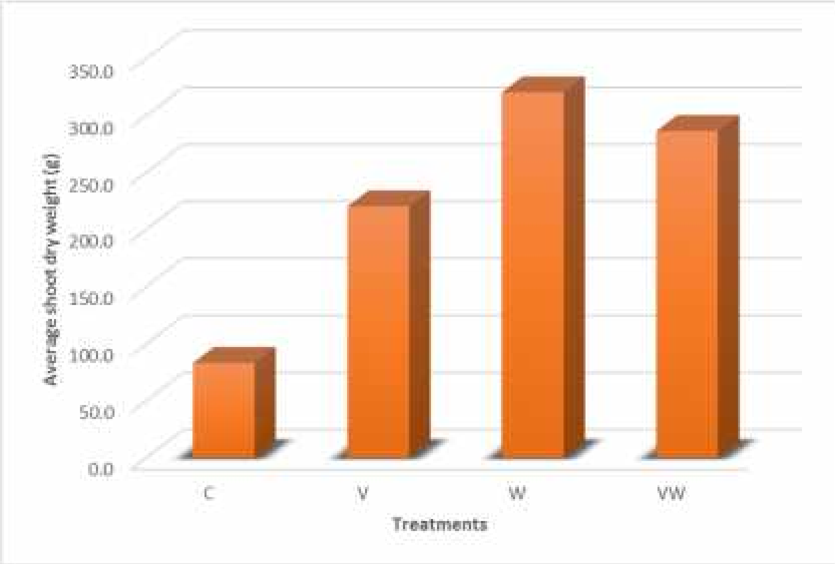

Figure 4.15. Average shoot dry weight (g) at the end of the experiment in the greenhouse

Table 4.7. Shoot fresh – and dry weight (Mean ± SEM) in grams and moisture content (%) in the greenhouse

Treatment	Shoot Fresh weight (Mean ± SEM)	Shoot Dry weight (Mean ± SEM)	Moisture content (%)
C	160 ± 4.04 a	83 ± 0.21 a	77
V	1030 ± 0.80 b	220 ± 0.26 b	810
W	1107 ± 0.45 c	320 ± 0.40 c	787
VW	1070 ± 0.70 d	286 ± 0.25 d	784

Note: Values followed by different letters are significantly different at $P \leq 0.05$ according to LSD multiple range test. Treatment codes: C=Control; V=Vermicompost; W=vermiwash; VW=Vermicompost+Vermiwash

b. Root fresh and dry weight

Based on the results of the LSD test for the root fresh weight, there was a significant difference between the treated and control plants ($p < 0.05$), the V and VW plants ($p = 0.013$) and the W and VW plants ($p = 0.004$). There was no significant difference between the V and W plants ($p = 0.453$) (Table 4.8). As shown in Fig. 4.16, the V plants had a higher fresh weight then the W plants. For the root dry weight, there was a significant difference between all the treatments ($p < 0.05$) (Table 4.8). The highest root fresh and dry weight was measured for the VW plants and the lowest for the C plants, with resp. the maximum moisture content of 123.33 and the minimum of 3.33 (Table 4.8). As shown in Fig. 4.18, the VW plants also had a bigger root structure, followed by the V and W plants.

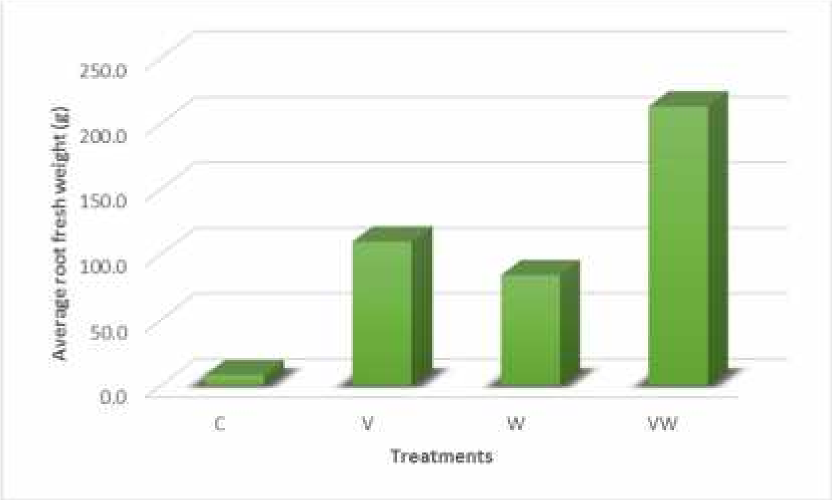

Figure 4.16. Average root fresh weight (g) at the end of the experiment in the greenhouse

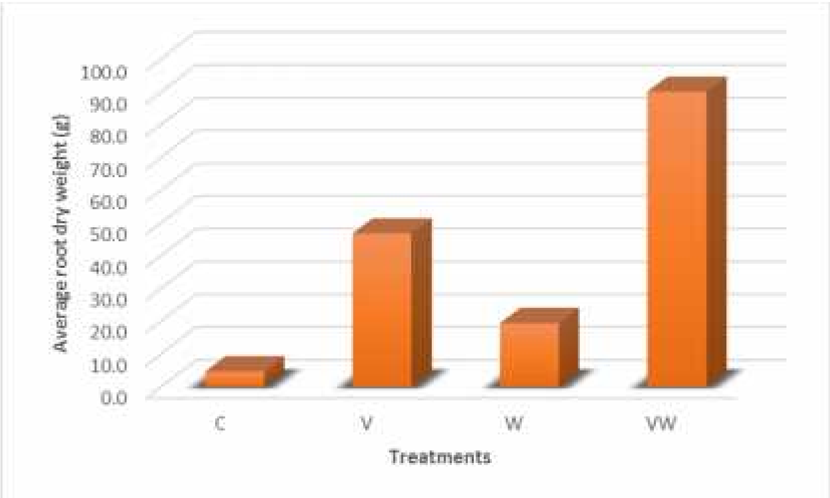

Figure 4.17. Average root dry weight (g) at the end of the experiment in the greenhouse

Table 4.8. Root fresh – and dry weight (Mean ± SEM) in grams and % moisture content in the greenhouse

Treatment	Root Fresh weight (Mean ± SEM)	Root Dry weight (Mean ± SEM)	Moisture content (%)
C	8.00 ± 1.73 a	4.67 ± 1.53 a	3.33
V	110 ± 17.32 b	46.67 ± 7.63 b	63.33
W	84.33 ± 3.79 b	19.33 ± 1.15 c	65.00
VW	213.33 ± 77.67 c	90.00 ± 10.00 d	123.33

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C=Control; V=Vermicompost; W=vermiwash; VW=Vermicompost+Vermiwash

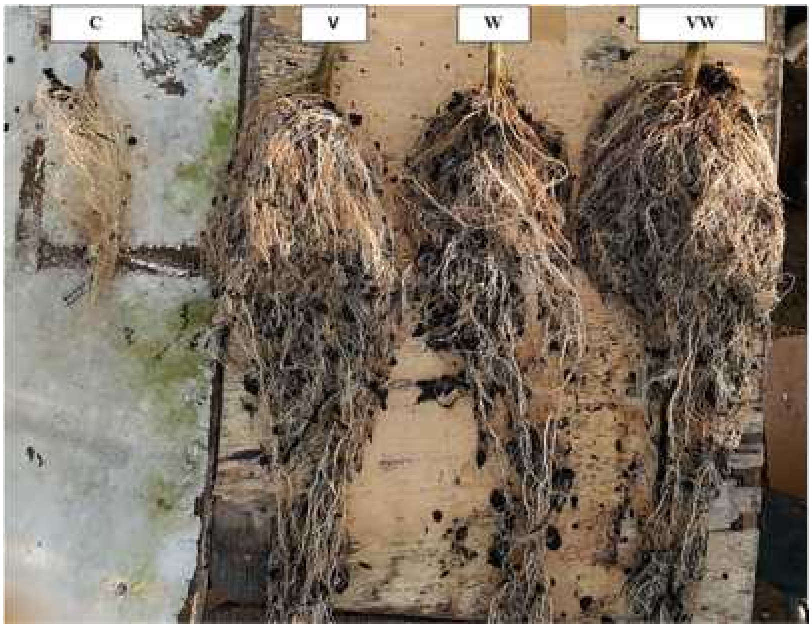

Figure 4.18. Root development of the different treatments in the greenhouse

c. Root length

According to the results of the LSD test, there was a significant difference between the treated and control plants ($p = 0.000$) and between the V and VW plants ($p = 0.025$). There was no significant difference between the V and W plants ($p = 0.101$) and the W and VW plants ($p = 0.392$) (Table 4.9). As shown in Fig. 4.19, the average root length of the VW plants (97.67 ± 5.51 cm) were the longest, followed by W (91.33 ± 8.08 cm), V (78.33 ± 14.01 cm) and C (38.67 ± 1.53 cm) plants.

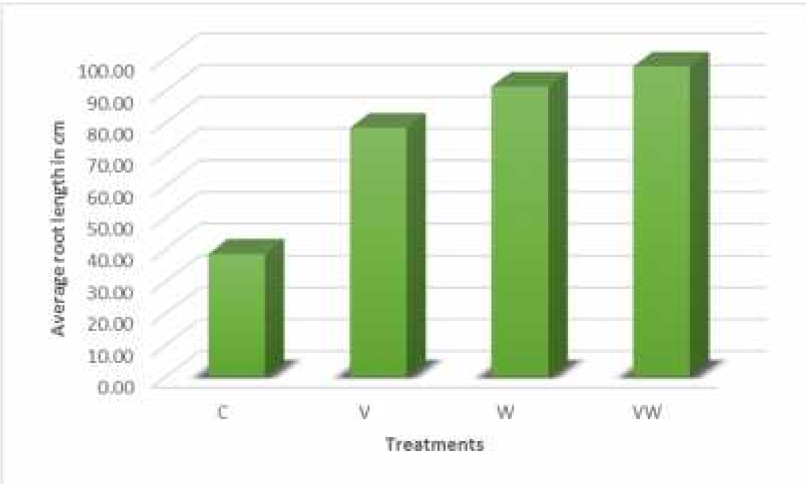

Figure 4.19. Average root length (cm) at the end of the experiment in the greenhouse

Table 4.9. Root fresh – and dry weight (Mean ± SEM) in the greenhouse

Treatment	Root length (Mean ± SEM)
C	38.67 ± 1.53 a
V	78.33 ± 14.01 b
W	91.33 ± 8.08 bc
VW	97.67 ± 5.51 c

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost + Vermiwash

4.2.3.5. Production

The bloom initiation in the greenhouse were seen three weeks after transplanting and well for all the VW plants (100%), followed by 60% of the V plants and 40% of the W plants, which means that the fertilization resulted in early flowering. During the period of the experiment the C plants had no fruits.

The results of the LSD test for the number of fruits and fruit weight showed that all the treatments differed from each other ($p < 0.05$) (Table 4.10). The highest (16.52 ± 1.01) average yield per plant in the greenhouse experiment was recorded for the VW plants, and the lowest (9.38 ± 0.44) for the V plants, which also had the highest (646.71 ± 68.09 g) and lowest (380.52 ± 31.88 g) average fruit weight per plant (Fig. 4.20; Table 4.10). Table 4.11 and Fig. 4.21, indicates that the VW plants also had the biggest fruits. The fruits of the VW plants had an average diameter of 5.40 cm.

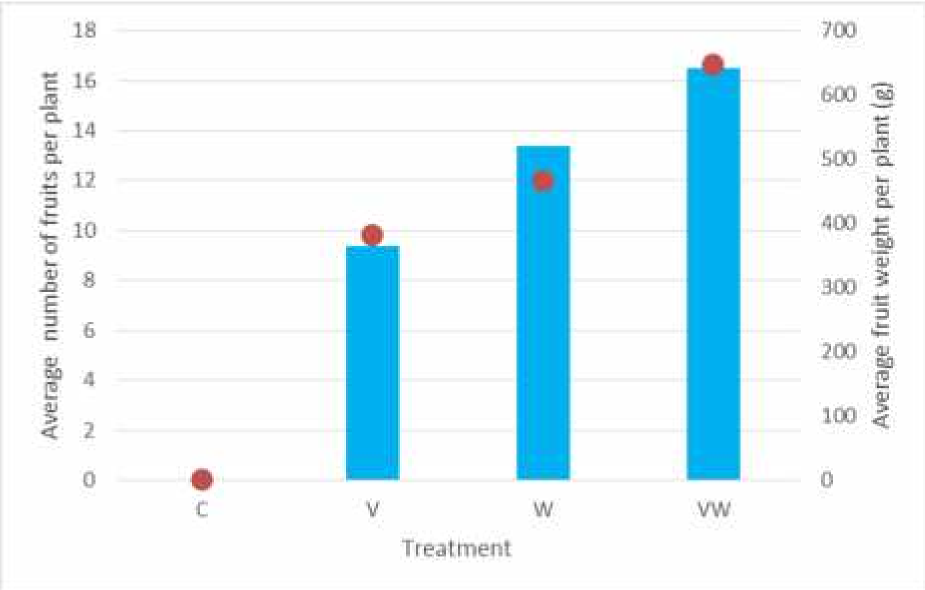

Figure 4.20. Average number of fruits - and fruit weight (g) per plant in the greenhouse

Table 4.10. Number of fruits – and fruit weight per plant (Mean ± SEM) in the greenhouse

Treatment	Number of fruits per plant (Mean ± SEM)	Fruit weight per plant (Mean ± SEM)
C	-	-
V	9.38 ± 0.44 a	380.52 ± 31.88 a
W	13.38 ± 0.58 b	466.05 ± 17.41 b
VW	16.52 ± 1.01 c	646.71 ± 68.09 c

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

Table 4.11. Average fruit diameter (cm) in the greenhouse

	Fruit diameter	
Treatment	**Big**	**Regular**
C	-	-
V	4.88	4.46
W	5.16	4.61
VW	5.40	4.55

Figure 4.21. Difference in fruit diameter between the treatments in the greenhouse

4.2.4. Field experiment

4.2.4.1. Plant height

The results of the field experiment showed that, the tallest plants had a height of 95.71 ± 9.32 cm (VW) and the shortest plants had a height 80 ± 12.49 cm (C) (Fig. 4.22 & Table 4.12), but the maximum (78.45 cm) increase was found for W plants and the minimum (65.48 cm) for C plants (Table 4.12). The photo collage of the difference in plant growth throughout the cultivation period is displayed in appendix D-b.

The LSD test showed that there was indeed a significant difference between the treated and the control plants ($p < 0.05$) (Table 4.12). There was no significant difference between the treated plants ($p > 0.05$) (Table 4.12). However, as can be seen in Fig. 4.22 during the cultivation period, the VW plants were the tallest followed by the W and V plants.

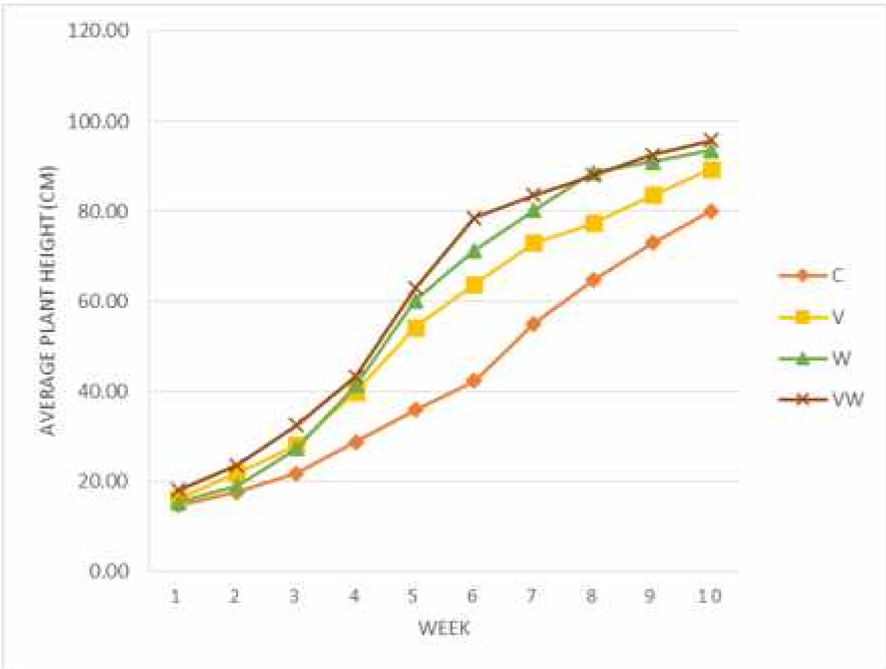

Figure 4.22. Average plant height of the plants (cm) in the field during the cultivation period

Table 4.12. Plant height (Mean ± SEM) and % increase in cm in the field

	Treatment			
Week	**C**	**V**	**W**	**VW**
1	14.52 ± 1.63	16.02 ± 2.10	15.17 ± 2.05	17.95 ± 1.87
2	17.55 ± 2.33	21.69 ± 2.39	18.76 ± 2.26	23.52 ± 2.34
3	21.62 ± 3.53	27.98 ± 4.54	27.24 ± 4.00	32.48 ± 3.83
4	28.60 ± 5.66	39.85 6.24	41.19 ± 4.31	43.14 ± 3.77
5	35.85 ± 8.29	54.05 ± 4.02	60.02 ± 5.85	62.86 ± 4.96
6	42.33 ± 9.97	63.76 ± 3.55	71.29 ± 3.54	78.52 ± 6.02
7	54.90 ± 12.61	72.95 ± 5.44	80.19 ± 7.81	83.52 ± 5.37
8	64.56 ± 12.54	77.33 ± 4.76	88.67 ± 8.76	88.00 ± 8.79
9	72.92 ± 12.68	83.62 ± 4.67	91.00 ± 8.83	92.57 ± 8.06
10	80.00 ± 12.49	89.43 ± 4.66	93.62 ± 9.33	95.71 ± 9.32
Increase (cm)	65.48	73.40	78.45	77.76
Increase (%)	82.00	82.00	84.00	81.00
Ranking	a	b	bc	c

Note: The different letters of the ranking are significant different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

4.2.4.2. Stem thickness

According to the results of the field experiment, the thickest (1.19 ± 0.10 cm) and thinnest (0.75 ± 0.09 cm) stem plants were resp. VW and C (Fig. 4.23 & Table 4-13), but the maximum increase of 0.83 cm was recorded for W plants and the minimum increase of 0.44 cm for C plants (Table 4-13).

The LSD test showed that there was a significant difference among the treated and the control plants ($p = 0.000$) (Table 4.13). There was no significant difference among the treated plants ($p < 0.05$) (Table 4.13). As can be seen in Fig. 4-23, during the cultivation period the VW plants were the thickest, followed by W and V plants, of which the maximum (0.85 cm) increase was recorded for the W plants (Table 4-13).

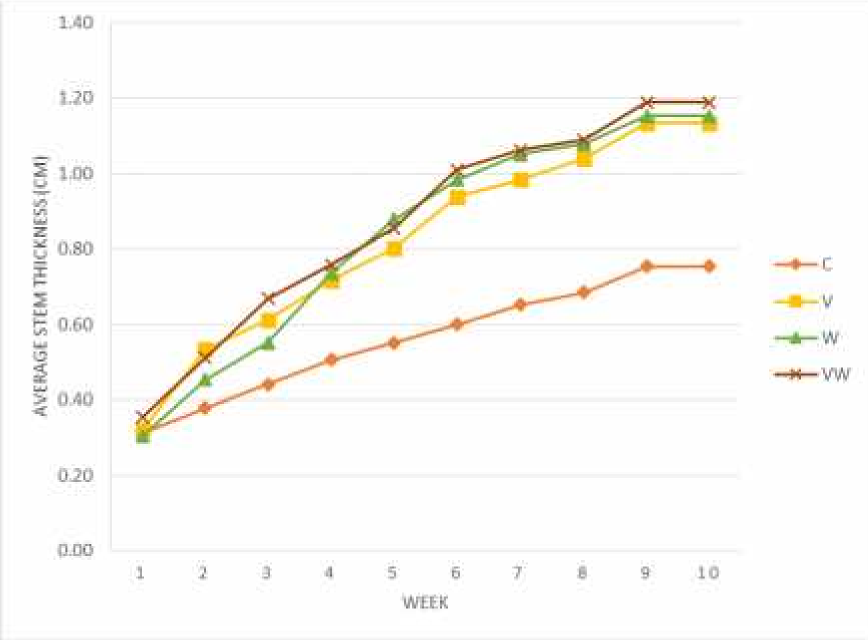

Figure 4.23. Average stem thickness of the plants (cm) in the field

Table 4.13. Stem thickness (Mean ± SEM) and % increase in cm in the field

	Treatment			
Week	**C**	**V**	**W**	**VW**
1	0.31 ± 0.03	0.32 ± 0.03	0.30 ± 0.02	0.35 ± 0.04
2	0.38 ± 0.06	0.53 ± 0.06	0.45 ± 0.05	0.51 ± 0.04
3	0.44 ± 0.05	0.61 ± 0.12	0.55 ± 0.08	0.67 ± 0.04
4	0.51 ± 0.09	0.72 ± 0.07	0.74 ± 0.07	0.76 ± 0.06
5	0.55 ± 0.08	0.80 ± 0.08	0.88 ± 0.07	0.85 ± 0.07
6	0.60 ± 0.08	0.94 ± 0.06	0.98 ± 0.09	1.01 ± 0.10
7	0.65 ± 0.09	0.98 ± 0.13	1.05 ± 0.10	1.06 ± 0.10
8	0.68 ± 0.07	1.04 ± 0.06	1.08 ± 0.11	1.09 ± 0.11
9	0.75 ± 0.09	1.13 ± 0.09	1.15 ± 0.10	1.19 ± 0.10
10	0.75 ± 0.09	1.13 ± 0.09	1.15 ± 0.10	1.19 ± 0.10
Increase (cm)	0.44	0.81	0.85	0.83
Increase (%)	59.00	72.00	74.00	70.00
Ranking	a	b	b	b

Note: The different letters of the ranking are significant different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

4.2.4.3. Branches

The results of the field experiment showed that, at harvest time, the maximum number of branches was recorded for the V plants (23 ± 4.59), and the minimum for the C plants (12 ± 0.5), which also had the maximum increase of 18 branches and minimum of 8 branches (Fig. 4.24).

The LSD test showed that there was a significant difference between the treated and control plants ($p = 0.000$) (Table 4.14). There was also a significant difference between the W and VW plants ($p = 0.034$), while there was no significant difference between the V and W plants ($p = 0.486$) and the V and VW plants ($p = 0.154$) (Table 4.14). During the cultivation period the VW plants had the most branches and also a bushier appearance then the V plants (Appendix D, Fig. D.7 & D.8). It should be taken in consideration that at harvest time, the old branches were removed to prevent fungal growth, which could be the reason for the obtained maximum branches for the V plants (Appendix D, Fig. D.10).

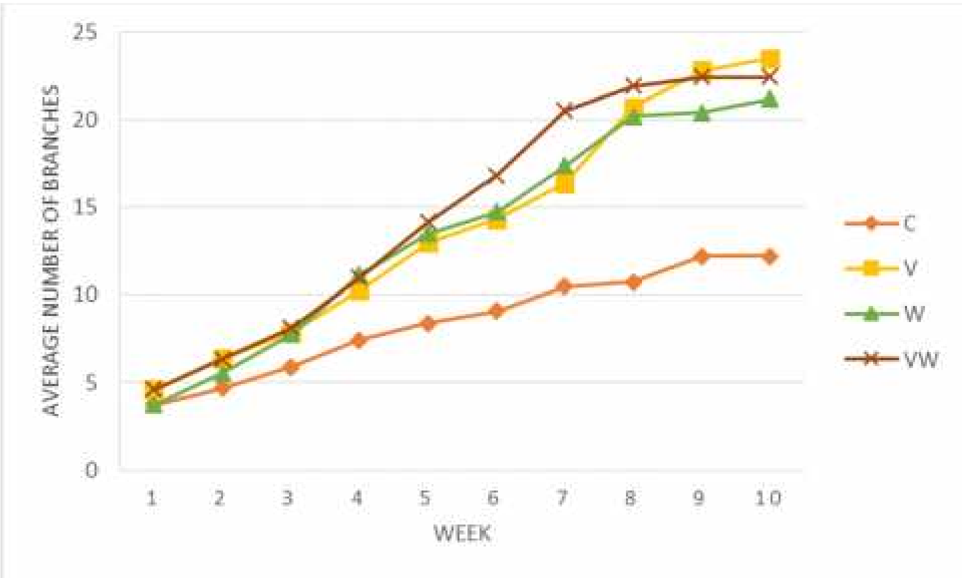

Figure 4.24. Average number of branches of the plants in the field

Table 4.14. Average number of branches per plant (Mean ± SEM) in the field

	Treatment			
Week	**C**	**V**	**W**	**VW**
1	3.71 ± 0.64	4.62 ± 0.50	3.71 ± 0.56	4.62 ± 0.50
2	4.67 ± 0.86	6.38 ± 0.59	5.52 ± 0.68	6.33 ± 0.58
3	5.89 ± 0.97	7.86 ± 1.01	7.76 ± 0.94	8.14 ± 0.72
4	7.43 ± 0.73	10.27 ± 0.94	11.14 ± 0.93	11.00 ± 0.77
5	8.40 ± 1.05	12.95 ± 1.50	13.48 ± 1.75	14.14 ± 1.53
6	9.07 ± 1.21	14.33 ± 2.01	14.71 ± 2.41	16.81 ± 1.54
7	10.46 ± 1.36	16.38 ± 2.38	17.38 ± 3.11	20.52 ± 2.25
8	10.74 ± 0.85	20.71 ± 2.19	20.19 ± 3.17	21.90 ± 4.47
9	12.18 ± 3.86	22.81 ± 2.40	20.43 ± 4.02	22.43 ± 4.59
10	12.18 ± 3.86	23.48 ± 2.29	21.19 ± 3.78	22.43 ± 4.59
Ranking	a	bc	b	c

Note: The different letters of the ranking are significant different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost +Vermiwash

4.2.4.4. Biomass and root length

a. Shoot fresh and dry weight

The LSD test for shoot fresh and dry weight showed that there was a significant difference between the treatments (p = 0.000) (Table 4-15). The highest average shoot fresh weight was recorded for the V plants (1246 ± 0.20 g), and the lowest for the C plants (179 ± 0.4 g) (Fig. 4.25 & Table 4.15), while the highest average dry weight was observed for the VW plants (365 ± 0.26 g) and the lowest for the C plants (62 ± 0.42 g) (Fig. 4-26 & Table 4.15).

Although the moisture content for greenhouse as the field experiment was observed the highest for the V plants (930 g) and the lowest for the C plants (117 g) (Table 4.15).

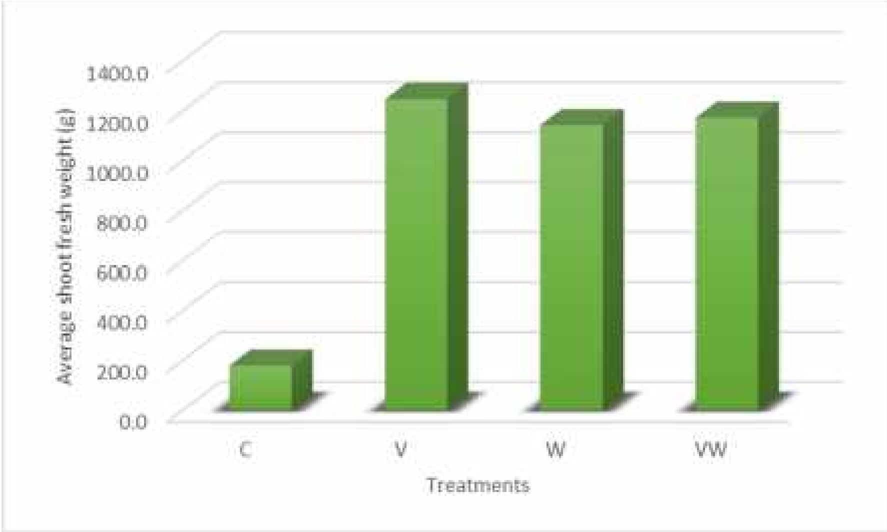

Figure 4.25. Average shoot fresh weight (g) at the end of the experiment in the field

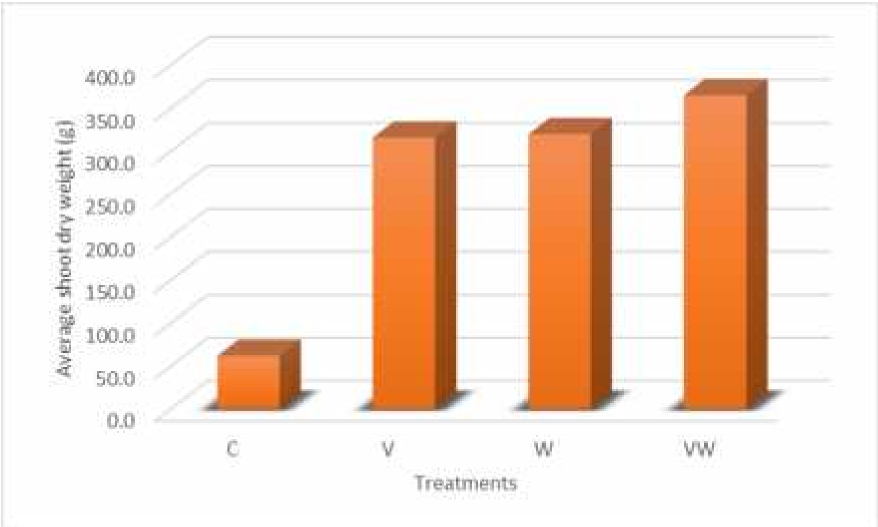

Figure 4.26. Average shoot dry weight (g) at the end of the experiment in the field

Table 4.15. Shoot fresh – and dry weight (Mean ± SEM) in grams and % moisture content in the field

Treatment	Shoot Fresh weight (Mean ± SEM)	Shoot Dry weight (Mean ± SEM)	Moisture content (%)
C	179 ± 0.40 b	62 ± 0.42 b	117
V	1246 ± 0.20 c	316 ± 0.21 c	930
W	1142 ± 0.40 d	320 ± 0.42 d	822
VW	1172 ± 0.36 e	365 ± 0.26 e	807

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C=Control; V=Vermicompost; W=vermiwash; VW=Vermicompost+Vermiwash

b. Root fresh and dry weight

The average root fresh and dry weights are shown in Fig. 4.27 and Fig 4.28. According to the LSD test for the root fresh weight there was a significant difference between the treated and control plants ($p < 0.05$) and between the W and VW plants ($p = 0.05$). There was no significant difference between the V and W plants ($p = 0.643$) and the V and VW plants ($p = 0.10$) (Table 4-20). As for the root dry weight there was a significant difference between the treated and control plants ($p < 0.05$). There was a significant difference between the treated plants ($p > 0.05$), except for the V and W plants (Table 4.16). As shown in Fig. 4.29, the VW plants also had a better root development.

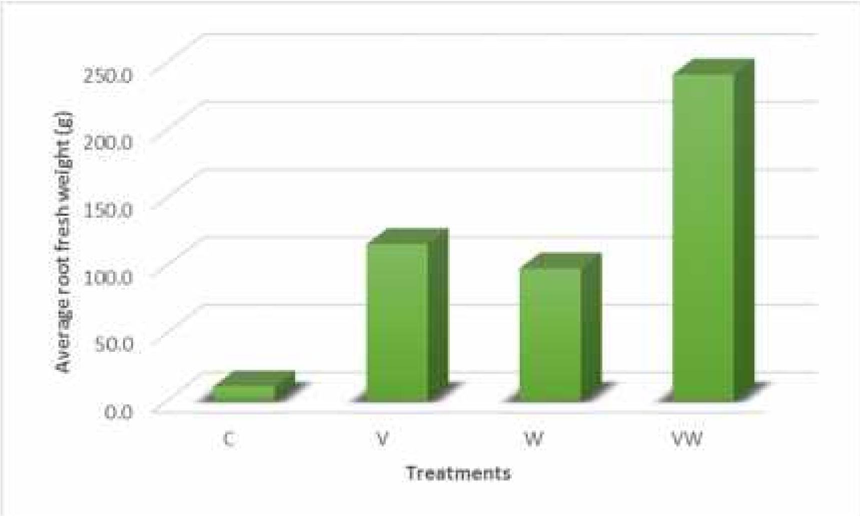

Figure 4.27. Average root fresh weight (g) at the end of the experiment in the field

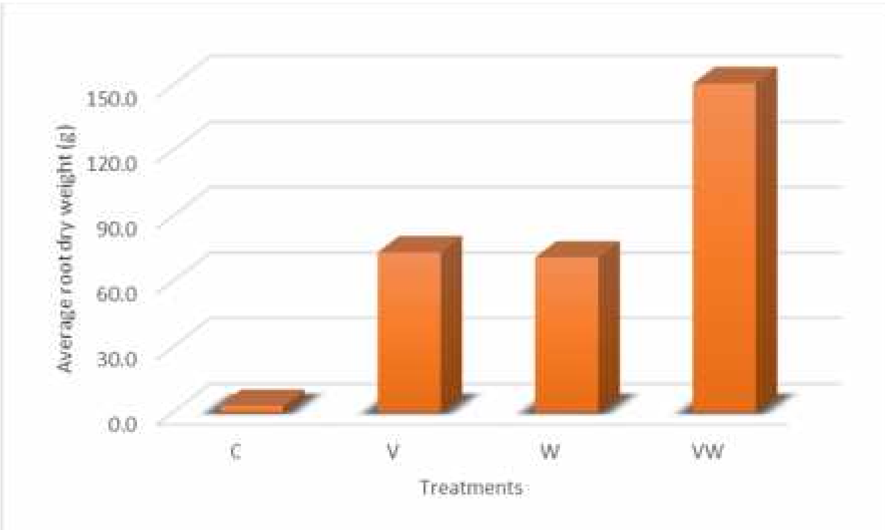

Figure 4.28. Average root dry weight (g) at the end of the experiment in the field

Table 4.16. Root fresh - and dry weight (Mean ± SEM) in grams and % moisture content in the field

Treatment	Root Fresh weight (Mean ± SEM)	Root Dry weight (Mean ± SEM)	Moisture content (%)
C	10.00 ± 2.00 a	3.00 ± 1.00 a	7.00
V	115.33 ± 21.78 b	73.33 ± 7.37 b	42.00
W	97.33 ± 11.68 b	71.00 ± 5.20 b	26.33
VW	240.67 ± 88.10 c	150.67 ± 71.04 c	90.00

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C=Control; V=Vermicompost; W=vermiwash; VW=Vermicompost+Vermiwash

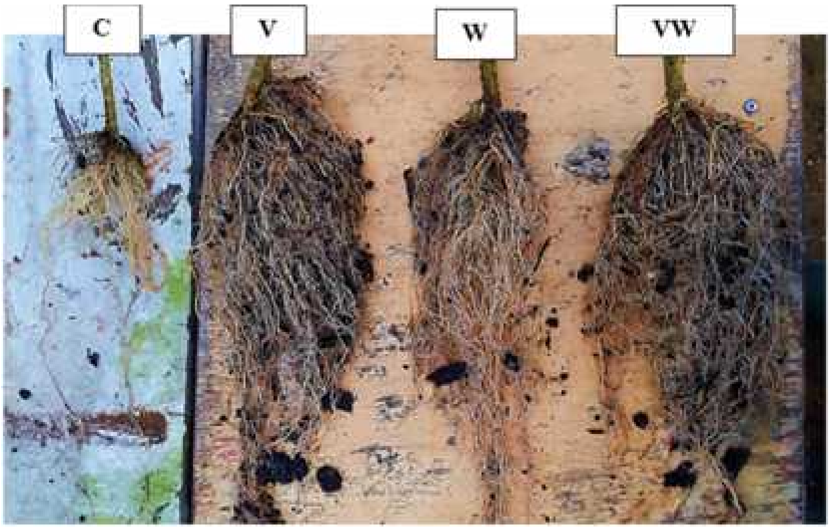

Figure 4.29. Root development of the different treatments in the field

c. Root length

The average root length is shown in Fig. 4.30. The roots of the V plants (56.67 ± 5.69 cm) were the longest followed by the W plants (54.33 ± 9.07 cm), VW plants (45.00 ± 7.21 cm) and C (30.33 ± 2.52 cm) plants (Fig. 4.30 & Table 4.17). The results of the LSD test showed that there was a significant difference between the treated and control plants ($p = 0.000$) and between the V and VW plants ($p = 0.062$). There was no significant difference between the V and W plants ($p = 0.675$) and the W and VW plants ($p = 0.120$) (Table 4.17).

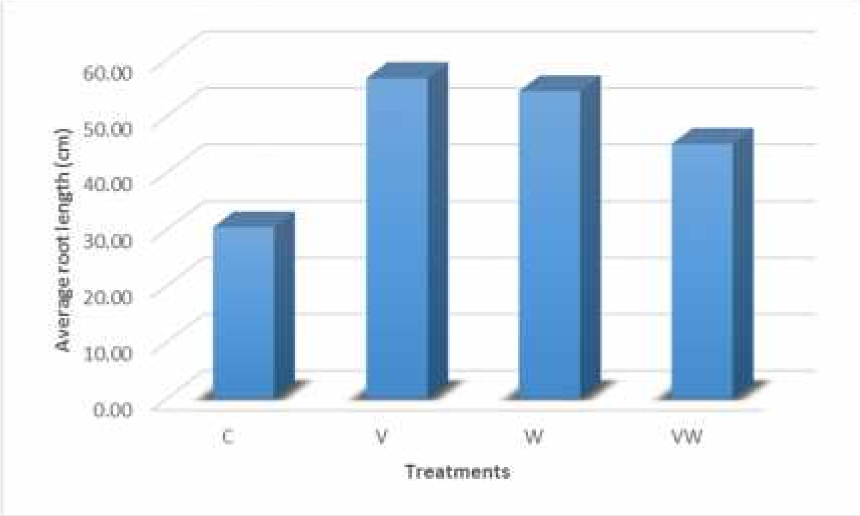

Figure 4.30. Average root length (cm) at the end of the experiment in the field

Table 4.17. Root length (Mean ± SEM) in the field

Treatment	Root length (Mean ± SEM)
C	30.33 ± 2.52 a
V	56.67 ± 5.69 b
W	54.33 ± 9.07 bc
VW	45.00 ± 7.21 c

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C = Control; V = Vermicompost; W = Vermiwash; VW = Vermicompost+Vermiwash

4.2.4.5. Production

The bloom initiation in the field experiment were seen three weeks after transplanting and well for all the VW plants, followed by 60% of the V plants and 40% of the W plants, which means that the fertilization resulted in early flowering. During the period of the experiment the C plants were yellow (appendix D, Fig. D.5 & D.10) and had no fruits (appendix D, Fig. D.10).

The results of the LSD test for the number of fruits and fruit weight showed that all the treatments were significantly different from each other ($p < 0.05$) (Table 4.18). The VW plants had the highest average yield per plant with 38.81 ± 0.41 fruits with an average fruit weight per plant of 1919.88 ± 20.40 g and V plants had the lowest average yield per plant with 25.43 ± 3.61 fruits with an average fruit weight per plant of 1295.34 ± 183.67 g (Fig. 4.31 & Table 4.18). The biggest fruits were observed for the VW plants (Ø5.41 cm), followed by W (Ø5.13 cm) and V (Ø4.92 cm) (Table 4.19) (Fig. 4.23).

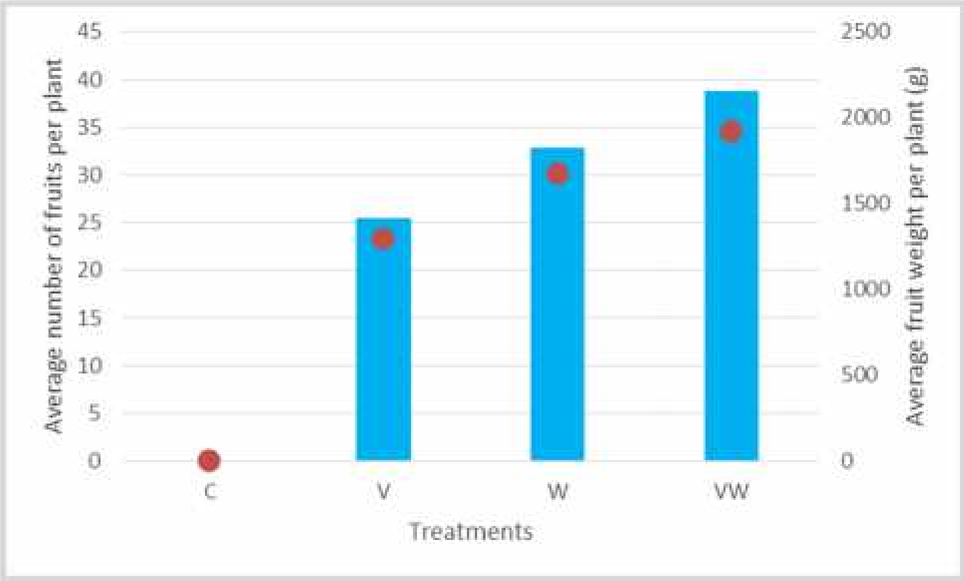

Figure 4.31. Average number of fruits - and fruit weight per plant (g) in the field

Table 4.18. Number of fruits – and fruit weight (g) per plant (Mean ± SEM) in the field

Treatment	Number of fruits per plant (Mean ± SEM)	Fruit weight per plant (Mean ± SEM)
C	-	-
V	25.43 ± 3.61 a	1295.34 ± 183.67 a
W	32.86 ± 2.86 b	1673.51 ± 145.52 b
VW	38.81 ± 0.41 c	1919.88 ± 20.40 c

Note: Values followed by different letters are significantly different at P≤0.05 according to LSD multiple range test. Treatment codes: C=Control; V=Vermicompost; W=vermiwash; VW=Vermicompost+Vermiwash

Table 4.19. Average fruit diameter (cm) in the field

	Fruit diameter	
Treatment	**Big**	**Regular**
C	-	-
V	4.92	4.63
W	5.13	4.71
VW	5.41	4.92

Figure 4.32. Difference in fruit diameter between the treatments in the field

4.3. Overall discussion

The results of phase 1, production of vermiwash, showed that the vermiwash experiment was successful. The obtained vermicompost from the bins were finely divided peat-like material with excellent structure, porosity, aeration, drainage and moisture holding capacity (Ansari and Ismail 2012; Maheswari et al. 2016). It was dark colored, with a desirable soil odor and fine smooth texture and an adequate nutritional value, which confirms that the obtained vermicompost was of good quality.
The obtained vermiwash was a brownish colored liquid and the analysis of the vermiwash indicated the presence of nutrients in a significant quantity, which was in line with the work done by Ansari and Sukhraj in 2010. The nutritional value of the vermiwash is dependent on the feed used for the vermicomposting process and the quality of the vermicompost (Kaur et al. 2015; Zarei et al. 2018). Thus it is obvious that the nutritional quantity in vermiwash will be lower than in the vermicompost. However, the micro and macro nutrients in the vermiwash are directly available for plants (Makkar et al. 2017), which makes it a potential foliar spray.

The overall results of phase 2, cultivation of tomato plants in the greenhouse and field experiment at harvest time indicate that the plant height, stem thickness, total branches, fresh and dry shoot and root weight, root density, yield and fruit weight were higher for the plants treated with a combination of vermicompost and vermiwash. It was also noted that the flowering and fruiting were significantly enhanced by the application of vermiwash as a foliar spray, which was in line with the research done by Makker and Parkash in 2017. The results also showed that when vermicompost and vermiwash was used separately, it had a positive effect on the plant growth, development and yield. Studies revealed that the application of vermiwash and vermicompost separately and in combination enhance the plant growth parameters (plant height, stem thickness and number of leaves) and yield parameters (number of flowers, fruits per plant and weight of fruits) (Jaybhaye and Bhalerao 2015; Kaur et al. 2015; Maheswari et al. 2016; Makkar et al. 2017). It is also reported that vermiwash and vermicompost are enriched in certain metabolites and vitamins that belong to the B group and provitamin D which help to enhance plant growth (Jaikisun et al. 2014; Lujan-Hidalgo et al. 2016). According to Makkar, Singh and Parkash in 2017, plants treated with a combination of 50% vermicompost and a foliar spray of vermiwash turned out to be the highest yielding plants with more branches, higher number of capsules, higher plant dry weight and maximum number of seeds.

According to a study of the plant biomass of strawberries, addition of vermicompost increased the plant dry weight (Joshi and Vig 2010). As for the addition of vermiwash it has been reported that it exhibited growth promoting effects on the exo-morphological characters such as plant height, length and diameter of the internode, number of leaves, leaf surface area and wet and dry weight of the shoot (Kaur et al. 2015; Samadhiya et al. 2013). A study about the effect of vermiwash on the plant growth parameters of brinjal plants found that the results obtained from the vermiwash were a little bit higher compared to the vermicompost (Jaybhaye and Bhalerao 2015). Another study reported that the combination of vermiwash and vermicompost resulted in the highest plant dry weight (Makkar et al. 2017).
It is also reported that fruits obtained from the combination of vermiwash and vermicompost showed even and uniform ripening and it is also suggested that the uniform maturation and fruit ripening is achieved with foliar spray of vermiwash (Makkar et al. 2017). Studies revealed that foliar application of vermiwash shortens the life cycle of flowering and fruiting plants (Makkar et al. 2017; Tamrakan, et al. 2018). Early flowering and fruit maturity was achieved for the plants treated with vermiwash and vermicompost (Makkar et al. 2017). Research investigators also stated that the flowering and fruiting ratio increased (Maheswari et al. 2016; Sundararasu and Jeyasankar 2014).

It is reported that vermicompost serves as a natural product, slow releaser of plant nutrients and it has been shown to increase plant dry weight and plant nutrient uptake. When vermicompost is applied to crops, it shows a slower growth in the beginning, but as the nutrients slowly release, the plant picks up rapid growth (Bhardwaj and Sharma 2016). As for vermiwash, the micro and macro nutrients are directly available for the plants and the nutritional value of available K, Ca, Mg and Na are higher than the vermicompost. The combination of vermicompost and vermiwash attributes to better growth of plants and higher yields by slow release of nutrients for absorption with additional hormones like auxins, cytokines and gibberellin (Ansari 2008). This could be the reason why the plants of the vermicompost were shorter and smaller in appearance than the VW and W plants. Investigators also found that the combination of vermiwash and vermicompost showed bushier appearance of plants with branching up to the fifth order (Makkar et al. 2017). The statement is in line with the observations, whereas the VW plants had indeed a bushier and greener appearance followed by the W and V plants (appendix D, Fig. D.3, Fig. D.7 & Fig. D.8), which indicates high or increased photosynthesis efficiency with foliar application that results in a greater yield and fruit weight (Makkar et al. 2017).

According to Tomati, Grappelli and Galli in 1988, earthworm casts promote root initiation and root biomass and increase root percentage. It also reported that vermicompost has a positive effect on plant development and promote root length (Jaikisun et al. 2014). Studies also suggested that the use of vermicompost alone and vermiwash alone increase the wet and dry weight of roots and root length, and the combination of vermiwash and vermicompost have much better results (Kaur et al. 2015; Makkar et al. 2017; Samadhiya et al. 2013 ;Sundararasu and Jeyasankar 2014). The effect of vermiwash and vermicompost on the enhanced root growth parameters can be attributed to the presence of humic and fulvic acids. These compounds have been shown to increase plant height, dry and fresh weight of plants and roots as well as enhancing nutrient uptake by increasing the root cell membrane permeability (Makkar et al. 2017; Wright and Lenssen 2013). Vermiwash was used as a foliar spray, and not applied to the roots. In comparison to the control plants, vermiwash plants had a bigger and longer root system, which is caused by the available nutrients, hormones and enzymes presence in the vermiwash. This could be the reason why the roots of the vermicompost treatment were bigger than the roots of the vermiwash treatment. The enhanced results of the combination of vermiwash and vermicompost is shown in the VW treatment, where the root structure was the biggest and the roots were the longest.

The results of the soil analysis in the end of the experiment are in line with the literature on the fact that vermicompost has a positive effect on the fertility of the soil, because it contains beneficial microorganisms, enzymes like amylase, lipase, cellulase and chitinase, which can break down the organic matter in the soil to release the nutrients and make it available to the plant roots (Adhikary 2012). The vermicompost when applied to the soil rejuvenates the depleted soil fertility, increases the water holding capacity, maintains the soil quality, and enriches the nutrient composition and biological resources (Prabina et al. 2018). Besides the vermicompost, the application of vermiwash to the soil also increases the soil nutrient status and microbiological activity. The application of vermiwash and vermicompost have an emphatic effect on the growth and production.

According to the results of the vegetative and reproductive stages of the tomato plants, there was a difference between the greenhouse and field experiment. The yield and fruit weight were higher in the field than the greenhouse. Also the fruits in field were larger than the greenhouse. The climatic conditions shown in paragraph 4.2.1. indicated that the average day temperature in the greenhouse was higher (29.5 - 30.61) than in the field (26.87 – 27.81).

Observations suggested that the air ventilation in the greenhouse was insufficient, which led to high air temperatures and continued heat stress for the plants. It is reported that the average daily temperature plays an important role in proper anther and pollen development and their function in tomato flowers (Harel et al. 2014). Studies revealed that a daily average temperature of 29 , decreases fruit number, percentage fruit set and fruit weight per plant in comparison with 25 . The impaired pollen and anther development and reduced pollen viability mainly reduces the yield (Harel et al. 2014). Another factor that plays an important role is the relative humidity. It is reported that the optimal relative humidity for tomato pollution is between the ranges of 50 – 70% (Shamshiri et al. 2018). Studies suggested increased humidity at an optimal temperature improves pollen and fertilization, which leads to a greater pollen quality and fruit set (Harel et al. 2014). This could be the reason that the field experiment had an increased yield and fruit weight.

At a high temperature above 29 it is suggested that an increased humidity of 90% would increase the pollen susceptibility to heat stress (Harel et al. 2014). The results of the greenhouse revealed that when the temperature increased above 29 , the relative humidity dropped below 77.81%, which damaged the fertilization process and led to a reduction in fruit yield.

During the cultivation period no fungicides or pesticides were used, there was no need felt at any point of the experiment. There was no incidence of disease or pest manifestation in the crop, probably due to the pesticide properties of the vermicompost and vermiwash (Verma et al. 2018).

5. Conclusions and recommendations

5.1. Conclusions

From this research study, it can be concluded that:

- The vermicomposting process with dry grass clippings, dry neem leaves and combination of dry grass clippings and dry neem leaves using *Eisenia foetida* earthworms was successful. The produced vermicompost had a dark color, finely divided peat-like material, with desirable soil odor and fine smooth texture and an adequate nutritional value, which confirms that the vermicompost was of good quality.
- The produced vermiwash from the different vermicomposting bins was a brownish colored liquid. It also had all the essential macro and micro plant nutrients like N, P, K, Ca, Mg and Na, which indicates the achievement of an environmental friendly enriched nutrient liquid fertilizer for sustainable agriculture.
- Vermicompost, vermiwash and the combination of vermicompost and vermiwash as a bio-fertilizer had a positive effect on the plant growth parameters and production of the tomato plants. The combination of vermicompost and vermiwash resulted in the highest yielding plants, followed by vermiwash and vermicompost.
- Comparison of the greenhouse experiment with the field experiment indicated that the climatic conditions in the field were optimal for tomato production, which had led to a higher production and bigger fruits.
- The analysis of the soil before and after harvesting tomato fruits did result in a slightly difference of the elements in the soil. The combination of vermicompost and vermiwash notable enriched the soil with plant available P and K elements.

5.2. Recommendations

According to the results of research study, the following can be recommended:

- The study on the production of vermiwash can be improved by using different types of organic plant materials that have a high nutrition value to enhance the bio-fertilizer, for example leguminous plants. Use different types of organic plant materials that are known for its bio-pesticide effect to enhance the bio – fertilizer with pesticide components.
- The study on the cultivation can be improved by repeating the study in another season of the year. Further research can be done by comparing vermicompost, vermiwash and combination of vermicompost and vermiwash with a chemical fertilizer or chicken manure. Repeating the study with other vegetable crops.

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A. Appendix A: Statistical analysis

Table A.1. Results of the Post hoc test for plant height, stem thickness and total branches between the treatments of the greenhouse experiment

Multiple Comparisons

LSD

Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Plant height	Control	Vermicompost	-17.42429*	3.14554	.000	-23.5905	-11.2580
		Vermiwash	-21.69810*	3.14554	.000	[illegible]	[illegible]
		Vermicompost_vermiwash	-26.25524*	3.14584	.000	-32.4295	-20.0810
	Vermicompost	Control	17.42429*	3.14554	.000	11.2580	23.5905
		Vermiwash	-4.27381	3.14584	.175	-10.4481	1.9005
		Vermicompost_vermiwash	-8.83095*	3.14554	.009	-15.0052	-2.6567
	Vermiwash	Control	21.69810*	3.14584	.000	15.5238	27.8724
		Vermicompost	4.27381	3.14554	.175	-1.9005	10.4481
		Vermicompost_vermiwash	-4.56714	3.14554	.148	-10.7314	1.6171
	Vermicompost_vermiwash	Control	26.25524*	3.14554	.000	20.0810	32.4295
		Vermicompost	8.83095*	3.14554	.009	2.6567	15.0052
		Vermiwash	4.56714	3.14584	.148	-1.6171	10.7314
Stem thickness	Control	Vermicompost	-.22590*	.02177	.000	-.2665	-.1832
		Vermiwash	-.17548*	.02177	.000	-.2182	-.1327
		Vermicompost_vermiwash	-.23990*	.02177	.000	-.2826	-.1972
	Vermicompost	Control	.22590*	.02177	.000	.1832	.2665
		Vermiwash	.05043*	.02177	.021	.0077	.0932
		Vermicompost_vermiwash	-.01400	.02177	.520	-.0567	.0287
	Vermiwash	Control	.17548*	.02177	.000	.1327	.2182
		Vermicompost	-.05043*	.02177	.021	-.0932	-.0077
		Vermicompost_vermiwash	-.06443*	.02177	.003	-.1072	-.0217
	Vermicompost_vermiwash	Control	.23990*	.02177	.000	.1972	.2826
		Vermicompost	.01400	.02177	.520	-.0287	.0567
		Vermiwash	.06443*	.02177	.003	.0217	.1072
Total Branches	Control	Vermicompost	-6.86190*	.71046	.000	-8.2564	-5.4674
		Vermiwash	-7.40952*	.71046	.000	-8.8040	-6.0150
		Vermicompost_vermiwash	-7.61429*	.71046	.000	-9.0088	-6.2198
	Vermicompost	Control	6.86190*	.71046	.000	5.4674	8.2564
		Vermiwash	-.54762	.71046	.441	-1.9421	.8469
		Vermicompost_vermiwash	-.75238	.71046	.290	-2.1469	.6421
	Vermiwash	Control	7.40952*	.71046	.000	6.0150	8.8040
		Vermicompost	.54762	.71046	.441	-.8469	1.9421
		Vermicompost_vermiwash	-.20476	.71046	.773	-1.5993	1.1897
	Vermicompost_vermiwash	Control	7.61429*	.71046	.000	6.2198	9.0088
		Vermicompost	.75238	.71046	.290	-.6421	2.1469
		Vermiwash	.20476	.71046	.773	-1.1897	1.5993

*. The mean difference is significant at the 0.05 level.

Table A.2. Results of the Post hoc test for plant height, stem thickness and total branches between the treatments of the field experiment.

Multiple Comparisons

LSD

Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Plant height	Control	Vermicompost	-11.26919*	2.71477	.000	-16.5970	-5.9405
		Vermiwash	-15.32871*	2.71477	.000	-20.6574	-10.0001
		Vermicompost_vermiwash	-18.45729*	2.71477	.000	-23.7859	-13.1285
	Vermicompost	Control	11.26919*	2.71477	.000	5.9405	16.5978
		Vermiwash	-4.05952	2.63829	.131	-9.3362	1.2171
		Vermicompost_vermiwash	-7.18810*	2.63829	.008	-12.4648	-1.9114
	Vermiwash	Control	15.32871*	2.71477	.000	10.0001	20.6574
		Vermicompost	4.05952	2.63829	.131	-1.2171	9.3362
		Vermicompost_vermiwash	-3.12857	2.63829	.245	-8.4052	2.1481
	Vermicompost_vermiwash	Control	18.45729*	2.71477	.000	13.1285	23.7859
		Vermicompost	7.18810*	2.63829	.008	1.9114	12.4648
		Vermiwash	3.12857	2.63829	.245	-2.1481	8.4052
Stem thickness	Control	Vermicompost	-.28252*	.02619	.000	-.3359	-.2311
		Vermiwash	-.29528*	.02619	.000	-.3467	-.2439
		Vermicompost_vermiwash	-.33000*	.02619	.000	-.3834	-.2766
	Vermicompost	Control	.28252*	.02619	.000	.2311	.3359
		Vermiwash	-.01276	.02619	.629	-.0642	.0385
		Vermicompost_vermiwash	-.04748	.02619	.070	-.0989	.0039
	Vermiwash	Control	.29528*	.02619	.000	.2439	.3467
		Vermicompost	.01276	.02619	.629	-.0385	.0642
		Vermicompost_vermiwash	-.03471	.02619	.195	-.0861	.0167
	Vermicompost_vermiwash	Control	.33000*	.02619	.000	.2766	.3834
		Vermicompost	.04748	.02619	.070	-.0039	.0989
		Vermiwash	.03471	.02619	.195	-.0167	.0861
Total Branches	Control	Vermicompost	-5.51846*	.60749	.000	-6.7109	-4.3261
		Vermiwash	-5.09943*	.60749	.000	-6.2910	-3.9079
		Vermicompost_vermiwash	-6.37662*	.60778	.000	-7.5680	-5.1852
	Vermicompost	Control	5.51846*	.60749	.000	4.3261	6.7109
		Vermiwash	.41905	.60030	.486	-.7602	1.5983
		Vermicompost_vermiwash	-.85714	.60030	.154	-2.0364	.3221
	Vermiwash	Control	5.09943*	.60778	.000	3.9079	6.2918
		Vermicompost	-.41905	.60030	.486	-1.5983	.7602
		Vermicompost_vermiwash	-1.27619*	.60030	.034	-2.4555	-.0969
	Vermicompost_vermiwash	Control	6.37582*	.60749	.000	5.1832	7.5683
		Vermicompost	.85714	.60030	.154	-.3221	2.0364
		Vermiwash	1.27619*	.60030	.034	.0969	2.4555

*. The mean difference is significant at the 0.05 level.

Table A.3. Results of the Post hoc test for shoot fresh and dry weight between the treatments of the greenhouse experiment.

Multiple Comparisons

LSD

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Shoot_fresh_weight	Control	Vermicompost	-871.03333*	1.71610	.000	-874.9907	-867.0760
		Vermiwash	948.30000*	1.71610	.000	552.2573	544.3427
		Vermicompost_vermiwash	-911.00000*	1.71610	.000	-915.2573	-907.3427
	Vermicompost	Control	871.03333*	1.71610	.000	867.0760	874.9907
		Vermiwash	-77.26567*	1.71610	.000	-81.2240	-70.3093
		Vermicompost_vermiwash	-40.26567*	1.71610	.000	-44.2240	-36.3093
	Vermiwash	Control	940.00000*	1.71610	.000	944.3427	952.2573
		Vermicompost	77.26567*	1.71610	.000	73.3093	81.2240
		Vermicompost_vermiwash	37.00000*	1.71610	.000	33.0427	40.9573
	Vermicompost_vermiwash	Control	911.00000*	1.71610	.000	907.3427	915.2573
		Vermicompost	40.26567*	1.71610	.000	36.3093	44.2240
		Vermiwash	-37.00000*	1.71610	.000	-40.9573	-33.0427
Shoot_dry_weight	Control	Vermicompost	-137.03333*	.23805	.000	-137.5823	-136.4844
		Vermiwash	237.00000*	.23805	.000	237.5480	236.4511
		Vermicompost_vermiwash	-203.06567*	.23805	.000	-203.5155	-202.5177
	Vermicompost	Control	137.03333*	.23805	.000	136.4044	137.5023
		Vermiwash	-99.96567*	.23805	.000	-100.5155	-99.4177
		Vermicompost_vermiwash	66.03333*	.23805	.000	65.5823	66.4844
	Vermiwash	Control	237.00000*	.23805	.000	236.4511	237.6169
		Vermicompost	99.96567*	.23805	.000	99.4177	100.5155
		Vermicompost_vermiwash	33.93333*	.23805	.000	33.3044	34.4023
	Vermicompost_vermiwash	Control	203.06567*	.23805	.000	202.5177	203.6158
		Vermicompost	66.03333*	.23805	.000	65.4044	66.5023
		Vermiwash	-33.93333*	.23805	.000	-34.4823	-33.3844

*. The mean difference is significant at the 0.05 level.

Table A.4. Results of the Post hoc test for shoot fresh and dry weight between the treatments of the field experiment

Multiple Comparisons

LSD

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Shoot_fresh_weight	Control	Vermicompost	-1067.06667*	.28771	.000	-1067.7301	-1066.4032
		Vermiwash	-962.93333*	.28771	.000	-963.5968	-962.2699
		Vermicompost_vermiwash	-993.26667*	.28771	.000	-993.9301	-992.6032
	Vermicompost	Control	1067.06667*	.28771	.000	1066.4032	1067.7301
		Vermiwash	104.13333*	.28771	.000	103.4699	104.7968
		Vermicompost_vermiwash	73.80000*	.28771	.000	73.1365	74.4635
	Vermiwash	Control	962.93333*	.28771	.000	962.2699	963.5968
		Vermicompost	-104.13333*	.28771	.000	-104.7968	-103.4699
		Vermicompost_vermiwash	-30.33333*	.28771	.000	-30.9968	-29.6699
	Vermicompost_vermiwash	Control	993.26667*	.28771	.000	992.6032	993.9301
		Vermicompost	-73.80000*	.28771	.000	-74.4635	-73.1365
		Vermiwash	30.33333*	.28771	.000	29.6699	30.9968
Shoot_dry_weight	Control	Vermicompost	-253.93333*	.27689	.000	-254.5718	-253.2948
		Vermiwash	-258.00000*	.27689	.000	-258.6385	-257.3615
		Vermicompost_vermiwash	-302.96667*	.27689	.000	-303.6052	-302.3282
	Vermicompost	Control	253.93333*	.27689	.000	253.2948	254.5718
		Vermiwash	-4.06667*	.27689	.000	-4.7052	-3.4282
		Vermicompost_vermiwash	-49.03333*	.27689	.000	-49.6718	-48.3948
	Vermiwash	Control	258.00000*	.27689	.000	257.3615	258.6385
		Vermicompost	4.06667*	.27689	.000	3.4282	4.7052
		Vermicompost_vermiwash	-44.96667*	.27689	.000	-45.6052	-44.3282
	Vermicompost_vermiwash	Control	302.96667*	.27689	.000	302.3282	303.6052
		Vermicompost	49.03333*	.27689	.000	48.3948	49.6718
		Vermiwash	44.96667*	.27689	.000	44.3282	45.6052

*. The mean difference is significant at the 0.05 level.

Table A.5. Results of the Post hoc test for root fresh and dry weight between the treatments of the greenhouse experiment

Multiple Comparisons

LSD

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Root_fresh_weight	Control	Vermicompost	-102.00000*	32.53374	.014	-177.0229	-26.9771
		Vermiwash	-75.33333*	32.53374	.047	-151.3563	-.3104
		Vermicompost_Vermiwash	-205.33333*	32.53374	.000	-280.3563	-130.3104
	Vermicompost	Control	102.00000*	32.53374	.014	26.9771	177.0229
		Vermiwash	25.66667	32.53374	.453	-49.3563	100.6896
		Vermicompost_Vermiwash	-103.33333*	32.53374	.013	-178.3563	-28.3104
	Vermiwash	Control	75.33333*	32.53374	.047	.3104	151.3563
		Vermicompost	-25.66667	32.53374	.453	-100.6896	49.3563
		Vermicompost_Vermiwash	-129.00000*	32.53374	.004	-204.0229	-53.9771
	Vermicompost_Vermiwash	Control	205.33333*	32.53374	.000	130.3104	280.3563
		Vermicompost	103.33333*	32.53374	.013	28.3104	178.3563
		Vermiwash	129.00000*	32.53374	.004	53.9771	204.0229
Root_dry_weight	Control	Vermicompost	-42.00000*	5.19615	.000	-53.9823	-30.0177
		Vermiwash	-14.66667*	5.19615	.022	-26.6490	-2.6843
		Vermicompost_Vermiwash	-85.33333*	5.19615	.000	-97.3157	-73.3510
	Vermicompost	Control	42.00000*	5.19615	.000	30.0177	53.9823
		Vermiwash	27.33333*	5.19615	.001	15.3510	39.3157
		Vermicompost_Vermiwash	-43.33333*	5.19615	.000	-55.3157	-31.3510
	Vermiwash	Control	14.66667*	5.19615	.022	2.6843	26.6490
		Vermicompost	-27.33333*	5.19615	.001	-39.3157	-15.3510
		Vermicompost_Vermiwash	-70.66667*	5.19615	.000	-82.6490	-58.6843
	Vermicompost_Vermiwash	Control	85.33333*	5.19615	.000	73.3510	97.3157
		Vermicompost	43.33333*	5.19615	.000	31.3510	55.3157
		Vermiwash	70.66667*	5.19615	.000	58.6843	82.6490

*. The mean difference is significant at the 0.05 level.

Table A.6. Results of the Post hoc test for root fresh and dry weight between the treatments of the field experiment

Multiple Comparisons

LSD

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Root fresh weight	Control	Vermicompost	-105.33333*	37.06300	.033	-191.4920	-19.1739
		Vermiwash	-87.33333*	37.36308	.048	[illegible]	[illegible]
		Vermicompost_Vermiwash	-230.66667*	37.36308	.003	-316.8261	[illegible]
	Vermicompost	Control	105.33333*	37.06300	.033	19.1739	191.4920
		Vermiwash	18.00000	37.36308	.643	-68.1594	104.1594
		Vermicompost_Vermiwash	-125.33333*	37.36308	.010	-211.4928	-39.1739
	Vermiwash	Control	87.33333*	37.06300	.043	1.1739	173.4920
		Vermicompost	-18.00000	37.06300	.643	-104.1594	68.1594
		Vermicompost_Vermiwash	-143.33333*	37.36308	.005	-229.4928	-57.1739
	Vermicompost_Vermiwash	Control	230.66667*	37.36308	.003	144.5072	316.8261
		Vermicompost	125.33333*	37.06300	.010	39.1739	211.4920
		Vermiwash	143.33333*	37.36308	.005	57.1739	229.4928
Root dry weight	Control	Vermicompost	-70.33333*	29.23558	.043	-137.7530	-2.9137
		Vermiwash	-68.00000*	29.23558	.048	-135.4197	-.5803
		Vermicompost_Vermiwash	-147.66667*	29.23550	.001	-215.0863	-80.2470
	Vermicompost	Control	70.33333*	29.23558	.043	2.9137	137.7530
		Vermiwash	2.33333	29.23558	.938	-65.0863	69.7530
		Vermicompost_Vermiwash	-77.33333*	29.23550	.029	-144.7530	-9.9137
	Vermiwash	Control	68.00000*	29.23558	.048	.5803	135.4197
		Vermicompost	-2.33333	29.23558	.938	-69.7530	65.0863
		Vermicompost_Vermiwash	-79.66667*	29.23558	.025	-147.0863	-12.2470
	Vermicompost_Vermiwash	Control	147.66667*	29.23550	.001	80.2470	215.0863
		Vermicompost	77.33333*	29.23558	.029	9.9137	144.7530
		Vermiwash	79.66667*	29.23558	.025	12.2470	147.0863

*. The mean difference is significant at the 0.05 level.

Table A.7. Results of the Post hoc test for root length between the treatments of the greenhouse experiment

Multiple Comparisons

Dependent Variable: Root length
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Controls	Vermicompost	-39.66667*	7.00397	.000	-55.8173	-23.5155
	Vermiwash	52.66667*	7.00397	.000	68.8173	36.5155
	Vermicompost_Vermiwash	59.00000*	7.00397	.000	75.1512	42.8488
Vermicompost	Controls	39.66667*	7.00397	.000	23.5155	55.8178
	Vermiwash	-13.00000	7.00397	.101	-29.1512	3.1512
	Vermicompost_Vermiwash	-19.33333*	7.00397	.025	-35.4845	-3.1822
Vermiwash	Controls	52.66667*	7.00397	.000	36.5155	68.8178
	Vermicompost	13.00000	7.00397	.101	-3.1512	29.1512
	Vermicompost_Vermiwash	-6.33333	7.00397	.392	-22.4845	9.8178
Vermicompost_Vermiwash	Controls	59.00000*	7.00397	.000	42.8483	75.1512
	Vermicompost	19.33333*	7.00397	.025	3.1822	35.4845
	Vermiwash	6.33333	7.00397	.392	-9.8173	22.4845

*. The mean difference is significant at the 0.05 level.

Table A.8. Results of the Post hoc test for root length between the treatments of the field experiment

Multiple Comparisons

Dependent Variable: Root length
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Controls	Vermicompost	-26.33333*	5.36957	.001	-38.7158	-13.9509
	Vermiwash	24.00000*	5.36957	.002	36.3825	11.6175
	Vermicompost_Vermiwash	14.66667*	5.36957	.026	27.0491	2.2842
Vermicompost	Controls	26.33333*	5.36957	.001	13.9509	38.7158
	Vermiwash	2.33333	5.36957	.675	-10.0491	14.7158
	Vermicompost_Vermiwash	11.66667	5.36957	.052	-.7158	24.0491
Vermiwash	Controls	24.00000*	5.36957	.002	11.6175	36.3825
	Vermicompost	-2.33333	5.36957	.675	-14.7158	10.0491
	Vermicompost_Vermiwash	9.33333	5.36957	.120	-3.0491	21.7158
Vermicompost_Vermiwash	Controls	14.66667*	5.36957	.026	2.2842	27.0491
	Vermicompost	-11.66667	5.36957	.052	-24.0491	.7158
	Vermiwash	-9.33333	5.36957	.120	-21.7158	3.0491

*. The mean difference is significant at the 0.05 level.

Table A.9. Results of the Post hoc test for harvest and fruit weight between the treatments of the greenhouse experiment

Multiple Comparisons

LSD

Dependent Variable	(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Total Harvest	Control	Vermicompost	-65.66667*	3.65903	.000	-73.8738	-57.4595
		Vermiwash	-93.66667*	3.65903	.000	-101.8738	-85.4595
		Vermicompost+vermiwash	-115.66667*	3.65903	.000	-123.8738	-107.4595
	Vermicompost	Control	65.66667*	3.65903	.000	57.4595	73.8738
		Vermiwash	-28.00000*	3.65903	.000	-36.2071	-19.7929
		Vermicompost+vermiwash	-50.00000*	3.65903	.000	-58.2071	-41.7929
	Vermiwash	Control	93.66667*	3.65903	.000	85.4595	101.8738
		Vermicompost	28.00000*	3.65903	.000	19.7929	36.2071
		Vermicompost+vermiwash	-22.00000*	3.65903	.000	-30.2071	-13.7929
	Vermicompost+vermiwash	Control	115.66667*	3.65903	.000	107.4595	123.8738
		Vermicompost	50.00000*	3.65903	.000	41.7929	58.2071
		Vermiwash	22.00000*	3.65903	.000	13.7929	30.2071
Fruit weight	Control	Vermicompost	-2663.66667*	220.65221	.000	-3172.2810	-2156.0724
		Vermiwash	-3262.33333*	220.65221	.000	-3770.8276	-2753.7390
		Vermicompost+vermiwash	-4527.00000*	220.65221	.000	-5035.5943	-4018.4057
	Vermicompost	Control	2663.66667*	220.65221	.000	2156.0724	3172.2810
		Vermiwash	-598.66667*	220.65221	.026	-1107.2610	-90.0724
		Vermicompost+vermiwash	-1863.33333*	220.65221	.000	-2371.9276	-1354.7390
	Vermiwash	Control	3262.33333*	220.65221	.000	2753.7390	3770.9276
		Vermicompost	598.66667*	220.65221	.026	90.0724	1107.2610
		Vermicompost+vermiwash	-1264.66667*	220.65221	.000	-1773.2610	-756.0724
	Vermicompost+vermiwash	Control	4527.00000*	220.65221	.000	4018.4057	5035.5943
		Vermicompost	1863.33333*	220.65221	.000	1354.7390	2371.9276
		Vermiwash	1264.66667*	220.65221	.000	756.0724	1773.2610

*. The mean difference is significant at the 0.05 level.

Table A.10. Results of the Post hoc test for total harvest and fruit weight between the treatments of the field experiment

Multiple Comparisons

Dependent Variable		(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Total Harvest	LSD	Control	Vermicompost	-170.00000*	13.19933	.000	-200.4377	-139.5623
			Vermiwash	-230.00000*	13.19933	.000	-260.4377	-199.5623
			Vermicompost+vermiwash	-271.66667*	13.19933	.000	-302.1044	-241.2290
		Vermicompost	Control	170.00000*	13.19933	.000	139.5623	200.4377
			Vermiwash	-52.00000*	13.19933	.004	-82.4377	-21.5623
			Vermicompost+vermiwash	-93.66667*	13.19933	.000	-124.1044	-63.2290
		Vermiwash	Control	230.00000*	13.19933	.000	199.5623	260.4377
			Vermicompost	52.00000*	13.19933	.004	21.5623	82.4377
			Vermicompost+vermiwash	-41.66667*	13.19933	.010	-72.1044	-11.2290
		Vermicompost+vermiwash	Control	271.66667*	13.19933	.000	241.2290	302.1044
			Vermicompost	93.66667*	13.19933	.000	63.2290	124.1044
			Vermiwash	41.66667*	13.19933	.010	11.2290	72.1044
Fruit weight	LSD	Control	Vermicompost	-9067.33333*	672.13478	.000	-10617.2789	-7517.3877
			Vermiwash	-11714.6667*	672.13478	.000	-13264.6123	-10164.7211
			Vermicompost+vermiwash	-13439.3333*	672.13478	.000	-14989.2789	-11889.3877
		Vermicompost	Control	9067.33333*	672.13478	.000	7517.3877	10617.2789
			Vermiwash	-2647.33333*	672.13478	.004	-4197.2789	-1097.3877
			Vermicompost+vermiwash	-4372.00000*	672.13478	.000	-5921.9456	-2822.0544
		Vermiwash	Control	11714.66667*	672.13478	.000	10164.7211	13264.6123
			Vermicompost	2647.33333*	672.13478	.004	1097.3877	4197.2789
			Vermicompost+vermiwash	-1724.66667*	672.13478	.033	-3274.6123	-174.7211
		Vermicompost+vermiwash	Control	13439.33333*	672.13478	.000	11889.3877	14989.2789
			Vermicompost	4372.00000*	672.13478	.000	2822.0544	5921.9456
			Vermiwash	1724.66667*	672.13478	.033	174.7211	3274.6123

*. The mean difference is significant at the 0.05 level.

Appendix B: Preparation of vermiwash units

Appendix C: Experimental design of tomato cultivation

a. **Experimental design in the greenhouse**

C	C	C	C	C	C	C	**Block 1**
V	V	V	V	V	V	V	
W	W	W	W	W	W	W	
VW	VW	VW	VW	VW	VW	VW	

V	V	V	V	V	V	V	**Block 2**
C	C	C	C	C	C	C	
VW	VW	VW	VW	VW	VW	VW	
W	W	W	W	W	W	W	

VW	VW	VW	VW	VW	VW	VW	**Block 3**
W	W	W	W	W	W	W	
V	V	V	V	V	V	V	
C	C	C	C	C	C	C	

b. **Experimental design in the field**

Block 1			
C	V	W	VW
C	V	W	VW
C	V	W	VW
C	V	W	VW
C	V	W	VW
C	V	W	VW
C	V	W	VW

Block 2			
V	C	VW	W
V	C	VW	W
V	C	VW	W
V	C	VW	W
V	C	VW	W
V	C	VW	W
V	C	VW	W

Block 3			
VW	W	V	C
VW	W	V	C
VW	W	V	C
VW	W	V	C
VW	W	V	C
VW	W	V	C
VW	W	V	C

Legend:

C		Blanco treatment
V	-	Plants fertilized with 100 gr. vermicompost
W	-	Plants fertilized with 100 ml vermiwash
VW		Plants fertilized with 50 gr. vermicompost and 50 mL vermiwash

Appendix D: Photo collection of tomato plants

a. Greenhouse experiment

Figure D.1. Difference in plant growth between the treatments, 1 week after transplanting. The VW plants were the longest

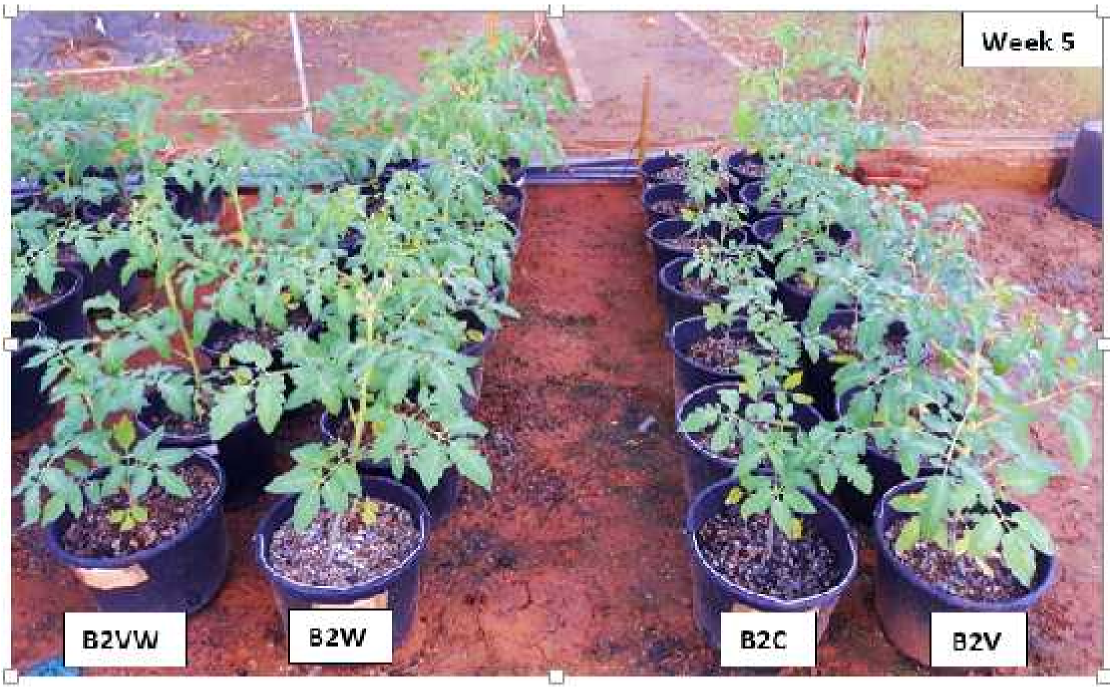

Figure D.2. Difference in plant growth between the treatments, 5 weeks after transplanting

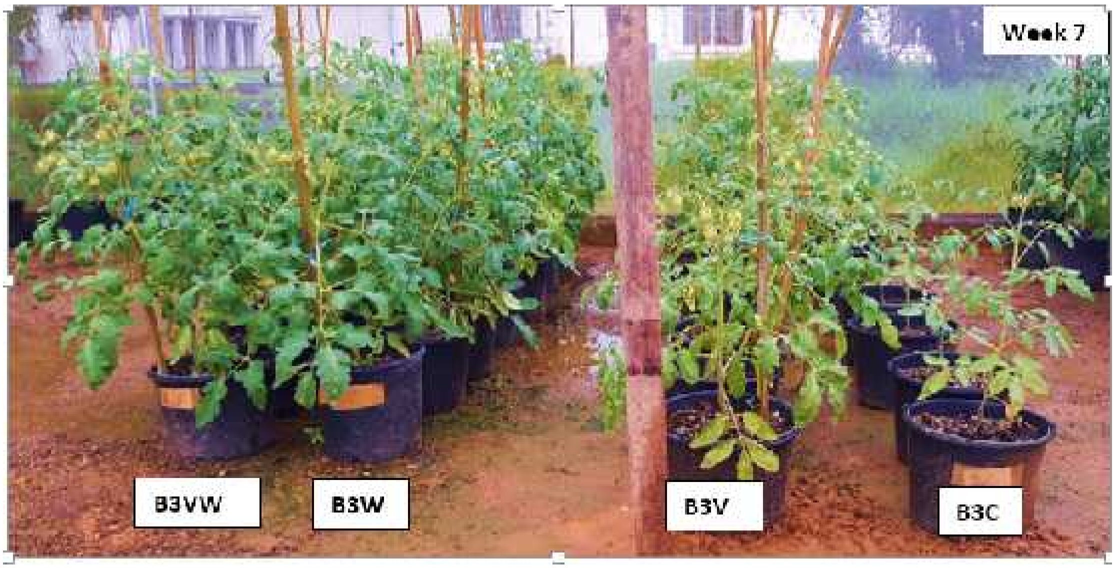

Figure D.3. The C plants were the shortest and the VW and W plants had a bushier appearance than the V plants

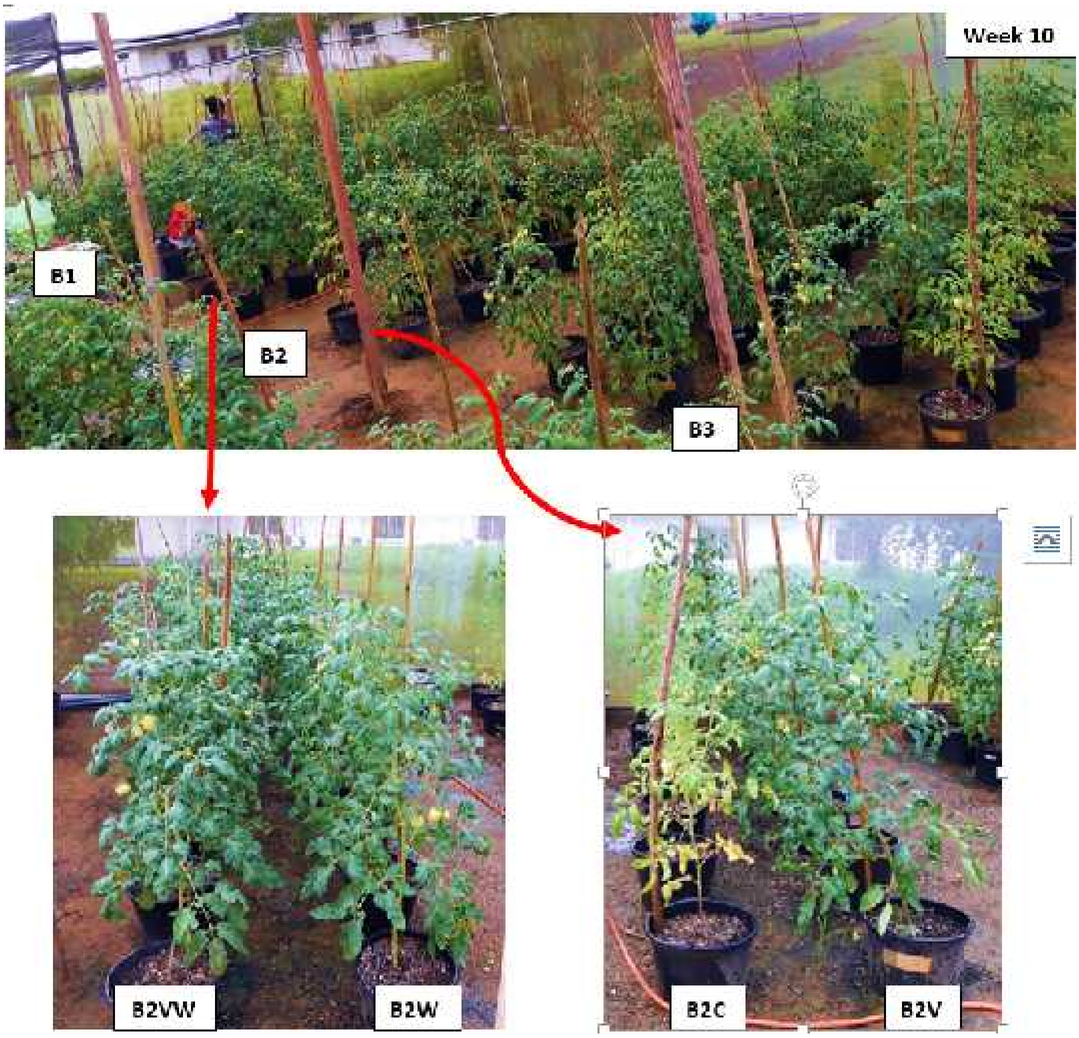

Figure D.4. The C plants were yellow and had no fruits. The old branches were removed

b. Field experiment

Figure D.5. Difference in plant growth between the treatments. The C plants were yellow

Figure D.6. The maximum height was obtained for the VW plants, followed by the W, V and C plants

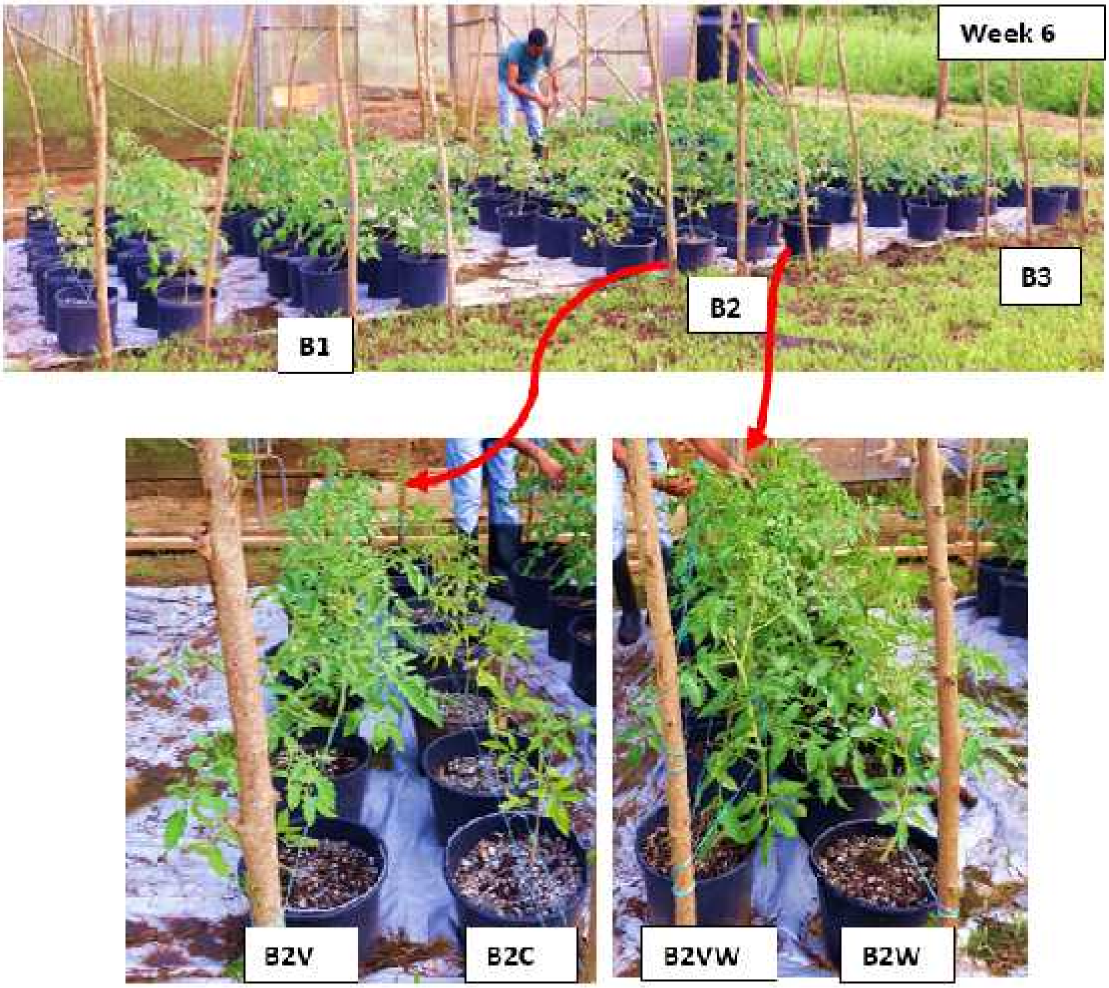

Figure D.7. The C plants were the shortest and the VW and W plants had a bushier appearance than the V plants

Figure D.8. Difference in plant growth between the treatments, 8 weeks after transplanting. The VW and W plants had a bushier appearance than the V plants

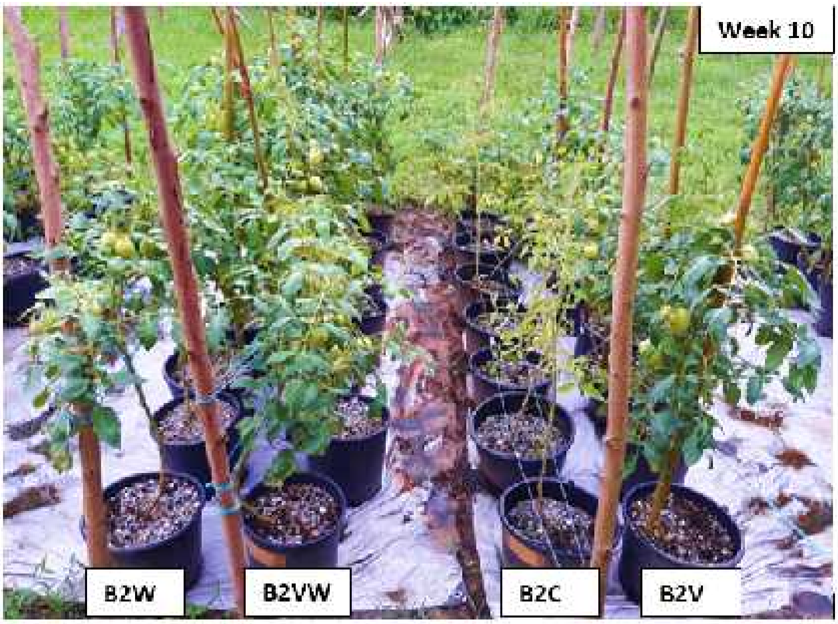

Figure D.9. The C plants were yellow and had no fruits. The old branches were removed