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Effect of different types of soil conditioners (plant-derived composts and animal manure) and application methods on quantitative and qualitative characteristics of tomatoes and selected soil parameters

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Abbreviations

B	Broad on the field
BRR	Basal Respiration Rate
CEC	Cation Exchange Capacity
CM	Cow Manure
DM	Dry Matter
EC	Electric Conductivity
FM	Fresh Matter
HC	Household Compost
K	Potassium
KUE	Potassium Use Efficiency
N	Nitrogen
NUE	Nitrogen Use Efficiency
P	Phosphorus
PUE	Phosphorus Use Efficiency
R	Row behind the plant
SMC	Spent Mushroom Compost
U	Under the root area
VC	Vermicompost

Zusammenfassung

Die steigende Weltbevölkerung hat den Bedarf an Nahrungsmittelproduktion erhöht, weshalb die nachhaltige Produktion von Nahrungsmitteln für Forscher der Agrarwissenschaften sowie für Politiker aufgrund der hohen Anforderungen der Verbraucher in verschiedenen Ländern der Welt von hohem Interesse ist.

In dieser Dissertation wurde die Wirkung verschiedener Arten von Komposten aus Restbiomasse auf verschiedene Eigenschaften von Pflanzen und Böden im ökologischen Produktionssystem untersucht. Drei getrennte Experimente wurden im Labor, Gewächshaus und Feld durchgeführt, um die Wirkung von Komposten und deren Suppressivität (in dem System *Pisum sativum*-*Pythium ultimum*) auf agronomische Eigenschaften von Tomaten zu untersuchen.

Die Ergebnisse des ersten Feldversuchs bestätigten, dass sich verschiedene Kompost-Arten (a. Bioabfallkompost (HC), b. Pilz(substrat)kompost (SMC), c. Vermicompost (VC) und d. Kuhdung (CM)) in unterschiedlichen Raten und Ausbringungsmethoden auf Ertrag und Qualität von Bio-Tomaten auswirken. Behandlungen mit CM zeigten im ersten Jahr einen signifikant höheren Tomatenertrag (103 t ha^{-1}) im Vergleich zu den anderen Komposten. Im zweiten Jahr, bei deutlich niedrigem Ertrag, wurde der höchste Ertrag mit SMC erreicht (58 t ha^{-1}). VC konnte bereits in geringerer Dosierung den Ertrag von Tomaten positiv beeinflussen. Die Düngeeffizienz der Komposte hängt vor allem auch von der Art der Ausbringung ab.

Ziel des zweiten Feldversuchs war es, Unter-Fuß-Düngung [U] mit traditionellen Ausbringungsarten (a) in Reihe [R] bzw. (b) gleichmäßig in der Fläche [B] bei der Anwendung von Vermicompost zu vergleichen. Für erstere (U) wurden 2, 4 und 6 t ha^{-1}, für

die beiden anderen Verfahren (R & B) wurden jeweils 3, 6 und 9 t ha^{-1} ausgebracht. Höhere VC-Raten, die als Reihe hinter der Tomate (R) und Unter-Fuß-Düngung angewendet wurden, erzeugten in beiden Jahren eine höhere Ausbeute [2014-2015]. Behandlungen mit mehr verfügbarem VC (Stufe 3) produzierten in beiden Jahren mehr Trockensubstanz. Ebenso, Stufe 2 und 3 des U-Verfahrens bewirkten eine höhere N-Aufnahme (23 % über dem U-Verfahren). Die Stickstoff-, Phosphor- und Kalium-Nutzungseffizienz ist im Vergleich zu den anderen Anwendungsmethoden um mehr als 200% in U-Behandlungsanwendungen gestiegen.

Die dritte und vierte Studie im Labor und im Gewächshaus zeigte, dass alle Komposte (Bioabfallkompost (HC), Pilz(substrat)kompost (SMC) und Vermicompost (VC)) eine unterdrückende Wirkung auf *P. ultimum* hatten, wobei dies mit HC aus Haushalt-Biorestmasse am ausgeprägtesten ausgelöst werden konnte. Dieses Experiment zeigte, dass höhere Kompost-Stufen *P. ultimum* signifikant mehr unterdrückten.

Zusammenfassend zeigt die Studie, dass Komposte eine gute Lösung sein können bei der Aufbereitung qualitativ akzeptabler industrieller und kommunaler Abfälle und der Verwendung nachhaltig wirksamer Bodenverbesserer in Landwirtschaft und Gartenbau.

Summary

World population prospect has increased the need for food production, therefore ensuring the sustainable production of food has been of interest to researchers of agricultural sciences, as well as politicians, due to high demands by consumers in various countries in the world.

In this dissertation, we have investigated the effect of different types of composts, from residual biomass (household compost (HC), Spent mushroom compost (SMC) and Vermicompost (VC)), on different characteristics of plant and soil in organic production systems. Three separated experiments have been conducted in the field, laboratory and greenhouse, to investigate the effect of composts on agronomical characteristics of tomato and also their effect on suppression of *Pythium ultimum*.

The results of the first field trial indicated that different types of fertilizers (HC, SMC, VC and Cow manure (CM)) in different rates (low, medium and high) and also with different methods of application (row application and broad on the field) could impact on the final result in organic tomato production. Treatments with CM showed significantly higher tomato yield in the first year (103 t ha^{-1}), however in the second year, SMC produced a higher yield (58 t ha^{-1}). The experiment showed that VC could be effective to boost tomato production with lower consumption of fertilizers. The proper rate of fertilizer application is dependent on the method of compost application. In general, compost broadened on the plots showed a higher yield production in cases with similar rates and compost type.

The aim of the second field trial was to evaluate under-root (U) method of VC application to improve yield characteristics of tomato and decrease the amount of fertilizer

consumption in organic farming. The VC rates with the R and B methods of the application were 3, 6 and 9 t ha^{-1} and for the U method were 2, 4 and 6 t ha^{-1} at low, medium and high rates, respectively. The results showed that application of higher rates of VC with R (92 and 63 t ha^{-1} in 2014 and 2015, respectively) and medium rates of U (94 and 57 t ha^{-1} in 2014 and 2015, respectively) method of application produced greater yields in both years. Treatments with more available VC produced more dry matter in both years. Also, treatments which have greater VC around the root area showed higher N uptake. This study showed that treatments with U method of application had 23 % higher N uptake as compared with the treatments where VC was broadened in the field (B). Nitrogen, phosphorus and potassium use efficiency have increased over 200 % in treatments with U application compared with the other methods of application.

The study of the suppressive potential of different composts in the laboratory and greenhouse illustrated that all composts had a suppressive effect on the *P. ultimum*, and HC had the most limiting effect on the mycelium. This experiment showed that a higher percentage of composts have a significantly more limiting effect on *P. ultimum*.

To conclude, the study demonstrated that composts can be a good solution to manage the industrial and municipal wastes by using their potential for agricultural production and soil improvement.

Chapter I

General introduction

1. General introduction

1.1. Need for sustainability

During recent years, agricultural research has focused on environmental problems and a need for a solution, which would compensate the man-made damage, has been growing. Application of chemical fertilizers as a product that the ecosystem has never previously been exposed to, in addition to overusing and degrading the soil, and water, may result of many of these problems.

Increasing the Earth's population has amplified the need for food production. Furthermore, the sustainability of this production is greatly depends on adequate plant nutrients in the soil. Therefore, it is essential to increase soil productivity to ensure sufficient food production. Our main challenge as agricultural scientists is to increase our farm income, enhance quality of life for farm communities as well as preserve our environment and maintain soil fertility while providing food for a growing population. Sustainable agriculture is referred to be a set of agricultural activities, both organic and conventional, aimed at producing sufficient quantities of food for a growing human population, environmental protection and the development of natural resources, as well as maintaining the economic sustainability of agricultural systems. According to the data provided by the Federal Ministry of Food and Agriculture in Germany (2017), the country has managed to reduce its nitrogen surplus in agriculture by 30% (38 kg ha^{-1}) since 1991, while agricultural production has increased. Similar conditions were also observed for plant protection products. Between 2009 and 2012, the amount of plant protection substances observed in near-surface groundwater in Germany was less than 5 %, compared to less than 10 % for the 1990 to 1995 period. Despite all these positive changes, there is still no provision for secure and sustainable use of resources and no reduction has been determined in the occurrence of nitrate-polluted water. For example, there has not been any reduction in the amount of water pollution to nitrate and the trend towards biodiversity loss in the agricultural landscape has not been stopped. Considering what was mentioned above, organic farming can be considered a good solution to improve agricultural systems. This farming method specifically promotes soil and ecosystem health through the prohibition of the use of chemical fertilizers, pesticides and herbicides and the recycling of farm wastes (Nandwani and Nwosisi 2016). For this purpose, organic farmers should carry out a series of tasks that include optimum use of fertilizers, nitrogen fixation with legumes and crop rotation, increased crop diversity, different livestock production, biological control of pests, and the recycle of agricultural wastes.

Almost 10 % of food wastes in EU countries come from primary production and 5 % comes from wholesale and retail (Eurostat 2017). This amount of agricultural waste can cause pollution of soil, water and the environment. Therefore, in order to maintain the sustainability of the system, it is important to look at the agricultural wastes as renewable and recyclable sources. In general, the production of compost from organic household and other recyclable materials are considered as a beneficial way to minimize the waste problem as well as optimize resource recovery as a low-cost alternative for animal-derived manures (Alvarenga et al. 2018; Fermoso et al. 2018).

1.2. Soil conditioners

One of the goals of organic agriculture is to eliminate the use of synthetically produced chemical fertilizers and replace them with organic materials. Composts are produced during the process of decomposition of organic matter by microorganisms in the presence of oxygen

(Onwosi et al. 2017; Wei et al. 2017; Bernal et al. 2009; Liang et al. 2003). At large, the use of compost maintains and enhances stability and the fertility of agricultural soil (Angin et al. 2017; Zhou et al. 2016). Compost can have direct effects against disease as well as stimulation of the competing microorganisms and development of resistance in plants against diseases (Carrera et al. 2007). In addition, compost is a cost-effective way to manage agricultural wastes (Ernst 1990).

One of the most important benefits of the organic matter in the soil, which is the main factor in the yield and quality of agricultural products, is soil fertility. On the other hand, by decreasing soil organic matter and increasing bulk density (reducing permeability) fertilizer recommendations do not increase the yield to the right amount. Therefore maintaining the optimum level of soil organic matter is a priority for sustainable agricultural. Preserving soil fertility is essential for increasing and sustaining crop production. Therefore, different strategies should be used to return the maximum amount of organic matter consumed in cultivated field. Many studies have indicated the positive effects of compost application on increasing the amount of soil organic matter (Rivero et al. 2004; Plaza et al. 2016; Peltre et al. 2017). For instant, Peltre et al. (2017) illustrated in a long term study that the amount of organic matter in the top soil increased after 12 years of household compost application relative to fertilization with NPK and cattle manure. They reported that 45 % of applied amendment C remained in topsoil after compost application while the figure for the cattle manure was 21%.

In these series of studies, we have investigated three different types of soil conditioner:

a. HC prepared from urban bio-wastes in the city of Mashhad, Iran via the usual composting method.

b. SMC prepared from residues of a mushroom cultivation bed. The applied SMC in this experiment is a composted combination of wheat straw, chicken manure and gypsum.

c. VC produced by a species of earthworm (*Eisenia Fetida)* from the mixture of household bio-waste, green manure and chinaberry (Persian lilac) leaves (*Melia azedarach*).

The reason for investigating these soil conditioners is based on their role in sustainable waste management and also their agricultural values. Due to the fact that most of soils in Iran are poor in terms of organic matter, the addition of organic matter especially in the form of compost has a beneficial effect on the physical, chemical and biological properties of the soil. More than 60% of Iran's soils have less than 1% organic matter, which reduces the availability of micro-elements in the soil and the lack of these elements in plants (Khadivi Borujeni et al. 2008). Furthermore, the absence of several available forms of micro-elements, such as zinc and copper is common in Iran's soils, due to the amount of calcium carbonate equivalent, high pH, low organic matter and abundant bicarbonate in irrigation water (Rafiee et al. 2005; Marschner 1993).

1.2.1. Household compost

Recycling organic waste should be a part of ecological considerations as it makes up 40% of the municipal solid waste share (Erhart et al. 2005). In Iran, over 70 % of municipal solid wastes are bio-waste materials (Farzadkia et al. 2009). However in the EU over 500 kg of household waste per inhabitant is produced each year (Eurostat Yearbook, 2004), which is a valuable source of humus and nutrients after composting (Herrera et al. 2008).

Previous studies illustrated that application of HC in the Panjab area in Pakistan showed significant improvements on the soil physical characteristics (Qazi et al. 2009). Also, Debosz et al. (2002) reported that household compost improved soil fertility a few weeks after application. There are various studies indicating that HC improves soil microbial biomass and soil respiration in the long term in applications of 20 and 40 t ha^{-1} as compared with the control treatment (Bhattacharyya et al. 2003; Garcia-Gil et al. 2000). By increasing the amount of HC in the soil, the concentration of phosphorus, potassium and the organic matter content of the soil have increased (Allahdadi et al. 2012). HC provides a short-term input to accessible nutrients and stimulates microbial activity, and in the long-run maintains the reservoirs of nutrients and organic material in the soil (Bhattacharyya et al. 2005). The use of HC for 2 years (Saha et al. 2007) and 12 years consecutively (Ros et al. 2006) has increased the total N content of the soil due to the gradual release of N from HC (Erhart et al. 2005). Ranjbar et al. (2017) indicated that application of HC for 7 years has increased nutrient concentrations in the soil and seed of rice in Iran.

1.2.2. Spent mushroom compost

SMC is a by-product of mushroom production industries in the form of residual compost waste. The need for recycling of organic by-product has increased in recent years due to its financial and environmental values (Wang et al. 2008; Chong and Rinker 1994). Every kilogram of mushrooms produced results in 5–6 kg of by-product (Ma et al., 2014) and is a source of humus as well as a useful soil conditioner. Studies shows that SMC has a good physical property, such as 'soil' structure or the total porosity, which is more than the minimum desired of 50 % by volume (Courtney et al. 2009; Chong and Rinker 1994). Arthur et al. (2012) reported that SMC increased the amount of organic matter and water content in sandy loam soil. Levanon and Danai (1995) reported that SMC can hold water up to the 60 % of their own fresh weight. However, SMC is alkaline and has high electric conductivity (EC) between 5.1 and 6.1 dS m^{-1} (in our experiment) causing soil salinity which is mainly due to excessive amounts of K, Ca and chalk content (Chong and Rinker 1994), however, this EC decreases with salt being washed out by rain and weathering (Uzun 2004). The pH level of our SMC was 7.9 and 8.1, which is close to the normal range of 5.5 to 7.0.

Zhang et al. (2012) discovered that SMC could be a good alternative growing medium for tomato and cucumber seedlings in a greenhouse. Jonathan et al. (2013) showed that applying SMC up to 10 % has a significant effect on height, leaf number, leaf area index, FM and DM of soybean. These findings were relevant to that of Zhang et al. (2012) on tomato and cucumber, where they used SMC as a growing media with SMC:perlite mixture (4:1, v:v) and SMC:vermiculite mixture (3:1, v:v).

The applied SMC in this experiment is a composted combination of wheat straw, chicken manure and gypsum provided by *Malard Mushroom Factory*.

1.2.3. Vermicompost

VC is a non-thermophilic composting process using various species of worms to create a mixture of peat-like product of decomposed organic residuals (Joshi et al. 2015; Arancon et al. 2004). VC has a good sponge structure and contains a high population of microorganisms with high ventilation and water storage capacity (Dominguez et al. 1997). The interaction between worms and microorganisms create higher plant-available forms of nutrients, such as nitrates and phosphates (Arancon et al. 2008). VC had a positive role in plant growth and yield of corn under drought stress conditions (Azizpour et al. 2017), which make VC a good medium for semi-arid conditions, such as Iran. In these experiments, VC has been provided by *Waste Management Organization* of Mashhad Municipality. The basic chemical characteristics of all fertilizers are summarized in Table 1.1.

Table 1. 1: Chemical characteristics of fertilizers in both years

Year	Type of fertilizer	N	P	K	Zn	Cu	Fe	Mn	EC	pH
		--------(g kg^{-1})-------			--------------(mg kg^{-1})---------------				(dS m^{-1})	
2014	**CM**	14	3	11	92	28	8778	350	4.5	8.2
	HC	20	4	8	836	165	3771	316	5.6	8.0
	SMC	21	3	7	226	24	2671	301	6.1	7.9
	VC	21	5	6	568	171	5255	210	2.9	7.9
2015	**CM**	11	4	10	89	21	8771	331	5.0	8.0
	HC	19	5	9	834	171	3812	301	5.4	7.8
	SMC	20	4	8	227	25	2660	303	5.1	8.1
	VC	19	6	6	563	168	5230	207	3.1	8.0

1.3. Compost placement

Application of fertilizers and other agricultural inputs has increased due to intensive agriculture extension, to provide enough food for the growing population of the world (Tilman et al. 2002). Therefore, it is important to reduce the agricultural inputs such as fertilizers and increase the use efficiency with proper input management. This has attracted the attention of many researchers; as there are many studies about the effects of fertilizer placement methods compared to the broadcast application of fertilizers on crop performance attributes such as yield (Kelley and Sweeney 2007; Jing et al. 2012) and nutrient uptake (Rose et al. 2009; Jing et al. 2012). In this study, we investigated various methods of placement in the field production of organic tomato (Figure 1.1).

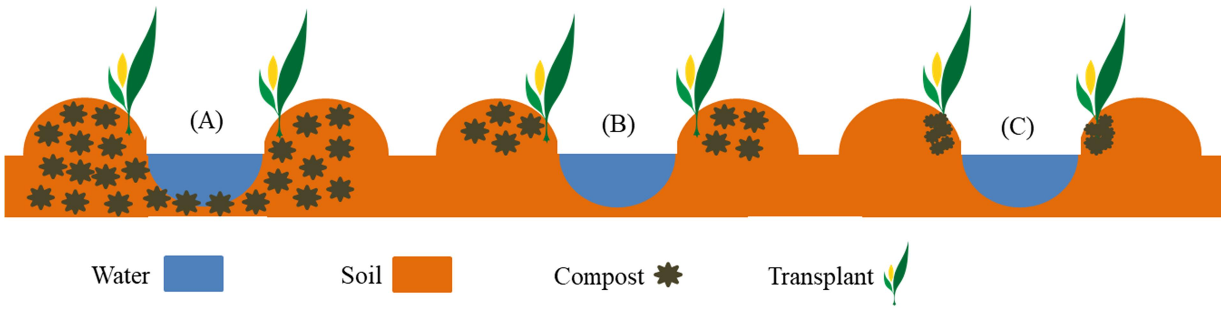

Figure 1. 1: Compost placement methods. (A) Broadcast on the field, (B) As a row behind the plantation lines, and (C) in the transplant hole under the root

Two different methods: 1. as a row on the soil surface with incorporation, behind the plantation lines, and 2. in the transplant hole under the root area (Just for Vermi-compost), applied to compare the effect of placement method to compost broadcast (control), on yield attributes and nutrient uptake of tomato plants.

1.4. Materials

This project is based on four studies in the laboratory, greenhouse and open field. The first and the second experiments were established in the Organic Research Stations of Ferdowsi University of Mashhad, located at 36◦ 15' North latitude and 59◦ 28' East longitude of Iran, for two growing seasons at 2014 and 2015. The soil type and the soil chemical characteristics of the field trial are shown in table 1.2. The first study focused on the effects of three different composts (VC, HC and SMC), as well as cow manure on yield and dry matter content of organic tomato (*Lycopersicon esculentum* L.).

All soil conditioners were applied at three different rates: 1. *Low*, 2. *Medium*, 3. *High* based on the application of local farmers. In addition to the quantitative factor, the method of application was also included as a third factor: 1. *As a row behind the plantation lines* (R) and 2. *Broadcast on the field* (B). The second study was conducted by VC with three different rates: 1. *Low*, 2. *Medium*, 3. *High* as well as three different methods of application as a second factor: 1. *As a row behind the plantation lines* (R), 2. *Broadcast on the field* (B), and in the transplant hole *Under the root area* (U). Both field experiments were conducted in 3 replications.

Table 1. 2: Selected soil properties of the experimental field site at Soil depth of 0-30 cm

Year	**2014**	**2015**
Texture	Silt loam	Silt loam
pH	7.8	7.9
EC (dS m^{-1})	2.4	2.4
Organic C (%)	3.0	1.1
Total N (%)	0.2	0.2
C/N	18.1	7.1
Available P (mg kg^{-1})	298	193
Available K (mg kg^{-1})	748	237
NO_3 (mg kg^{-1})	7.0	3.0
Fe (mg kg^{-1})	7.9	2.6
Zn (mg kg^{-1})	2.1	1.3
Cu (mg kg^{-1})	1.4	2.4
Mn (mg kg^{-1})	14.1	7.9

The third and fourth studies were conducted in the laboratory of the Department of Organic Farming and Cropping Systems and in the greenhouse of the Faculty of Organic Services of the University of Kassel, Germany. The study focuses on the suppressive effect of three composts: 1. HC, 2. SMC, and 3. VC, against *Pythium ultimum* by *in vitro* and *in vivo* test. The *in vivo* test was conducted with pea (*Pisum sativum* L.) seedlings (cv. Alvesta).

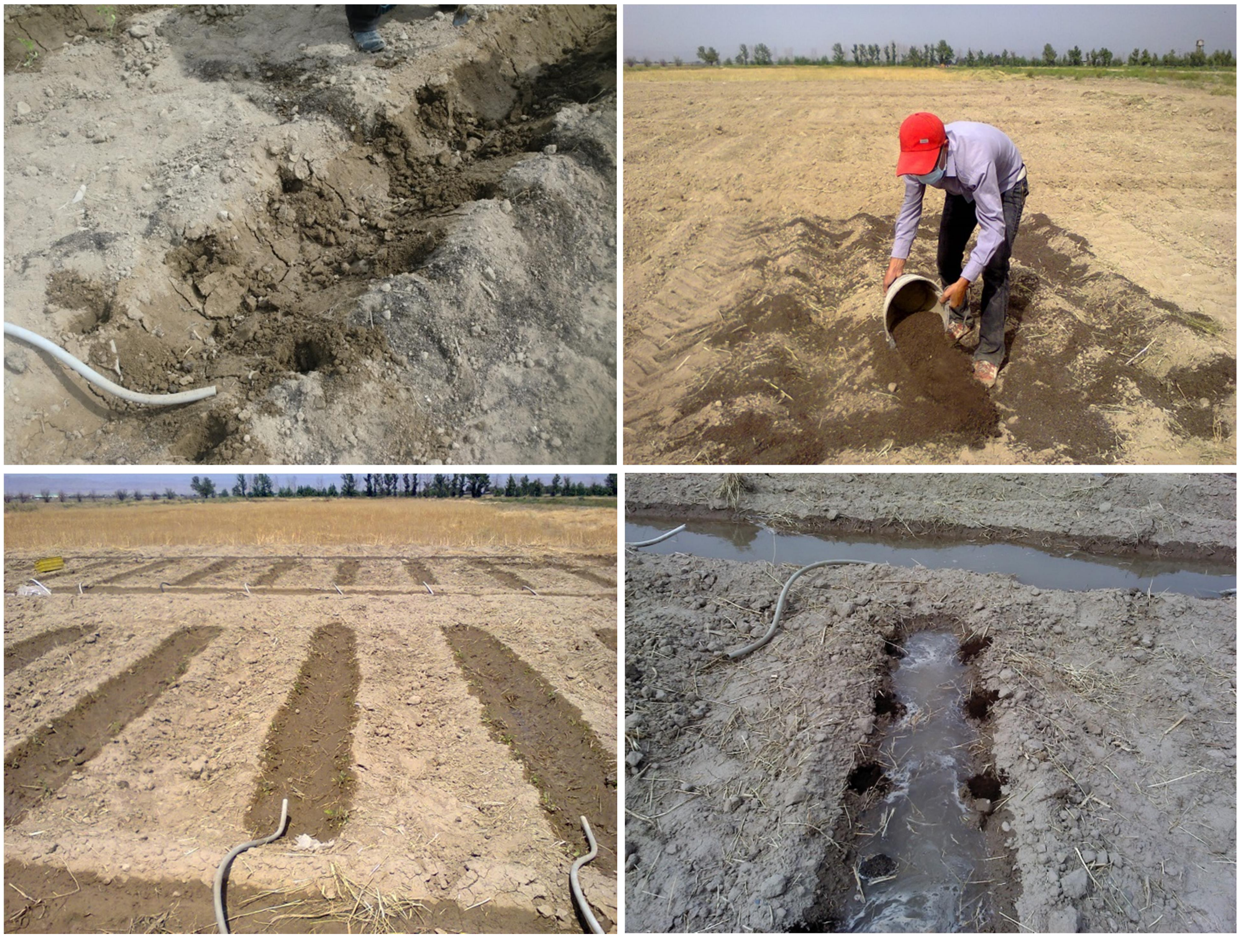

Photo: Ehsan Ebrahimi

1.5. Objectives and research questions

The general objective of this thesis was to compare different soil conditioners and evaluate their effect on yield and nutrient uptake in tomato production. With this assumption, we studied the comparison between HC, VC, and SMC compost with cow manure on yield and growth parameters of tomato. For better evaluation, different methods of compost placement and rates of application were placed under scrutiny. We also studied the suppressive effect of different composts on *P. ultimum* as a known pathogen for some vegetables. Finally, the interactions between type of composts, method of application and rate of application were evaluated under organic conditions in semi-aired temperatures.

The related research questions mainly addressed in this thesis are:

1. What are the effects of different types of compost on organic tomato production? (Q1)
2. Does compost placement has a relative effect compared to compost broadcast on yield and nutrient content of tomato? (Q2)
3. Is there any advantage of applying vermicompost in a relatively close proximity to the root area? (Q3)
4. Which compost is more effective against *Pythium ultimum*? Is there any advantage of incubating compost extracts? (Q4)

1.6. Outline of thesis

The thesis is composed of seven chapters of which three comprise the introduction (Chapter 1), discussion (Chapter 6) and conclusion (Chapter 7). Chapters 2 to 5 contain the main results of the study. A brief overview on the type of studies and methods in this thesis is presented in Table 1.3. To answer the first question (Q1), a two-year experiment was conducted in the Organic Research Stations of Ferdowsi University of Mashhad, Iran. In this experiment, the fertilizing effect of all soil conditioners became obvious despite existing discrepancies of the graded levels of application (Chapter 2). The second question (Q2) was addressed by analysis of the data of nutrient uptake and nutrient efficiency of different soil conditioners for organic tomato for the period of experiment 2014-2015 (Chapter 4). A two-year experiment of three methods of placement which was investigated by the single use of VC was designed to answer the third question (Q3). Beside the broadcast and row application, deep placement of VC was the third variable under test (Chapter 3). The last question (Q4) was answered by a bio-test on *Pisum sativum* and *Pytjium iltimum* mycelium. The comparison of the profile of HC, SMC, and VC provided new perspective (Chapter 5). Lastly, Chapter 6 and 7 summarizes the findings of these series of studies with a partition into the main topics of the project and would have initiated a broader discussion about the effects of soil conditioners on crop performance and environment.

Table 1. 3: Overview on the types of studies and methods used to answer the main research questions of the thesis

Topic of the study	Methodology
- A field study on the effect of organic soil conditioners with different placements on dry matter and yield of tomato (*Lycopersicon esculentum* L.)	- **Study period:** 2014-2015 - **Scale:** Field Experiment (Iran) - **Study crop:** Tomato - **Medium:** Cow manure, Household compost, Spent mushroom compost, Vermicompost - **Placement method:** Broadcast, Row application
- Effects of vermicompost placement to improve nutrient use efficiency and yield of tomato (*Lycopersicum esculentum* L.)	- **Study period:** 2014-2015 - **Scale:** Field Experiment (Iran) - **Study crop:** Tomato - **Medium:** Vermicompost - **Placement method:** Broadcast, Row application, Under the root area
- Suppressive effect of different composts from residual biomass on *Pythium ultimum*	***in vitro:*** - **Scale:** Laboratory Experiment (Germany) - **Study fungi:** *Pythium ultimum* - **Medium:** Household compost, Spent mushroom compost, Vermicompost - **Incubation day:** 7 and 14 days - **Concentration rate:** 10 and 20 % (v/v) ***in vivo:*** - **Scale:** Biotest Experiment (Germany) - **Study fungi:** *Pythium ultimum* - **Study crop:** Pea - **Medium:** Household compost, Spent mushroom compost, Vermicompost - **Inoculum rate:** 1 and 5 %

1.7. References

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Chapter II

A field study on the effect of organic soil conditioners with different placements on dry matter and yield of tomato (*Lycopersicon esculentum* L.)

Based on:

Ebrahimi E, Asadi G, von Fragsteign und Niemsdorff P (2019) A field study on the effect of organic soil conditioners with different placements on dry matter and yield of tomato (*Lycopersicon esculentum* L.). *International Journal of Recycling of Organic Waste in Agriculture* 8:59-66.
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2. The Effects of Different Organic Soil Conditioners from Residual Biomass on Yield and Dry matter Content of Organic Tomato (*Lycopersicon esculentum* L.)

Abstract

Purpose: Four different types of composts were assessed in two methods of application for their potential to support tomato yield.

Methods: A two-year experiment was conducted using four different fertilizers: cow manure (CM), household compost (HC); spent mushroom compost (SMC); and Vermicompost (VC); were applied. As a second factor, three different rates of application (10, 20 and 30 t ha^{-1} for CM, HC, SMC and 3, 6 and 9 t ha^{-1} for VC) was included. Two methods of fertilizer application (as a row behind the root area and broad on the field) were considered as a third factor.

Results: The yield was influenced by all factors at the first year; at the second year, just interactions were significantly different. Treatments with CM showed significantly higher tomato yield at the first year (103 t ha^{-1}) but at the second year, SMC produced a higher yield (58 t ha^{-1}). The experiment indicated that treatment with CM in high level with broad application had higher DM production (3.1 t ha^{-1}) in 2014, and treatment with CM in low rate and broad application had higher DM production (5.8 t ha^{-1}) in 2015.

Conclusion: compost broadened on the plots showed a higher yield production in cases with similar rates and compost type. The proper rate of fertilizer application is dependent on the method of compost application.

Keywords: Household compost, Organic farming, Soil conditioners, Spent mushroom compost, Vermicompost, Waste management

2.1. Introduction

Ensuring the sustainable production of healthy food and eco-friendly products has been of interest to researchers of agricultural sciences and ecology, as well as politicians due to high demands by consumers in various countries in the world. Maintaining soil fertility is one of the main factors affecting the sustainability of food production. Indiscriminate use of chemical fertilizers, coupled with neglected maintenance of the vitality of the soil and the use of destructive methods, has caused loss or destruction of the existing population of soil organisms (Geisseler and Scow 2014; Ebrahimi et al. 2016). Moreover, the common fertilization system is focused on providing a limited number of macronutrients, while it is scientifically known that plant needs at least 13 available minerals in the soil (Atiyeh et al. 2000).

Chemical fertilizers provide short-term nutrient needs of agricultural products, and long-term soil fertility is fallen into oblivion by farmers and agricultural producers. Studies have shown that excessive and unbalanced use of chemical fertilizers in the long run decrease crop yield, biological activity, soil physical properties, and increase accumulation of nitrates and heavy metals and soil acidity (Ghosh and Bhat 1998; Adediran et al. 2005; Aseri et al. 2008; Yoshida et al. 2016). Optimizing the amount of organic matter in the soil is one of the most basic principles of sustainable agriculture. Soil organic matter is rich in natural resources, such as nitrogen, phosphorus and potassium (N, P, and K) in organic forms but compared to their mineral forms, availability and mobility of these elements in organic compounds are usually a lot less (Angin et al. 2017). The use of organic debris depends on their quantitative and qualitative characteristics, climate condition, plant type, soil organisms, and management methods. Long-term studies have proven that continued use of chemical fertilizers reduce crop yield due to soil acidification, loss of soil physical and chemical characteristics, and the lack of appropriate micronutrient in these fertilizers (Ghimire et al. 2017; Gliessman and Engles 1998).

In most cases, soils contain sufficient quantities of micro elements in accordance with the plant needs, but lack of micro elements occur in some areas, which can reduce the crop yields (Zhou et al. 2016). Shuman et al. (1980) showed that in more than 30 countries, on average, approximately 30 percent of the soils are suffering from deficiency of one or more micronutrients. The use of organic fertilizers increases soil organic matter, improves microbial activity and provides both macro- and micro elements required for the plant in a more efficient way (Angin et al. 2017).

Compost application is one method to maintain soil fertility. Composts are produced during the process of the decomposition of organic matter by microorganisms in the presence of oxygen. In general, the use of compost maintains and enhances stability and fertility of the agricultural soil (Angin et al. 2017; Zhou et al. 2016). Compost can have direct effects against disease, as well as stimulation of the competing microorganisms and also development of resistance in plants against diseases (Carrera et al. 2007). Organic matter is also an important source of energy for bacteria, fungi and earthworms (Montemurro et al. 2005; Davis and Wilson 2004).

Municipal waste production has amplified due to increasing of the population growth and urbanization (Lim et al. 2016). One of the most effective methods to neutralize the adverse effects of waste and other plant residues is to separately collect the waste materials, and convert them into compost, to be reused as organic fertilizer on farmlands (Vogtmann & Fricke 1988; Fricke & Vogtmann 1994; von Fragstein & Schmidt 1999; Olowoake et al.

2018). Studies revealed the effect of municipal compost on increasing the amount of micro elements in the soil (Zheljazkov and Warman 2004). In regions with arid and semi-arid climates, using municipal solid waste compost as organic fertilizer can be a way to improve the permeability and porosity of the soil due to soil conditions in that areas.

Vermicomposting promotes a large and active microbial biodiversity population in the soil as compared to composts produced by the thermal process. In addition, VC is a great soil modifier amendment, as it has high porosity, good drainage and high water holding capacity (Atiyeh et al. 2000).

Tomato (*Lycopersicon esculentum* L.) is an annual plant and one of the most important crop worldwide. This plant grows in almost all types of soil. Most of the tomato producers use both organic fertilizers and traditional methods, though reports suggest that the quality of the fertilizers can have an adverse effect on the tomato quality (Ghorbani et al. 2008).

It is well known that organic fertilizers increase soil fertility and provide long-term nutrients by gradual decomposition (Angin et al. 2017; Gaiotti et al. 2017; Zhou et al. 2016). Research that investigated the different compost application methods in organic vegetable fields are quite limited. Thus, closer look at this topic is needed to understand how distribution of compost on the field can influence the final yield and DM. In this study, we aim to investigate the impact of four different types of organic fertilizer on tomato yield: 1. Vermicompost (VC); 2. Household compost (HC); 3. Spent mushroom compost (SMC); and, 4. Cow manure (CM). All composts and cow manure were used in three different levels (low, medium and high) based on local use of these materials by farmers.

2.2. Materials and Method

The study was established in the Organic Research Stations of Ferdowsi University of Mashhad, Iran, located at 36° 15’ North latitude and 59° 28’ East longitude of Iran for two growing seasons at 2014 and 2015. The soil type of the experimental field was Silt loam with a pH of 7.8 and 1.3 organic matter (Table 2.1). The site was previously fallow for five years before tomatoes were established for this study in June 2014. The plots’ locations were not changed in 2015.

Table 2. 1: Selected soil properties of the experimental field at Soil depth of 0-30 cm

Year	2014	2015
Texture	Silt loam	Silt loam
pH	7.8	7.9
EC (dS m^{-1})	2.4	2.4
Organic C (%)	3.0	1.1
Total N (%)	0.16	0.16
C/N	18.1	7.1
Available P (mg kg^{-1})	298	193
Available K (mg kg^{-1})	748	237
NO_3 (mg kg^{-1})	7.0	3.0
Fe (mg kg^{-1})	7.9	2.6
Zn (mg kg^{-1})	2.1	1.3
Cu (mg kg^{-1})	1.4	2.4
Mn (mg kg^{-1})	14.1	7.9

The experiment was conducted using Randomized Complete Block Design (RCBD) with four different types of soil conditioners, 1. *Vermicompost,* 2. *Household compost* and 3. *Spent mushroom compost* and 4. *Cow manure*, were applied at three different rates: 1. Low, 2. Medium, 3. High. The amount used for spent mushroom compost, household compost, and cow manure were 10, 20 and 30 t ha^{-1}, respectively, and 3, 6 and 9 t ha^{-1} for VC for low, medium and high applications. Immediately after application, a rotary cultivator was used to mix amendments properly with the soil. (Arancon et al. 2003; Ghorbani et al. 2008). Beside the quantitative factor, the method of application was also included as third factor: 1. As a row behind the root area and 2. Broad on the field. Organic fertilizers were tested and analyzed for chemical and nutrition values at both years (table 2.2).

Table 2. 2: Chemical characteristics of organic fertilizers

Year	Type of fertilizer	N	P	K	Zn	Cu	Fe	Mn	EC	pH
		---------(g kg^{-1})---------			-----------------(mg kg^{-1})----------------				(dS m^{-1})	
2014	**CM**	14	3	11	92	28	8778	350	4.5	8.2
	HC	20	4	8	836	165	3771	316	5.6	8.0
	SMC	21	3	7	226	24	2671	301	6.1	7.9
	VC	21	5	6	568	171	5255	210	2.9	7.9
2015	**CM**	11	4	10	89	21	8771	331	5.0	8.0
	HC	19	5	9	834	171	3812	301	5.4	7.8
	SMC	20	4	8	227	25	2660	303	5.1	8.1
	VC	19	6	6	563	168	5230	207	3.1	8.0

Each plot contained 4 rows, spaced 150 cm apart and four meters in length. Each tomato plant was placed 50 cm apart within each row and each plot had 2 furrows for irrigation. All sampling was taken from the two middle rows of each plot. Tomato seeds of *Early Urbana Y* variety provided by *Yekan Bazr* Co. were used for this experiment. Transplants were prepared in two different ways for each year. In the first year, they were planted and grown in seedling trays in coco pits media for eight weeks and transplanted to the field with their whole root area. In the second year, they were planted in a field of loamy sand soil for six weeks and then transplanted to field in a traditional way, which caused some damage to the root area during transplantation. Tomato seedlings were transplanted to field by hand on the first week of June 2014 at the first year, and on the third week of May 2015 for the second year based on the weather condition in both years. Tomatoes were irrigated right after transplanting and then every 7 days until the end of the growing season.

During the growing season, plots were observed to protect against any disease and pests, where no significant disease or pest invasion was observed. Each year tomatoes were harvested 3 times during the growing season at 13, 16 and 19 weeks after transplanting, beginning in the first week of September in the first year, and the second week of September in the second year. In each harvest, the whole plot area was harvested, but all other samplings for further analysis were obtained from the two middle rows of each plot. Hand-weeding was done during the growing season to control the weed population. Plot yields were converted to (t ha^{-1}) for the statistical analysis and presentation of results. After the last harvest, 5 plants were taken from the two middle rows of each plot for dry matter and nutrient uptake analysis.

Data were analyzed by analysis of variance (ANOVA) and the means were compared with Tukey and LSD test with the help of MS Excel and MINITAB 17 software. The probability level for determination of significance was either p=0.05 or p=0.01.

2.3. Results and Discussion

Analysis of variance shows that total yield responded to all factors at the first year. Table 2.3 indicates that interaction between type of fertilizer and rate of fertilizers were also significant ($p \leq 0.01$). In this experiment, tomato responded to the interaction of all factors at both experimental years. Compost is a good resource to release nutrients during growing season (Abbasi et al. 2002), and to ensure a sustainable and healthy production of tomato. Erhart et al. (2005) reported an increase of yield up to 10 % for compost treatments as compared to the control in wheat, barley and potato for 10 years. They also reported that yield response to compost amendment was increased over time. Furthermore, Mehdizadeh et al. (2013) has also illustrated that tomato fruit yield has been increased by 94 % in comparison with control.

Table 2. 3: Mean square for tomato yield for both years

Year		2014	2015
Source	**DF**	MS	MS
Replication	2	454.7 NS	175.7 NS
Organic Fertilizer (A)	3	715.7 **	137.1 NS
Rate (B)	2	564.6 *	189.0 NS
Application (C)	1	1376.7 **	190.5 NS
(A × B)	6	753.9 **	99.9 NS
(A × C)	3	69.5 NS	112.3 NS
(A × B × C)	6	1040.4 **	444.3 *
Error	46	---	---
Year	---	Variance: 664.1 NS	

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively.

In the year 2014 treatments with CM produced significantly ($p \leq 0.01$) more tomatoes (103 t ha^{-1}) than the other fertilizers, however in the second year, the differences were not significant (Table 2.4). Higher yield production in treatments with CM could be due to higher mineralization of organic matter in CM, which can provide enough nutritional release for the plant (Angin et al. 2017).

Table 2. 4: Effects of different soil amendments on total yield (t ha $^{-1}$)

Year	Type of fertilizer				Rate of application		
	CM	**HC**	**SMC**	**VC**	**Low**	**Medium**	**High**
2014	103 a	94 b	90 b	89 b	95 uv	98 u	88 v
2015	56 A	55 A	58 A	52 A	57 U	52 U	57 U

Means followed by different letters are significantly different ($p \leq 0.05$, LSD test). CM: *Cow Manure*, HC: *Household Compost*, SMC: *Spent Mushroom Compost*, VC: *Vermi Compost*.

Table 2.4 shows that higher rates of fertilizer did not produce a higher amount of tomatoes at the first year. Yield production in treatments with a medium rate of fertilizer application were significantly higher (98 t ha-1) than treatments with a high rate of fertilizer application (88 t ha^{-1}). Reduction of yield at a higher level of fertilizer application might be linked to salinity of the soil by compost and organic fertilizer application. This reduction is higher at SMC with row application and HC with broad application, which can be due to the incorporation of salt and possible heavy metals into the soil. Similar results were reported by Angin et al. (2017). However, applying nutrients have different effects on soil microbes and plant communities. Studies show that N fertilizers can suppress soil micro-organisms (Geisseler and Scow 2014). At the second year, there was no significant difference between treatments with different rates of compost application.

Table 2. 5: Effects of different soil amendments with different rate and method of application on total yield (t ha $^{-1}$)

Year	Application	Rate	Type of fertilizer			
			CM	**HC**	**SMC**	**VC**
2014	**Row**	**Low**	99 b-e	77 f-i	112 abc	85 e-h
		Medium	93 c-g	107 a-d	78 ghi	72 hi
		High	109 abc	87 d-h	61 i	92 c-h
	Broad	**Low**	99 b-f	100 a-e	76 ghi	112 abc
		Medium	115 ab	114 ab	120 a	85 e-h
		High	103 a-e	75 ghi	92 c-g	88 d-h
2015	**Row**	**Low**	67 uv	53 uvw	64 uv	47 vw
		Medium	48 vw	53 uvw	55 uv	53 uvw
		High	69 u	62 uv	53 uvw	62 uvw
	Broad	**Low**	46 vw	60 uv	53 uvw	64 uv
		Medium	59 uv	56 uv	64 uv	32 w
		High	49 uvw	47 vw	62 uv	53 uv

Means followed by different letters are significantly different ($p \leq 0.05$, LSD test). CM: *Cow Manure*, HC: *Household Compost*, SMC: *Spent Mushroom Compost*, VC: *Vermi Compost*.

In the first year of the experiment, treatments with SMC at a medium rate with broad application produced the maximum amount of tomato (120 t ha^{-1}), which was not significantly different with treatments of the same compost but in low rate and with row application behind the root area. This could be explained by the availability of compost for root area in row application. On the other hand, SMC in higher rates produced less tomato in row application, which might be due to high salinity around the root area (Table 2.2). All soil conditioners showed a high amount of tomato production with the medium rate and broad application with the exception of VC (Table 2.5). This result is understandable because VC has been applied 14 t ha^{-1} less than the other composts due to its higher price. Table 2.5 demonstrates that, using CM does not necessarily produce higher yield. A study by Mehdizadeh et al. (2013) published similar result with regard to application of HC and CM in tomato production. In their experiment, with application of 20 t ha^{-1} for HC and CM, 33 and 27 t ha^{-1} of tomato were produced respectively.

In the second year of experimentation, the yield was significantly lower, which could be due to transplant or weather condition in transplanting period. The differences between treatments (Table 2.5) during the second year were not as large as compared to the first year. This could be a result of the homogeneity of the soil or enhancement of soil quality after one year of plantation with organic soil conditioners (Table 2.1). In the second year, CM treatment with high rate and row application produced a higher amount of yield (69 t ha^{-1}), which did not differ significantly with any other compost using the same rate and method of application. On the contrary, tomato yield decreased in treatments with CM more than the other soil conditioners. However, the differences between these diminished treatments in the second year are not significant. This indicates that composts have a better effect over time in comparison with CM. Studies showed that we cannot expect a big response on plant growth in a short time because compost is not a rich source for N availability, but there is evidence that compost is a suitable amendment for long term improvement of soil organic matter (Abbasi et al. 2002; von Fragstein and Schmidt 1999). Mehdizadeh et al. (2013) showed that HC had a significantly better effect as compared to CM, poultry manure, and sheep manure, in total tomato yield and the number of tomato per plant. In the proposed study, there was a reduction on tomato yield at the second year due to warm weather during the transplanting phase, and also transplant conditions. Flowering is an important phase in plant development as the plants are vulnerable to environmental stress. It is the stage of plant development that determines when vegetables are ripe for harvest (Wien 1997). This amount did not show any significant difference with other soil conditioners in different rates of application. The analysis of variance between 2 years of experiment was not significantly different ($p \leq 0.05$) for yield production (Table 2.3).

Vermicomposting had less production in comparison with other fertilizers in this experiment however, the amount of VC applied was almost one-third of the amount of other fertilizers, based on the local consumption by farmers. For this reason, VC can be considered as a suitable fertilizer and soil conditioner for tomato production when applied at a relatively higher rate (9 t ha^{-1}), as it could have significantly increased tomato production during the second year. Yang et al. (2015) reported that tomato yield with VC amendment had greater yield in comparison with horse and chicken composts, and also chemical fertilizer under medium irrigation systems. Compared with the traditional composting process, VC has a higher degree of humification (Jeyabal and Kuppuswamy 2001). Special substances in VC, such as plant growth regulators that are biologically active, and also, the existence of functional micro-organisms due to higher soil microbial biomass, are the reasons that separate VC from other composts (Arancon et al. 2003; Amossé et al. 2013; Yang et al. 2015). There are studies which indicate that VC had a positive effect on sugar content and vitamin C level in tomato fruits compared with other fertilizers (Yang et al. 2015).

Analysis of variances for plant DM illustrates that different organic fertilizers as well as the methods of application differed markedly between treatments in the first year of production. Whereas in the second year, only different fertilizer type showed significant difference, but rate of fertilizer and method of application have no significance. In both years, the interaction effect between factors shows significant differences between treatments (table 2.6).

Table 2. 6: Mean square for shoot DM

Year		**2014**	**2015**
Source	**DF**	**MS**	**MS**
Replication	2	0.27 ^{NS}	0.63 ^{NS}
Organic Fertilizer (A)	3	2.01 **	1.99 *
Rate (B)	2	0.04 ^{NS}	0.76 ^{NS}
Application (C)	1	1.51 *	0.60 ^{NS}
(A × B)	6	0.60 ^{NS}	1.30 *
(A × C)	3	0.52 ^{NS}	1.91 *
(A × B × C)	6	1.00 **	1.75 **
Error	46	---	---
Year	---	Variance: 0.66 ^{NS}	

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant, respectively.

In the first year, treatments with CM produced more DM (2.4 t ha^{-1}) than treatments with HC and SMC while their differences with VC treatments (2.1 t ha^{-1}) were not significant. However, in the second year, treatments with VC produced markedly lower DM (2.8 t ha^{-1}) than treatments with CM (3.6 t ha^{-1}). Despite that the yield production decreased in the second year, but the DM concentration had increased in the same year (Table 2.7). Studies show that DM content has a direct correlation with the improvement of the nutritional status of soil and the soil structure. (Azarmi et al. 2008; Gutierrez-Miceli et al. 2007).

Table 2.8 indicates that treatment with CM in high rate and with broad application created the largest DM (3.1 t ha^{-1}) in 2014. This amount did not differ compared with other treatments with CM, different rates, and different application methods.

Table 2. 7: Effects of different soil amendments on shoot DM (t ha $^{-1}$)

Year	Type of fertilizer			
	CM	**HC**	**SMC**	**VC**
2014	2.4 a	1.7 b	1.8 b	2.1 ab
2015	3.6 u	3.1 uv	3.2 uv	2.8 v

Means followed by different letters are significantly different ($p \leq 0.05$, Tukey test). CM: *Cow Manure*, HC: *Household Compost*, SMC: *Spent Mushroom Compost*, VC: *Vermi Compost*.

This finding is relevant to that of Pellejero et al. (2017) on lettuce, which treatments with higher compost dosage showed higher root dry weight as well. This also included treatments with other fertilizers and with high rate and broad application. Based on these results, treatments with SMC in high rate and row application, as well as HC in low rate and row application, showed the lowest DM production (1.2 t ha $^{-1}$ and 1.2 t ha $^{-1}$ respectively) in 2014.

Table 2. 8: Effects of different soil amendments with different rates and methods of application on DM (t ha $^{-1}$)

Year	Application	Rate	Type of fertilizer			
			CM	**HC**	**SMC**	**VC**
2014	**Row**	**Low**	2.2 abc	2.0 abc	1.7 abc	1.9 abc
		Medium	2.6 abc	1.5 abc	1.4 bc	2.2 abc
		High	1.9 abc	1.9 abc	1.2 c	2.5 abc
	Broad	**Low**	2.9 abc	1.7 abc	1.9 abc	3.1 ab
		Medium	2.5 abc	1.7 abc	2.3 abc	1.4 bc
		High	3.1 a	2.3 abc	1.9 abc	1.5 abc
2015	**Row**	**Low**	3.0 v	3.3 v	3.1 v	3.0 v
		Medium	2.9 v	3.3 v	3.8 v	2.4 v
		High	3.3 v	3.3 v	3.5 uv	2.8 v
	Broad	**Low**	5.8 u	2.7 v	2.7 v	2.8 v
		Medium	3.6 uv	2.2 v	3.6 uv	2.6 v
		High	3.0 v	3.9 uv	3.0 v	3.1 v

Means followed by different letters are significantly different ($p \leq 0.05$, Tukey test). CM: *Cow Manure*, HC: *Household Compost*, SMC: *Spent Mushroom Compost*, VC: *Vermi Compost*.

On the contrary, treatment with CM in low rate and broad application had the highest DM (5.8 t ha^{-1}) in the second year, and this amount did not differ significantly with treatments of CM and SMC in medium rate and HC in high rate, all with broad application and treatment of SMC in high rate and row application (3.6, 3.6, 3.9 and 3.5 t ha^{-1}, respectively). As the result indicates at Table 2.6 and 2.8, DM production was significantly higher in the second year of experiment owing to availability of compost around the plot area. The analysis of variance between 2 years of experiment was not significantly different ($p \leq 0.05$) for DM production (Table 2.6).

2.4. Conclusion

The results of the proposed study indicated that different types of fertilizers, different rates and also different methods of application could impact the final result in organic tomato production. In the long-term production of tomatoes; composts have multiple advantages when compared with other soil conditioners. Applying HC and SMC is a sustainable solution for waste reduction in both urban and industrial level. The experiment showed that VC could be effective to boost tomato production with lower consumption of fertilizers. The proper rate of fertilizer application is dependent on the method of compost application. In general, compost broadened on the plots showed a higher yield production in cases with similar rates and compost type. To conclude, the study demonstrated that composts can be a good solution to manage the industrial and municipal wastes and using their potential for agricultural production and also soil improvement. Further studies should be conducted on different methods of application to optimise the rate of fertilizer consumption as much as possible.

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Chapter III

Effects of vermicompost placement to improve nutrient use efficiency and yield of tomato (*Lycopersicum esculentum* L.)

Based on:

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3. Effects of vermicompost placement to improve nutrient use efficiency and yield of tomato (*Lycopersicum esculentum* L.)

Abstract

This study investigated different methods of application of vermicompost (VC), with the aim to improve yield in organic tomato production and decrease the amount of fertiliser used. Three methods of placement of the VC were used in a two-year field trial: a. VC placed in a row on the soil surface with incorporation, behind the plantation lines (R), b. Broadcast (B), and c. In the transplant hole, under the root (U). As a second factor, VC was applied at three different rates of application (3, 6 and 9 t ha^{-1} for R and B, and 2, 4 and 6 t ha^{-1} for U. In both years, the different rates and placement methods had no significant effect on the fresh yield of tomatoes. However, in treatments with the higher rate and using the U placement increased the dry matter (DM) yield of the plants by up to 50 % (8.4 t ha^{-1}) in the second year. Evidently, treatments with U method of application had 23 % higher N uptake (156 kg ha^{-1}) compared to the treatments where VC was broadcast in the field (121 kg ha^{-1}). Nitrogen, phosphorus and potassium use efficiency have increased by 200 % in treatments with U application. The study demonstrated that applied U placement method for VC could increase the dry matter, nutrient uptake and nutrient use efficiency in organic tomato production.

Keywords: Fertilizer placement, Nutrient use efficiency, Organic fertiliser, Tomato, Vermicompost

3.1. Introduction

With the current increase in the world population, the need for increased food production has never been more important. This dilemma is coupled with the task of mitigating environmental crises, climate change, and the need to create more sustainable agro-ecosystems (Ghorbani et al. 2008; Ebrahimi et al. 2016;). There is a need to investigate and evaluate different agronomic systems and their production potential, considering all environmental costs and benefits (Gliessman 2014). Organic farming has been defined as a holistic approach to food production that incorporates environmentally friendly agricultural practices. One of the goals of organic farming is to maintain long-term soil fertility. Organic farming can create healthy and biologically active soils by improving on-farm nutrient cycling and recycling and reducing organic waste materials. On average, biologically active soils contain two million living creatures per gram of soil and have an important effect on soil fertility (Sylvia et al. 2005). Maintenance of soil organisms is possible through holistic management of the physical, chemical and biological properties of soil (Atiyeh et al. 2001; Fornes et al. 2012;). Hence, all soil properties, such as soil quality, fertility and microbial and chemical conditions should be considered in effective planning.

Composting is a method used for the recycling of organic materials, whereby microorganisms convert organic matter nutrients into mineralised nutrients under aerobic, thermophilic conditions (Liang et al. 2003; Bernal et al. 2009; Onwosi et al. 2017; Wei et al. 2017). Application of compost can be an effective strategy in agriculture, but the use of earthworms to degrade organic materials (to produce vermicompost) is also becoming increasingly popular. Vermicomposting has advantages over normal composting due to the interaction of earthworms and microorganisms in the non-thermophilic process. This process creates higher concentrations of plant-available forms of nutrients, such as nitrate and phosphate (Arancon et al. 2008), and greater cation exchange and water holding capacity (Atyieh et al. 2000; Arancon et al. 2008; Azarmi et al. 2008; Hatamzadeh 2011). In addition, studies show that vermicompost not only increases the level of humic acid (Atyeh et al 2002) and microbial populations (Arancon et al. 2006), but may also increase the plant's resistance against plant pathogens (Ebrahimi et al. 2018). Increasing nutrient uptake in plants due to higher humic acid (HA) level a larger population of microorganisms, was shown to result in improved germination, flowering and growth in plants (Atyieh et al. 2002; Arancon et al. 2006; Hatamzadeh 2011). Azarmi et al. (2008) illustrated that an application of 15 t ha^{-1} vermicompost (VC) increased the concentrations of Zn and Mn substantially and decreased soil pH compared to control treatments without amendments. Arancon et al. (2004) reported more than 30 % increase in fruit weight of strawberries in treatments with 10 t ha^{-1} compared to treatments with 5 t ha^{-1} VC.

Effective fertilizer management can enhance nutrient use efficiency. There are different methods of nutrient management, such as applying fertilizers at different times or using different methods and rates of application (Zheng et al. 2017). However, there are only limited numbers of studies that have investigated different methods of placing organic amendment in organic vegetable production. Therefore, more in depth investigations are needed to understand how the rate and placement of compost on the field can influence the final yield and crop dry matter (DM). The present research aimed to compare different placement methods of VC in the field, especially the application of VC under the root area. The overall aim of using this method of placement was to reduce the amount of fertilizer whilst simultaneously improving nutrient availability for the tomato plants.

3.2. Material and methods

The present study was established in the Organic Research Stations of the Ferdowsi University of Mashhad, Iran. Located at 36° 15' North latitude and 59° 28' East longitude. The experiment was conducted over two growing seasons in 2014 and 2015. The soil type of the experimental field was a silt loam with a pH of 7.8 and nitrate level of 7 and 3 (mg kg^{-1}) for the first and second year, respectively (Table 3.1). The field had been a bare fallow for five years.

Table 3. 1: Selected soil properties of the experimental field site at Soil depth of 0-30 cm

Year	2014	2015
Texture	Silt loam	Silt loam
pH	7.8	7.9
EC (dS m^{-1})	2.4	2.4
Organic C (%)	3	1.1
Total N (%)	0.16	0.16
C/N	18.1	7.1
Available P (mg kg^{-1})	298	193
Available K (mg kg^{-1})	748	237
NO_3 (mg kg^{-1})	7	3
Fe (mg kg^{-1})	7.9	2.6
Zn (mg kg^{-1})	2.1	1.3
Cu (mg kg^{-1})	1.4	2.4
Mn (mg kg^{-1})	14.1	7.9

The study included treatments with three different rates of VC, classified as low (L), medium (M), and high (H). The VC was applied to the soil using three different methods: a row on the soil surface with incorporation, behind the plantation lines (R), broadcast uniformly on the soil surface (B) (Nkebiwe et al. 2016; Ebrahimi et al. 2019) and in the transplant hole under the root (U) (Figure 3.1). The amounts of VC used for the R and B applications were 3, 6 and 9 t ha^{-1}, and for the U method, the amounts were 2, 4 and 6 t ha^{-1} for low, medium and high application rates, respectively. These amounts were based on standard application rates used by local farmers. The U placement method had lower application rates of VC to compare the effects of reduced rates of VC by changing the placement method. Immediately after VC application, a rotary cultivator was used to mix amendments properly with the soil in treatments of R and B (Ghorbani et al. 2008). The VC was provided by the Waste Management Organization of Mashhad Municipality (Mashhad, Iran). The basic chemical characteristics of applied VC are summarized in Table 3.2.

Figure 3. 1: Under the root placement ;(Left): Transplant's holes, (Right): Holes filled with VC and tomato transplant is placed on the VC before filling the hole with soil. (Photos: *Ehsan Ebrahimi*)

The experiments were designed on a complete randomized block design with three replications. Each plot contained 4 rows, 150 cm apart and four meters in length. The distance between the tomato plants within the row was 50 cm and each plot had 2 furrows for irrigation. All samples were taken from the two middle rows of each plot. The tomato cultivar 'Early Urbana Y' from *Yekan Bazr Co.* (Mashhad, Iran) was used. Eight-week old transplants were transplanted into the field by hand in the first week of June in 2014, and in the third week of May in 2015, in accordance with the weather conditions. The experiment was repeated in the same field and plots in the second year, i.e. the same treatments were applied in two consecutive years to the same plots. The tomatoes were irrigated right after transplanting and every 7 days until the end of the growing season.

Table 3. 2: Chemical characteristics of vermicomposts before application in the experimental field

Year	**N**	**P**	**K**	**Zn**	**Cu**	**Fe**	**Mn**	**EC**	**pH**
	---------($g\ kg^{-1}$)---------			--------------------($mg\ kg^{-1}$)-----------------				($dS\ m^{-1}$)	
2014	21	5	6	568	171	5255	210	2.9	7.9
2015	19	6	6	563	168	5230	207	3.1	8

During the growing season, plots were observed to identify any diseases and pests and weeds were managed by hand weeding. The tomato fruits were harvested 3 times during each year; at 13, 16 and 19 weeks after transplanting. The results from each harvest were converted to t ha-1 before statistical analysis. After the final harvest, 5 plants from middle rows of each plot were removed for determination of shoot DM yield of the plants and nutrient uptake (nutrient concentration in plant foliage and fruits). Plants were oven dried (60 - 75 °C) to constant weight. Nutrient analysis was done at the laboratory of plant physiology at Ferdowsi University of Mashhad. Total N content was determined by Kjeldahl method (Bradstreet, 1954; Bremner, 1960) and P and K were analyzed by using spectrophotometer (Matt, 1970) and flame photometry (O'neill and Webb, 1970), respectively. In this study, the nutrient use efficiency was calculated using the following equation (Van Eerd 2007):

$$\frac{Fn - Fc}{Sn} \times 100 \qquad (1)$$

where *Fn* is nutrient (N, P or K) uptake in the treatments, *Fc* is nutrient (N, P or K) uptake in non-fertilized control and *Sn* is the amount of each nutrient (N, P or K) applied in the treatments each year.

Data were assessed for each year separately by analysis of variance (ANOVA). The differences of means were compared with least significant difference (LSD) test using

MINITAB software (version 17; Minitab Inc. State College, PA). The probability level for determination of significance was either $p \leq 0.05$ or $p \leq 0.01$.

3.3. Results

3.3.1. Yield and Dry Matter

In this study, there were no significant effects on the yield of the tomatoes between the different treatments. However, the different VC regimes had an effect on the DM yield (Table 3.3).

Table 3. 3: Effect of VC with different rates and placement methods on yield (fresh weight of tomatoes, t ha^{-1}) and DM (t ha^{-1})

	Yield		DM	
Year	**2014**	**2015**	**2014**	**2015**
Rate (A)				
L	91	52	4	6 ab
M	84	47	4.4	5.5 b
H	89	61	4	6.7 a
LSD	NS	NS	NS	*
Method of Application (B)				
R	83	54	5 a	6 b
B	95	50	4 a	5.4 b
U	86	57	4 a	7 a
LSD	NS	NS	NS	**
(A × B)				
LR	85	47	3.3 abc	5.2 BC
LB	112	64	6.2 ab	6.4 B
LU	76	45	2.5 c	6.3 B
MR	72	53	5.1 abc	6.1 B
MB	85	32	2.5 c	4.4 C
MU	94	57	5.6 abc	6.0 B
HR	92	63	6.6 a	6.4 B
HB	88	53	2.8 bc	5.2 BC
HU	88	68	2.7 c	8.4 A
LSD	NS	NS	*	**

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively. Means followed by different letters are significantly different ($p \leq 0.05$, LSD test). *L*: Low, *M*: Medium, *H*: High, *R*: Row, *B*: Broad in the field, *U*: Under the root.

Table 3.3 illustrates that the DM production was affected by the interaction of both the rate and method of placement ($p \leq 0.05$) in each year. In the first year, DM production was the highest in HR (6.6 t ha^{-1}) followed by LB (6.2 t ha^{-1}), MU (5.6 t ha^{-1}) and MR (5.1 t ha^{-1}), respectively. However, in the second year, DM production was the highest at HU (8.4 t ha^{-1}), and the DM yield was significantly higher in this treatment than in all other treatments.

In the second year, DM production in HU was 24 % and 38 % higher compared to that of HR and HB, respectively. This has also been observed in MU with an increase of up to 27 % compared to MB. However, these differences were not similar in the first year. Table 3.3 shows that treatments with U placement method have had a positive effect on DM yield.

3.3.2. Plant nutrient uptake

Depending upon different environmental and physiological aspects, N is mainly taken up by plants in the form of nitrate and ammonium. The various rates and methods of VC applications in the field have created significant differences ($p \leq 0.05$) among the treatments and interactions in the second year (Table 3.4). In the first year, no significant differences were observed in the R placement with different rates while the L rate was more successful in treatments with the B method, and the L rate was less successful in treatments with a U method of placement. In the second year the results were different. HU showed the greatest N uptake (197 kg ha^{-1}) followed by HR (159 kg ha^{-1}). In M and H rates, treatments with the R and U method of placement had advantages over a B method of placement.

Treatments where the VC was placed under the roots showed higher N uptake in the second year. In 2015, treatments with a U method of application had a 23 % higher N uptake (156 kg ha^{-1}) compared to the treatments where VC was broadcast uniformly over the soil surface (121 kg ha^{-1}) (Table 3.4).

Table 3.4 indicates that the interaction between the rate and method of placement has created a significant difference in the P uptake in the first year. The HB treatment (61 kg ha^{-1}) showed the greatest uptake followed by the MU (41 kg ha^{-1}) and LU (43 kg ha^{-1}).

Table 3. 4: **Effect of VC with different rates and placement methods on N, P and K uptake (kg ha^{-1})**

Source	**N**		**P**		**K**	
Year	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Rates (A)						
L	99	131 B	31	10	105	167 AB
M	103	121 B	28	8	103	146 B
H	113	157 A	35	12	81	199 A
LSD	NS	*	NS	NS	NS	*
Methods of Placement (B)						
R	117	132 B	27	9	110	161
B	95	121 B	35	10	92	159
U	102	156 A	33	11	87	192
LSD	NS	*	NS	NS	NS	NS
(A×B)						
LR	93 ab	116 CD	34 ab	7	98	138 D
LB	150 a	150 BC	18 b	10	133	203 AB
LU	55 b	129 BCD	43 ab	12	85	159 BCD
MR	102 ab	120 BCD	18 b	8	110	143 CD
MB	67 b	101 D	25 b	9	75	122 D
MU	140 a	141 BCD	41 ab	7	123	173 BCD
HR	157 a	159 AB	29 b	12	121	201 ABC
HB	69 b	114 CD	61 a	10	69	152 BCD
HU	111 ab	197 A	16 b	14	52	243 A
LSD	**	*	*	NS	NS	*

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively. Means followed by different letters are significantly different ($p \leq 0.05$, LSD test). *L*: Low, *M*: Medium, *H*: High, *R*: Row, *B*: Broad in the field, *U*: Under the root.

Unlike N and P, the difference between the rate and method of placement interaction for K uptake was not significant in the first year. Yet, different rates and method of placement of VC created a significant difference among treatments in the second year. HU (243 kg ha^{-1}) showed the greatest K uptake in the second year among all other treatments amounting to a 37 % higher K uptake when compared with the B method of placement and a similar rate of application (152 kg ha^{-1}).

This interaction among treatments illustrates a significant difference in the P and K use efficiency. In low rates of VC applications, treatments with a U placement method showed a significantly higher P use efficiency (PUE) (42 %) and K use efficiency (KUE) (242 %) in 2015. In contrast, concerning the nutrient uptake, the use efficiency of the applied VC was significantly ($p \leq 0.05$) affected by different methods of application, except for N (Table 3.5).

Table 3. 5: **Effect of VC with different rate and placement method on N, P and K use efficiency (%)**

Source	NUE		PUE		KUE	
Year	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Rates (A)						
L	65	90 A	138	17 A	211 a	192 A
M	58	35 B	99	- 2 B	133 ab	73 C
H	43	50 B	57	8 AB	34 b	133 B
LSD	NS	**	NS	*	*	**
Methods of placement (B)						
R	62	38 B	49 b	- 2 B	139	78 B
B	37	34 B	72 b	7 AB	138	103 B
U	66	102 A	173 a	18 A	99	217 A
LSD	NS	**	*	*	NS	**
(A×B)						
LR	80	47	75 bc	-11D	192 abc	76 BCD
LB	84	77	58 c	20 B	360 a	256 A
LU	30	145	280 a	42 A	80 bc	242 A
MR	45	27	30 c	- 1 BCD	125 bc	49 CD
MB	13	11	51 c	0 BCD	39 bc	8 D
MU	114	68	216 ab	- 5 CD	234 ab	162 AB
HR	60	41	42 c	6 BCD	101 bc	108 BC
HB	14	15	108 bc	3 BCD	16 c	45 CD
HU	54	94	23 c	16 BC	- 16 c	245 A
LSD	NS	NS	*	**	*	**

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively. Means followed by different letters are significantly different ($p \leq 0.05$, LSD test). *L*: Low, *M*: Medium, *H*: High, *R*: Row, *B*: Broad in the field, *U*: Under the root.

The U placement method enhanced the N, P and K use efficiency in the second years, although this enhancement in efficiency for P occurred in both years. On the other hand, a higher rate of VC decreased the nutrient use efficiency by the plants. In the second year, using a U method of application increased N use efficiency (NUE), PUE and KUE (Eq. (1)) by almost 200 % compared to the other methods of VC application. In 2015, the NUE for the U method was 102 % while the R and B method of applications showed 38 and 34 %, respectively.

Table 3.5 shows that the amount of VC applied around the root area in this U placement method increased its use efficiency subsequently. When a lower rate of VC was applied, the NUE increased in the treatments with the B method of placement compared to the R method. In this research, the KUE was similar to that of N, while the PUE was not markedly different between the R and B methods of placement.

3.4. Discussion

The aim of this paper was to evaluate the effects of VC placement methods on the yield and nutrient use efficiency of tomato plants. In this study, we found that high levels of VC do not necessarily result in increased yield and DM production. The produced yield and DM with a low rate of VC indicates that the placement method should be considered. VC improves plant growth not only because of its nutrient levels but also substances such as humic acids or plant growth regulators (Atyieh et al. 2002; Arancon et al. 2004, 2006; Padmavathiamma et al. 2008), which have been produced as a result of the increase in soil microbial activity (Casenave de Sanfilippo et al., 1990; Arancon et al. 2004; Padmavathiamma et al. 2008). Arancon et al. (2004) illustrated that humic acid extracted from VC increased the growth of strawberry plants independent of their nutrient supply. They indicated that the levels of nutrients in the plots with VC and the plots using organic fertilizers were not significantly different, a finding also similar to that of an earlier study by Atyieh et al. (2002) on tomatoes.

VC increases root growth by improving the soil environment as more water and nutrient will become available for plant uptake from a larger area (Padmavathiamma et al. 2008). Investigations of the N uptake by different rates of application and method of placement resulted in different findings. The N uptake in different treatments showed that a higher rate of VC does not necessarily result in a significantly greater N uptake. Treatments with the U and R method of placement were superior to the B placement in a medium with a high rate of VC applied while the B placement method was superior at a low rate of VC application. This finding is relevant to that of Maddux et al. (1991) where plant N content was higher under an R nitrogen placement compared to that of a B placement in corn and barley; however, in a study by Übelhör et al. (2014) the B placement was superior to the R placement in white cabbage (Brassica oleracea). In general, the N uptake in the plots with a U placement was significantly ($p \leq 0.05$) higher (23 %) when compared to B placement methods in the second year. VC causes an increase of microorganism growth in the rhizosphere, which leads to more biological fixation. This increase may be attributed to a higher availability of N in the soil and consequently enhanced N uptake (Padmavathiamma et al. 2008; Joshi et al. 2015). Atiyeh et al. (2001) indicated that the N concentration of tomato seedling grown in media with 10%, 25%, and 50% of VC were higher than those grown in lower amounts. Other studies showed that applying higher amounts of VC increased the N uptake of spinach (Peyvast et al. 2008) and even rice by 21 % as compared with a N fertilizer alone (Jeyabal and Kuppuswamy 2001). These findings are relevant to that of our results where a higher amount of applied VC affected the N uptake outcome in the second year (Table 3.4). Most of the N in VC is in the nitrate form, which improves N availability and stimulates N uptake compared to the ammonium forms of nitrogen (Atiyeh et al. 2001).

Different rates of VC application did not significantly affect P uptake; however, the differences were significant ($p \leq 0.05$) for K uptake in the second year. Other studies illustrated that VC could increase P and K uptake in plants (Joshi et al. 2015). The application of VC has increased P uptake in African marigolds (*Tagetes erecta*) (Paul and Bhattacharya 2012) and maize (*Zea mays*) (Gutie´rrez-Miceli et al. 2008). Furthermore, there are references indicating that VC application has elevated the K uptake of Setaria grass (*Setaria splendida*) (Sabrina et al. 2013), the Lilium plant (*Lilium asiatic*) (Moghadam et al. 2012) and rice (*Oryza sativa*) by 9-14 % (Jeyabal and Kuppuswamy 2001). In tomato plants a higher temperature at the beginning of a season can cause a reduction in P uptake in the early stages of plant growth due to less root development (Gardner et al. 1985). Padmavathiamma et al. (2008) illustrated that the availability of K in the form that is more readily available in the soil could cause an increase in K uptake for the crop. In the present study, treatments with a higher rate of VC showed a higher K uptake by tomatoes in the second year. As our results showed, treatments with a low rate of VC and a B placement method had low N uptake levels, which could affect the K uptake when compared with treatments with a higher rate of VC applied. This could be portrayed by an increase in the cation exchange capacity (CEC) from using organic fertilizers. The change in the CEC may have increased the K availability for tomatoes (Jeyabal and Kuppuswamy 2001).

Sustainable agriculture demands more productivity and nutrient use efficiency while reducing environmental damages (Gliessman 2014). Greater available nutrients could increase the yield; therefore, it is important to use fertilizers as efficiently as possible. The excess N will be released from the plant root area and lost via leaching or evaporation (Yang et al. 2017). In this study, we found a negative relationship between the NUE and a higher rate of fertilizer application (Table 3.5). This finding is similar to that of Zheng et al. (2017) where treatments with the rate of 120 kg ha^{-1} N showed a 20 % higher NUE compared to treatments with the rate of 240 and 360 kg ha^{-1} N in the wheat field. A higher rate of VC decreased the P and K use efficiency. This study demonstrated that different methods of application had a clear impact on nutrient use efficiency (Table 3.5). Effective management of fertilizer applications can not only improve nutrient use efficiency but also the availability of nutrients for plants (Zheng et al. 2017). By applying VC with a U placement method, the NUE, PUE and KUE have increased in the second year, and the interactions between the treatments indicate that a U placement is a good application method for low rates of VC. The availability of VC around the roots in a U placement increases root access to the nutrients needed, thereby increasing the use efficiency of nutrients with lower quantities of fertilizer (Rengel and Damon 2008; Nkebiwe et al. 2016).

3.5. Conclusion

This study showed that the proper rate of VC applications is dependent upon the method of the VC placement. The U method of placement seems to be a suitable alternative to the R and B methods for field-grown vegetables such as the tomato. The U method of placement produced a higher amount of DM in the M and H rates of VC; however, this did not have an effect on the yield. It should be noted that when we discuss the U method of placement, we are actually discussing a method that has reduced VC applications by more than 30% (Refer to Material and Methods section). This study showed that the U method of placement creates better N and K uptake in both the M and H rates of VC applications. The present research illustrates that the rate and method of VC applications have a direct impact on the nutrient use efficiency in tomatoes. Therefore, higher nutrient use efficiency has been observed in treatments with a U placement of VC followed by the R and B placement methods. There was a clear difference in the NUE and PUE for treatments with a U placement compared to the other placement methods. Localized placement of N and P could optimize the availability of these nutrients at the beginning of the season. To conclude, this study demonstrated that it is possible to reduce the application rate of VC by more than 30% using a convenient method of placement (under the root), and while the total amount of yield does not change significantly, the efficiency of the nutrient use increases. It is found that VC is a good medium to place close to the rhizosphere of the tomato plant. However, further studies are recommended on different placement methods in order to optimize the rate of which VC application can be as productive as possible.

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Chapter IV

Influence of household compost and spent mushroom compost on nutrient uptake and nutrient use efficiency in organic tomato field

An approach to nutrient values

4. Influence of household compost and spent mushroom compost on nutrient uptake and nutrient use efficiency in organic tomato field

4.1. Introduction

Intensive conventional farming has increased crop yield but also, it has caused a lot of losses such as soil fertility, biodiversity and soil physical condition. A fertile soil provides proper microbial activity, respiration and nutrients (Carbonell et al. 2011). Organic farming has been of interest in many countries as an alternative for conventional methods in agriculture (Mäder et al. 2002; Sainju et al. 2001).

Compost is one of the most effective recycling methods, improving soil conditions and increasing crop production (Carbonell et al. 2011; Keeling et al. 2003) by improving soil physical conditions and also increasing resistance to diseases (Ebrahimi et al. 2018). Studies showed that the effect of household compost can improve microelements in soil (Bhattacharyya et al. 2007; Zheljazkov and Warman 2004), which can be an effective method to enhance the permeability and porosity of the soil, especially in the regions with arid and semi-arid climates. Compost as a slow nutrient-releasing fertilizer, is considered in organic cropping systems (Gitari et al. 2018). Almost 5 kg of residuals is producing for every kilogram of mushroom production, which contains a high level of nutrients (Meng et al. 2018). Due to this, spent mushroom compost can be considered as a valuable bio fertilizer in farming to reduce environmental effect of waste production and to increase yield and soil characteristics at the same time (Meng et al. 2018; Medina et al. 2009).

Both above mentioned composts have been investigated in this study, to evaluate their effect on nutrient uptake and nutrient use efficiency in organic tomato production.

4.2. Materials and Methods

A two-year study was established in the Organic Research Stations of Ferdowsi University of Mashhad, Iran, located at 36° 15' North latitude and 59° 28' East longitude. The soil type of the experimental field was Silt loam with a pH of 7.8 and 1.3 organic matter (Table 4.1).

Table 4. 1: Selected soil properties of the experimental field site at Soil depth of 0-30 cm

Year	**2014**	**2015**
Texture	Silt loam	Silt loam
pH	7.8	7.9
EC (dS m^{-1})	2.4	2.4
Organic C (%)	3	1.1
Total N (%)	0.16	0.16
C/N	18.1	7.1
Available P (mg kg^{-1})	298	193
Available K (mg kg^{-1})	748	237
NO_3 (mg kg^{-1})	7	3
Fe (mg kg^{-1})	7.9	2.6
Zn (mg kg^{-1})	2.1	1.3
Cu (mg kg^{-1})	1.4	2.4
Mn (mg kg^{-1})	14.1	7.9

The studied treatments including three types of organic fertilizers including *Household compost* (HC) and *Spent mushroom compost* (SMC) and *Cow manure* (CM), classified as *Low* (L), *Medium* (M) and *High* (H). The rate used for fertilizers was 10, 20 and 30 t ha^{-1}, respectively. The fertilizers were applied to the soil using two different methods including *a row behind the root area* (R), and *broad on the field* (B). (Arancon et al. 2003; Ghorbani et al. 2008). Organic fertilizers have been tested and analyzed for chemical and nutrition values in both years (table 4.2). Each plot contained 4 rows, 150 cm apart and four meters in length. The distance from one tomato plant to the next plant on the row was 50 cm and each plot had 2 furrows for irrigation. All samples were taken from the two middle rows of each plot. *Early Urbana Y* variety of tomato from *Yekan Bazr Co.* were applied. In the first year, transplants were planted and grown in seedling trays in coco pits media and later moved to the field with their whole root area and in the second year, they were planted in a field of loamy sand soil for six weeks and then they were transplanted to the field by hand. Due to the weather conditions in both years, the tomato seedlings were transplanted to field during the first week of June in 2014, as well as the third week of May in 2015.

Table 4. 2: Chemical characteristics of soil conditioners before application in the experimental field

Year	Type of fertilizer	**N**	**P**	**K**	**Zn**	**Cu**	**Fe**	**Mn**	**EC**	**pH**
		---------($g\ kg^{-1}$)---------			-----------------($mg\ kg^{-1}$)----------------				($dS\ m^{-1}$)	
2014	**CM**	14	3	11	92	28	8778	350	4.5	8.2
	HC	20	4	8	836	165	3771	316	5.6	8.0
	SMC	21	3	7	226	24	2671	301	6.1	7.9
2015	**CM**	11	4	10	89	21	8771	331	5.0	8.0
	HC	19	5	9	834	171	3812	301	5.4	7.8
	SMC	20	4	8	227	25	2660	303	5.1	8.1

Tomatoes were irrigated right after transplanting and every 7 days until the end of the growing season. Plots were observed to protect against any disease and pests. Tomato fruits were harvested 3 times during each year at 13, 16 and 19 weeks after transplanting. After the final harvest, 5 plants from middle rows of each plot were taken for nutrient uptake analysis. In this study, the nutrient use efficiency was calculated using the following equation (Van Eerd 2007):

$$\frac{Fn - Fc}{Sn} \times 100 \qquad (1)$$

where *Fn* is nutrient (N, P or K) uptake in the treatments, *Fc* is nutrient (N, P or K) uptake in non-fertilized control and *Sn* is the amount of each nutrient (N, P or K) applied in the treatments.

Data were analyzed by analysis of variance (ANOVA). The differences of means were compared with *LSD* test using MINITAB 17 software. The probability level for determination of significance was either p=0.05 or p=0.01.

4.3. Results

Analysis of variance for two-year-data showed that method of application did not affect the N, P and K uptake but, different composts created a significant difference between treatments for N (p=0.01) and K (p=0.05) uptake in the first year (Table 4.3).

Table 4. 3: Results of analysis of variance for N, P and K uptake

Source	DF	N		P		K	
Year		2014	2015	2014	2015	2014	2015
Replication	2	NS	NS	NS	NS	NS	NS
Compost (A)	2	**	NS	NS	NS	*	NS
Rate (B)	2	NS	NS	*	NS	NS	NS
Application (C)	1	NS	NS	NS	NS	NS	NS
(A × B)	4	**	NS	**	NS	NS	NS
(A × C)	2	NS	NS	NS	NS	NS	NS
Error	34	---	---	---	---	---	---

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively.

Table 4. 4: Analysis of variance for N, P and K use efficiency

Source	DF	NUE		PUE		KUE	
Year		2014	2015	2014	2015	2014	2015
Replication	2	NS	NS	NS	NS	NS	NS
Compost (A)	2	**	**	**	NS	NS	NS
Rate (B)	2	**	**	**	NS	**	**
Application (C)	1	NS	NS	**	NS	NS	NS
(A × B)	4	NS	**	**	NS	NS	NS
(A × C)	2	NS	NS	*	NS	NS	NS
Error	34	---	---	---	---	---	---

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively.

In the first year, treatments with CM increased N uptake more than 20 % in comparison with treatments with SMC (109 kg ha^{-1}) and HC (99 kg ha^{-1}). These increases followed a similar pattern for K uptake. Although all differenced were not significant in the second year (Table 4.5).

This study showed that analysis of variance for N and P use efficiency is completely different. Table 4.4 indicates that not only different compost but, different rates of application created a significant difference between treatments for NUE in both years. However, these differences were significant for PUE just in the first year.

Table 4. 5: Effect of different soil conditioners with different rates and methods of application on N, P and K uptake (kg ha^{-1})

Source	N		P		K	
Year	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Compost (A)						
CM	141 a	148	29	9	140 a	183
HC	99 b	143	25	12	99 b	186
SMC	109 b	147	41	10	116 ab	184
LSD	**	NS	NS	NS	*	NS
Rates (B)						
L	107	150	42 a	11	114	186
M	114	140	21 b	10	111	175
H	129	149	33 ab	10	131	190
LSD	NS	NS	*	NS	NS	NS
Methods of Application (C)						
R	119	149	27	10	118	186
B	114	143	37	10	119	183
LSD	NS	NS	NS	NS	NS	NS

Means with * and NS are significant with $p≤0.05$, $p≤0.01$ and not significant respectively. Means followed by different letters are significantly different ($p≤0.05$, LSD test). *L*: Low, *M*: Medium, *H*: High, *R*: Row, *B*: Broad in the field.

Table 4.6 illustrates that in the first year, CM had 17 % and 11 % higher NUE compared to that of HC and SMC, respectively and 14 % and 17 % higher NUE compared to that of HC and SMC, respectively in the second year. Also, treatments with a low rate of application (10 t ha^{-1}) showed a higher NUE compared to HC and SMC (Table 4.6). On the other hand, PUE in the first year was 40 % and 29 % higher compared to that of HC and CM, respectively. In this study, treatments with B method of application indicated 28 % higher

PUE in the first year. In both years, the use efficiency for N, P and K were higher in low rate of application compared to the higher rates (Table 4.6).

Table 4. 6: Effect of different soil conditioners with different rate and method of application on N, P and K use efficiency (%)

Source	NUE		PUE		KUE	
Year	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Compost (A)						
CM	34 a	34 a	35 b	1	36	41
HC	17 b	20 b	24 b	4	32	53
SMC	23 b	17 b	64 a	3	46	54
LSD	**	**	**	NS	NS	NS
Rates (B)						
L	33 a	42 a	86 a	5	61 a	86 a
M	23 b	16 b	19 b	2	28 b	34 b
H	18 b	13 b	22 b	1	24 b	28 b
LSD	**	**	**	NS	**	**
Methods of Application (C)						
R	26	25	28 b	2	37	51
B	23	22	56 a	3	39	48
LSD	NS	NS	**	NS	NS	NS

Means with *, ** and NS are significant with $p \leq 0.05$, $p \leq 0.01$ and not significant respectively. Means followed by different letters are significantly different ($p \leq 0.05$, LSD test). *L*: Low, *M*: Medium, *H*: High, *R*: Row, *B*: Broad in the field.

4.4. Discussion

This study showed that, even though the N content of CM was lower than SMC and HC but, treatments with CM higher N uptake due to a higher and faster availability of N in manure than compost (Eghball and Power 1999). The non-significant difference between treatments in the second year, indicate that slow-releasing fertilizers such as composts could be considered as a replacement for CM. Treatments with CM showed a higher K uptake but, unlike N, CM had a higher level of K compared to HC and SMC. Eghball and Power (1999) illustrated that surface application of CM decreased N loss due to a higher impact of CM on C: N ratio on top-soil than deeper layers (Amlinger et al. 2003). This finding is not relevant with our results, where different method of application did not significantly change N uptake and NUE.

The results for NUE indicate that CM has a higher NUE in both years. This is because those treatments with CM showed a higher N uptake while the CM had a lower N content itself. Table 4.2 indicates that CM has a higher level of K but, KUE is not significantly different among various soil conditioners. This is due to the possible luxury consumption of K in the field. HC and CM have a high content of non-exchangeable K, which indicates that these mediums could be a good supply for K gradually. Other experiment showed that CM could increase K uptake in grain and straw of rice (Bhattacharyya et al. 2007). Higher activities or crop removal decrease the level of exchangeable K, which causes a release of non-exchangeable K to the exchangeable forms. Therefore, compost application can be a suitable medium to increase the level of plant available K in the soil (Bhattacharyya et al. 2007; Eghball and Power 1999).

In this experiment SMC showed almost 30 % higher PUE compared to HC and CM while, differences in P uptake where not significant. This might be due to lower pH level in SMC compared to HC and CM in the first year (Table 4.2). Gardner et al. (1985) showed that higher pH causes a decrease in P absorption by plant. Also, higher level of fertilizer application did not increase the level of absorption or PUE. This might be due to a higher possibility of leaching and non-available forms of P in the soil (Bhattacharyya et al. 2007). Eghball and Power (1999) showed that continuous application of composts can decrease P leaching into the deeper depth of the soil. P absorption is depended on root development at the begging of plant growth (Gardner et al. 1985). Due to that, it is crucial to provide P at the beginning of the season.

4.5. Conclusion

Composts are media, which are considered as a slow release source of nutrients for plants and soil and its residual effect lasts during a growing season (Bhattacharyya et al. 2007; Eghball and Power 1999). In this experiment, we showed that even though CM can be a high valuable organic fertilizer, but composts are a good alternative for a long term run in organic farming. This study showed that higher fertilizer application might increase nutrient uptake, but not necessarily increase nutrient use efficiency.

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Chapter V

Suppressive effect of different composts from residual biomass on *Pythium ultimum*

Based on:

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5. Suppressive effect of different composts from residual biomass on *Pythium ultimum*

Abstract

Two experiments were established in the laboratory of the Department of Organic Farming and Cropping Systems, and the greenhouse of the University of Kassel, Germany, in 2017. The experiments studied the suppressive effects of three composts ,1. Household-waste compost, (HC); 2. Spent mushroom compost, (SMC); and 3. Vermicompost, (VC) against *Pythium ultimum* on pea. For *in vitro* experiment, two different incubation periods for every compost extract (7 and 14 days) and tap water as control were established. All composts had a suppressive effect on the pathogen, and HC had the most limiting effect on the mycelium. HC suppressed the mycelium disc up to 34 mm, while SMC, VC, and control showed 46, 64 and 106 mm mycelium inhibition, respectively. This experiment showed that a higher percentage of composts have significantly more liming effect on *P. ultimum*. Moreover, longer extraction time had significantly less suppressive effect on *P. ultimum*. The infection index for pots with 1 % infection was not significantly different between VC (1.4) and HC (1.7); however SMC (2.2) was significantly less suppressive. This work demonstrates that all composts are suppressive against *P. ultimum*, though SMC had significant difference toward the infection index by the control treatment in both infection levels.

Keywords: Bio control, Biowaste compost, Pea, Plant protection, Pythium, Spent mushroom compost, Vermicompost

5.1. Introduction

Soil borne pathogens are one of the main agents for causing agricultural damages every year (De Corato et al. 2016). *Pythium* is a pathogen damaging a large number of plants. This oomycete appear in all agricultural soils and can cause serious damage alone or together with other pathogens (Weerakoon et al. 2012; Yu et al. 2015). *Pythium ultimum* is responsible for some plant diseases such as *damping off* and *wilting* in some crops (Yu et al. 2015). There is a need for protection against pathogens, however, the use of chemical fungicides is not effective as a long-term solution and poses possible risks for human health (On et al. 2015).

There are researchers indicated that bio-fertilizers can have a positive effect on plant production, such as nitrogen level or chlorophyll content of plants (Jahan et al. 2013). It is crucial to improve soil fertility in organic farming by providing nutrition during the vegetative period (Jahan et al. 2013; Ebrahimi et al. 2016). Composts are promoted as a multipurpose soil organic amendment that improve vegetable and fruit quality by stimulating nutrient uptake in the soil. Compost has been offered not only as a bio-fertilizer to improve soil condition, but also as a plant protection mean against soil borne diseases (Szczech 1999; Everts et al. 2006; Pane et al. 2011). Compost amendments are able to control some pathogens by the microbial activities, improving bio-interactions and diffusing anti-fungal chemicals in the soil (Pane et al. 2011; Suárez-Estrella et al. 2013; Yu et al. 2015). The studies indicating that plant green-waste based composts have long term effects on disease suppression, even when their biologically active compounds including isothiocyanates had been emitted (Weerakoon et al. 2012; De Corato et al. 2016, 2018). There are various studies indicating that composts from different sources can stimulate both root and vegetative growth (Pane et al. 2011; Jahan et al. 2013).

The researchers denoted that composts are suppressive against a wide range of pathogens in plants (Everts et al. 2006; Markakis et al. 2016). Studies have shown that some abiotic characteristics of compost, such as acidity, C: N ratio and moisture increase the inhibition effect on soil borne pathogens (Yu et al. 2015). Markakis et al. (2016) presented that composts with a lower pH level are more effective against fungal pathogens, such as *Verticillium dahliae*.

There are many investigations concluding that microbial capacity and biological activities of compost play a critical role in pathogen suppressive effect in composts (Szczech 1999; On et al. 2015). Compost microbial activities were effective against *Fusarium* in tomato production. These activities create a competition for nutrient, produce anti-biotic materials and decrease nutrient availability due to competition for ecological niches (Suárez-Estrella et al. 2013). Szczech (1999) could demonstrate that VC was suppressive against *Fusarium oxysporum* on tomatoes. He explained that VC causes an increase in microbial activities. Also, in their experiment, pots with VC were characterized higher salinity (3.0-5.6 mg NaCl per liter of medium) than others, which can be a reason for inhibiting *F. oxyporum*.

Pea (*Pisum sativum L.*) as an essential legume plays a role in organic farming due to its ability to fix nitrogen (Fuchs et al. 2014; Jannoura et al. 2014; Akhter et al. 2015). There are numerous diseases which reduce the total yield in peas. There is evidence signifying that *Pythium spp*. could have a negative effect on peas and decrease the total yield in grain legume production (Akhter et al. 2015; Fuchs et al. 2014).

5.2. Method and Materials

This study was carved out in the laboratory of the Department of Organic Farming and Cropping Systems and in the greenhouse of the Faculty of Organic Services of the University of Kassel, Germany. The study focuses on the suppressive effect of three composts: 1. Household-waste compost (HC), 2. Spent mushroom compost (SMC), and 3. Vermicompost (VC), against *Pythium ultimum* by *in vitro* and *in vivo* test. Similar source of compost has been applied for both experiments.

5.2.1. Laboratory test

The treatments comprised of three composts, with two incubation times for each compost extract (7 and 14 days). Additionally, tap water was used as a control measure. Each compost was mixed with tap water at the ratio of 1:2 (v/v) and extracted at 20-25 ºC for 7 and 14 days in incubator. After incubation the mixtures were filtered by cheesecloth and clean extracts were kept separated for the application in the plates. Sterilized Potato dextrose agar (PDA) was used as media for *in vitro* test. Petri dishes were filled with 18 ml of PDA and cooled under sterile condition. Then 0.1 ml of compost extracts were added on PDA in concentration from 10 to 20 % (v/v) and spread above PDA surface on the petri dish. Mycelia (5 mm) of 14 day-old of *Pythium ultimum* (Isolated from sugar beets; Laboratory of Dr. J. Hess, University of Kassel) were placed in the center of each plate. Plates treated with sterile water were used as control. Petri dishes were incubated at 25 ºC. The diameters of the colonies were measured after three days of incubation. In this experiment each treatment was replicated six times.

5.2.2. Greenhouse test

All composts were prepared with uniform particle size after sieving with (Ø 5 mm) mesh. The chemical characteristics of composts were determined according to the official methods of the International Society of Soil Science (De Corato et al. 2018) (Table 5.1).

The experiments were conducted with pea seedlings (cv. Alvesta) under greenhouse condition at the Faculty of Organic Services at the University of Kassel, located at 51°20' North latitude and 9°51' East longitude of Witzenhausen, Germany. Composts were mixed with sterile sand, using pots (450 ml) in every treatment that contained 30 % compost (except control with 100 % sterile sand). Liquid fertilizer (WUXAL®: 8 % N, 8 % P_2O_5, 6 % K_2O) was added to reach the optimal level in control pots 8 days after planting. Water was added every 48 hours up to the peak moisture level for each pot. All pots were kept in the greenhouse with 16 hours of day light (10,000 Lux with artificial light) and at a temperature of 20 ºC and 16 ºC for day and night, respectively.

An inoculum of 14 day old *P. ultimum* (Isolated from sugar beets; Laboratory of Dr. J. Hess, University of Kassel) was placed on sterile sand and incubated at 25 ºC for 14 days. The two weeks old cultures were mixed and homogenized with potting media based on the designed treatments.

Table 5. 1: The chemical characteristics of composts

Type of fertilizer	**N**	**P**	**K**	**Zn**	**Cu**	**Fe**	**Mn**	**EC**	**pH**
	---------($g\ kg^{-1}$)---------			----------------($mg\ kg^{-1}$)----------------				($dS\ m^{-1}$)	
HC	16	4	7	831	168	3802	292	5.4	7.8
SMC	15	3	8	217	21	2581	289	5.9	7.9
VC	17	4	5	556	152	5211	201	2.8	7.8

Four potting media were prepared as follow: 1. Sand (control), 2. HC, 3. SMC, and 4. VC, with 30 % compost for each treatment. In this experiment, three levels of inoculum are applied as second factor: 0 %, 1 % and 5 %. Five replicates for each treatment and five seeds were planted in each pot.

Fresh matter (FM) and level of infected plants were measured after 23 days of incubation. *Damping off* were indexed with 1 to 5, which is; 1. Healthy, 2. Healthy, but weaker and significantly smaller in growth, 3. Deformation, 4. Post-emergence dead, and 5. Pre-emergence death.

5.2.3. Statistical analysis

All collected data were analyzed with analysis of variance (ANOVA). The differences between treatments were compared with LSD test with the help of MS Excel and MINITAB 17 software. The probability level for determination of significance was $p \leq 0.01$.

5.3. Results

5.3.1. In vitro test

All composts had a suppressive effect on the pathogen. Analysis of variance indicated that different type of composts, concentrations of compost liquid and extraction days had significant suppressive effect on *Pythium ultimum* (Table 5.2).

HC had the most limiting effect on the mycelium. HC could suppress the mycelium disc up to 34 mm, while SMC and VC reduced mycelium to 46 and 64 mm, respectively. Overall, all composts had significant suppressive effects when compared to the control treatment.

Table 5. 2: Mean square for colony diameter of *Pythium ultimum* after 3 days

Source	DF	MS
Replication	5	20 NS
Compost (A)	2	5498 *
Concentration % (B)	1	356 *
Extraction day (C)	1	968 *
A × B	2	276 *
A × C	2	533 *
B × C	1	35 NS
A × B × C	2	1 NS
Error	55	---

Means with * and NS are significant with $p \leq 0.01$ and not significant respectively.

This experiment showed that a high concentration percentage of compost extracts will significantly increase the liming effect on *P. ultimum* mycelia. Moreover, longer extraction time had significantly less suppressive effect on *P. ultimum* colony in comparison with 7 days of extraction (Figure 5.2).

This work illustrated that HC extract with 20 % concentration after 7 days of extraction is the most suppressive (31 mm) among all treatments. Nevertheless, this liming effect was significantly similar to HC with 10 % and SMC with 20 % concentration after 7 days of extraction (34 and 35 mm respectively). All treatments with HC extracts showed better effect than other composts (Figure 5.1).

Among all treatments, SMC showed higher difference between the extraction times. The SMC treatments with 14 days of extraction were less suppressive in comparison with SMC treatments with 7 days of extraction (Figure 5.2).

Figure 5.1 indicated that VC treatments are less suppressive against *P. ultimum*. Also, VC was the only treatment that showed smaller diameter size at 20 % concentration in comparison with 10 % concentration with 7 days of extraction after 3 days.

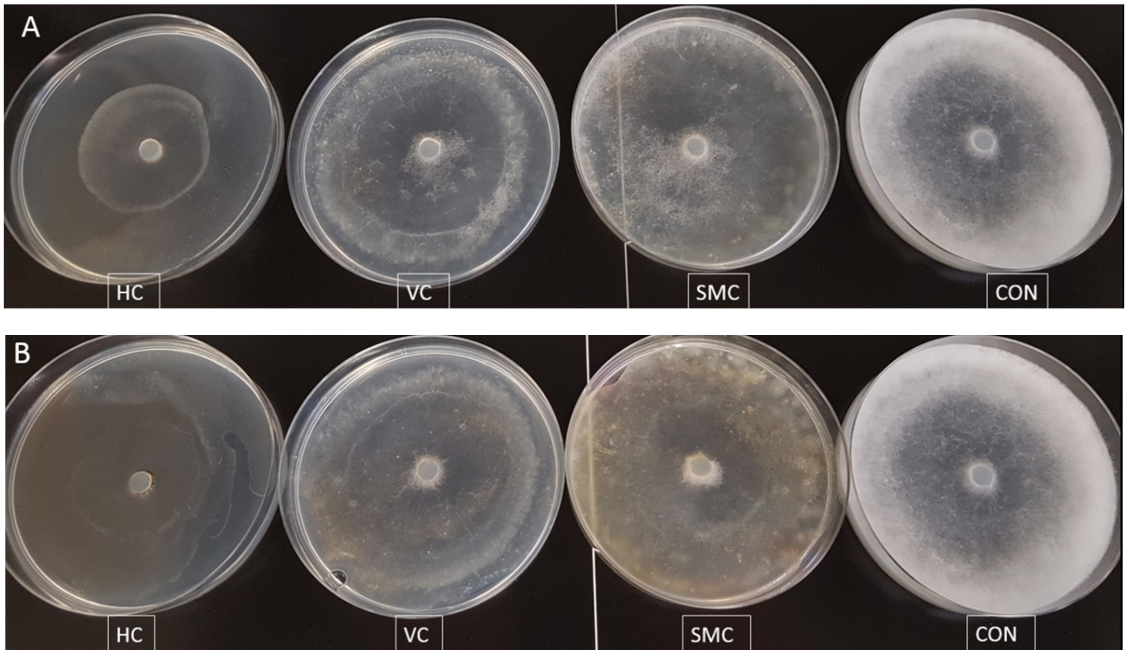

Figure 5. 1: Antagonism of 7-days compost extract against Pythium ultimum after 3 days. (A). 10 % compost concentration. (B). 20 % compost concentration. CON: Control, HC: Household-waste Compost, SMC: Spent Mushroom Compost, VC: Vermicompost.

5.3.2. In vivo test

Infection of pea seedlings by *P. ultimum* was lower in all of the tested potting media that were amended with compost, with the exception of SMC (Figure 5.2). Analysis of variance indicated that all composts had suppressive effect against *damping off* of pea. Also, different infection levels (0, 1 and 5 %) showed significant difference in pathogenicity effect on pea plants (Table 5.3).

Table 5. 3: Mean square for infection index of pea plants after 23 days

		FM (g)	**Infection index**
Source	DF	MS	MS
Replication	4	0.3 NS	0.3 NS
Compost (A)	3	89 *	2.0.*
Infection % (B)	2	36 *	4.0 *
A × B	6	10 *	1.0 *
Error	44	---	---

Means with * and NS are significant with $p \leq 0.01$ and not significant respectively.

Based on figure 5.3, among all treatments, VC had the best infection index (1.4) at 1 % infection level. The infection index for pots with 1 % infection was not significantly different between VC (1.4) and HC (1.7) but SMC (2.2) was significantly less suppressive against *P. ultimum* in comparison with VC. However, treatments with higher infection level responded differently to the composts.

Pots treated with HC showed lower infection index (1.7) than pots with VC (2.0) and SMC (2.2), but the differences were not significant at 5 % infection level. With the same infection level, all composts were significantly more suppressive against pathogen than the control. This experiment showed that all composts are suppressive against *P. ultimum*, however SMC had a significant difference for infection index with control treatment at both infection levels. Also, all compost showed similar suppressive effects among the treatments with the similar compost although with different infection level, except for VC treatment. VC was significantly less suppressive in the pots with 5 % infection as compared to the pots with 0 % infection. SMC was the only treatment which showed high amount of infection even in the pots with 0 % infection rate (Figure 5.3).

Additionally, FM was weighed after 23 days as well. The data showed significant differences among composts and also with control pots. In all pots, FM was affected by pathogen except VC with 1% infection. Instead, all treatments with no infection had significantly less FM in comparison with control pots, except for pots with VC. Figure 5.4 shows that HC and SMC produced similar fresh biomass in all infection levels, which indicates that compost, had positive effect against pathogen. That being said, in VC, the FM has decreased by an increase of percentage of infection. Moreover, the FM in sand pots with 5

% infection (1.7 g) shows that HC and VC at the same level of infection (2.9 and 4.9 g, respectively) has significantly produced more FM after 23 days (Figure 5.4).

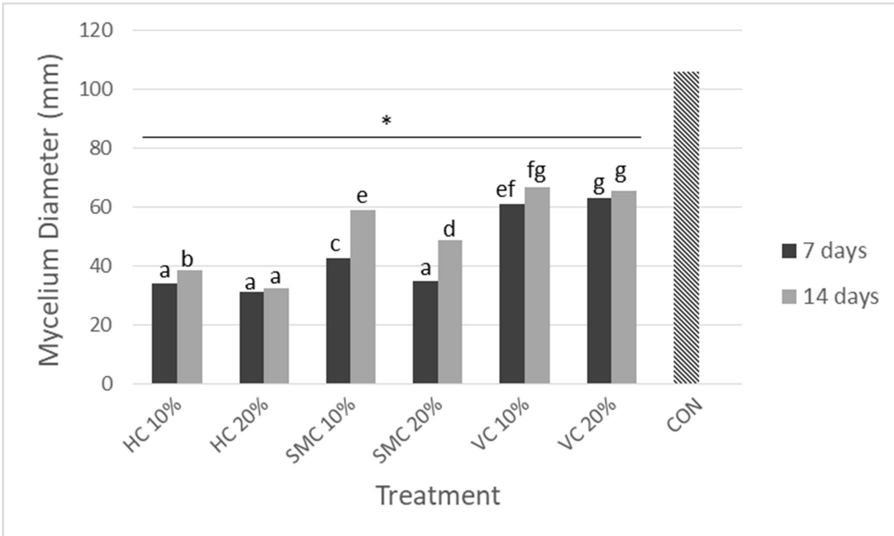

Figure 5. 2: Influence of different composts with different concentration level with 7 and 14 days of extraction on colony diameter (mm) of *Pythium ultimum* after 3 days. Means followed by different letters are significantly different and means followed by * are significantly different compared to Control ($p \leq 0.01$, LSD test). CON: Control, HC: Household-waste Compost, SMC: Spent Mushroom Compost, VC: Vermicompost. 10% and 20% are concentration level.

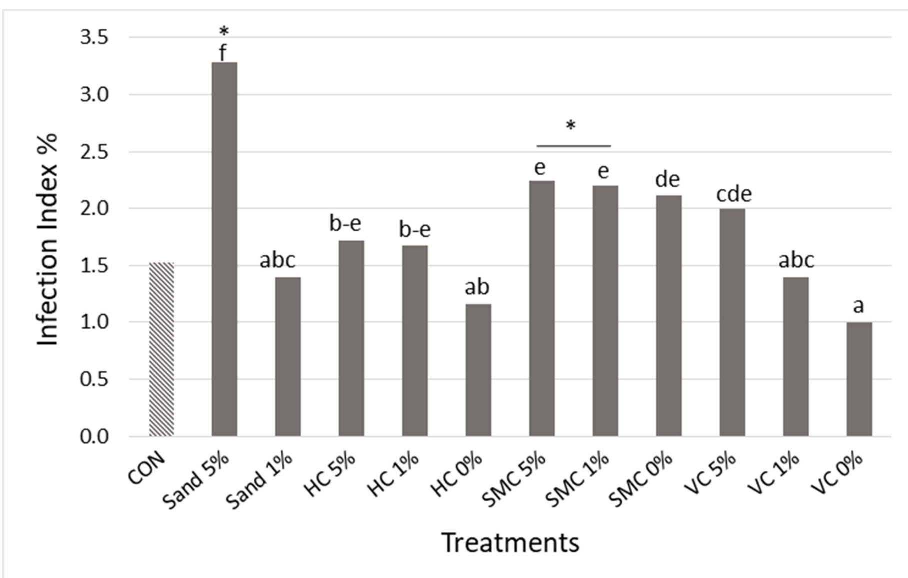

Figure 5. 3: Influence of different composts on infection index at different pots with different *Pythium ultimu*m infection levels, after 23 days. 0%, 1% and 5% are infection level. Means followed by different letters are significantly different and means followed by * are significantly different compared to Control ($p \leq 0.01$, LSD test). CON: Sand with 0% infection, HC: Household-waste Compost, SMC: Spent Mushroom Compost, VC: Vermicompost.

Figure 5.3 and 4.4 show that pots with both HC and no infection, not only had low infection index (1.2), but a low FM (3.3 g) production as well. However, this pattern did not occur in VC. Table 5.1 shows that there is no big difference in nutritional values between HC and VC, although the EC level are almost double in HC than VC (5.4 and 2.8 dS m^{-1}, respectively).

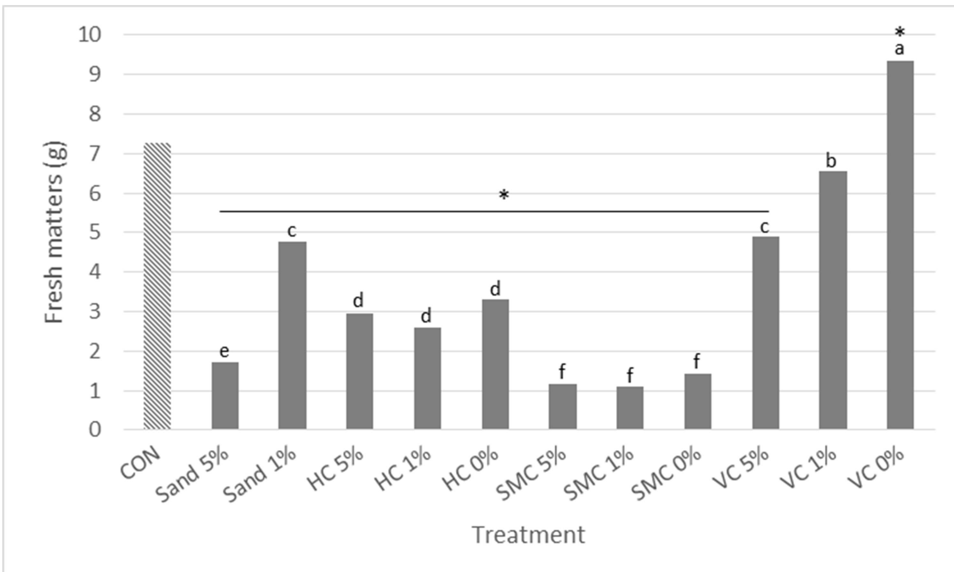

Figure 5. 4: Influence of different composts on FM (g) at different pots with different *Pythium ultimu*m infection levels, after 23 days. 0%, 1% and 5% are infection level. Means followed by different letters are significantly different and means followed by * are significantly different compared to Control ($p \leq 0.01$, LSD test). CON: Sand with 0% infection, HC: Household-waste Compost, SMC: Spent Mushroom Compost, VC: Vermicompost.

5.4. Discussion

Basing on the results of this work, compost have tested are effective against *P. ultimum*. We observed that there is a difference between composts in terms of suppressive effect against other pathogens. Several studies show variability among different composts against fungal pathogens as well. Markakis et al. (2016) illustrated that HC was effective in terms of disease incidence against *Verticillium dahliae*. They indicated that the composts originating from plant sources had longer resistance against fungi. This may be due to higher content of lignin in green composts (De Corato et al. 2016, 2018). The microbial activities in composts by production of lytic enzymes can create a variety of effects against pathogens. Moreover, competition for nutrients can have a deterrent effect on fungal pathogens (Bonanomi et al. 2007; Pane et al. 2011; Suárez-Estrella et al. 2013; Yu et al. 2015). In several experiments, heating or sterilizing treatments (Yogev et al. 2009) eliminated the suppressive effect of VC. This represents the crucial role of VC microbiota on pathogen suppression (Szczech 1999). Also, sterilized filtered compost extracts showed a reduction in their suppressive potential against pathogens (Yogev et al. 2009; Pane et al. 2013). Furthermore, the level of inhibition in composts depends on the different compost characteristics and different pathosystems response to them. Also, pathogens with diverse biology will cause different response to various diseases (Pane et al. 2013).

In vitro test showed that all different types of composts were effective against *P. ultimum*. Among them, HC were more suppressive against the pathogen in comparison with control Markakis et al. (2016) showed that VC and HC water extracts have anti-fungal activities. Other researcher indicates that bacteria from sheep compost teas are playing an effective role against mycelial growth of *Botrytis cinerea* and *Alternaria solani* in tomato production (On et al. 2015). Pane et al. 2011 showed that HC could control up to 60 % of *P. ultimum* and *Sclerotinia minor* at the same time.

In *in vitro* experiments, we found that higher concentration of compost in the liquid is more effective on disease inhibition. These data are relevant with findings from Szczech (1999), which showed that higher concentration of VC in potting media (30 %) decreased the disease incidence of *Fusarium wilt* of tomato. Also, we found that different extraction times are not effective on suppressive quality of composts against pathogen.

The greenhouse experiments had similar results. Different types of composts showed an antagonist effect against pathogen in pea plants. Overall, VC was the most effective compost against *P. ultimum* at the 1 % infection level. At the higher infection level (5 %), all composts were virtually the same.

Our findings agree with the previous observations of Markakis et al. (2016), where all compost amendments were suppressive against disease incident in most treatments. Among composts, there was no distinctive difference between treatments and control. VC was more effective against pathogen in lower infection rate, although its effectiveness still correlates with higher infection rates. Table 5.1 shows that VC has lower EC than the other composts. This can provide better basal respiration rate (BRR) for the pots with this medium. There are different studies that found a positive correlation between BRR and disease suppression in the soil (Veeken et al. 2005; Ghini et al. 2016). However, other studies indicate a negative effect between lower EC and disease suppression for *Fusarium wilt* of tomato (Cotxarrera et al. 2002) or no significant effect for EC in terms of disease inhibition for *Fusarium wilt* of lettuce (Chitarra et al. 2013). On the other hand, we are able to replace more compost in potting media when BRR is higher. Therefore, VC has a great advantage to be replaced with peat or other media in pot production systems, which will increase the level of suppression against soil borne diseases in the growing medium. Veeken et al. (2005) could increase the disease suppression against *P. ultimum* in cucumber from 31 to 94 % by increasing the compost amendments from 20 to 60 % of potting mixes.

Markakis et al. (2016) illustrated that low pH value as well as phenolic substances, ammonia and volatile fatty acids, have all suppressive effect on fungal pathogens. Compost with higher phenolic compounds, such as HC, is suppressive against fungi in comparison with composts with lower phenolic values, such as pruning residues or sewage sludge. They also observed the same effect for HC on *Verticillium wilt* of eggplant. In other experiments, treatment with bio-waste compost was effective against *V. dahlia* on eggplant. Nelson and Boehm (2002) reported that HC could suppress *Pythium root rot* and *Brown patch* in turf grass by 68 % and 25 %, respectively as well as, SMC could suppress *Brown patch* in turf grass by 25 %.

The comparison between figure 5.3 and 4.4 illustrates that FM shows a similar pattern as the disease incidence. Figure 5.4 displays that there is no significant difference between treatments with similar compost amendment with the exception of VC (figure 5.3). Consequently, VC showed lower disease index and higher FM. These two figures indicate that, despite the significant difference between treatments with HC and control in disease index, a significant difference between HC treatment and control in terms of FM production was found (Figure 5.3 and 5.4). This can be due to the higher EC level in HC (5.4 dS m^{-1}) in comparison with VC (2.8 dS m^{-1}).

5.5. Conclusion

This work showed that compost materials are effective mediums for pea protection against *P. ultimum*. All compost extracts were effective by *in vitro* test on *P. ultimum* mycelium, although HC were significantly more suppressive among all compost extracts. The diameter of mycelium in Petri dishes indicated that higher concentration of compost in the liquid and shorter extraction periods (7 days) were more effective in pathogen inhibition.

The *in vitro* test showed that the studied composts can have significant suppressive effect on mycelium of *P. ultimum*. All treatments with different composts, concentration percentage, and extraction days were significantly suppressive against *P. ultimum* in comparison with control (Figure 5.1 and 5.2).

The data collected from the *in vivo* test was slightly different. Inhibition capability of VC differed in various infection levels while both HC and SMC showed similar pattern in suppression. It was also discovered that composts with lower EC could produce more FM in comparison with other composts while the suppressive effect did not follow this pattern. From this, it is important to find the proper amount of compost for a specific plant to reach the optimal level of suppression and yield production in the future.

5.6. References

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Chapter VI

General discussion

6. General discussion

6.1. Yield aspect

The sustainability of food production is dependent on the maintenance of soil fertility in agricultural fields (Geisseler and Scow 2014). Chemical fertilizers provide short-term nutrient needs of plants in conventional farming and long-term soil fertility is voided by farmers and agricultural producers. Different studies indicated that long-term fertilization with chemical fertilizers will decrease crop yield, biological activity, soil physical properties, and increase the accumulation of nitrates and heavy metals in the soil (Ghosh and Bhat 1998; Adediran et al. 2005; Aseri et al. 2008; Yoshida et al. 2016). One of the benefits of compost is that it can provide the nutrients needed for the plant during the growing season (Abbasi et al. 2002). Furthermore, it ensures a sustainable and healthy production of tomato. Sustainable agriculture demands for more productivity and nutrient use efficiency while reducing environmental damages (Gliessman 2014). Higher available nutrients could increase yields; however the risk of losing nutrients via leaching, luxury consumption by plants or evaporation also increases.

Under the climatic condition of our field experiment, CM seemed to be more effective (in the first year or as effective (in the second year) than the other composted sources. Treatments with CM had a better yield production, which might be due to higher mineralization of organic matter in CM (Angin et al. 2017) but applying higher amounts of fertilizers did not necessarily show a significant increase on tomato yield production. This reduction is higher at SMC and HC, which can be due to the incorporation of salt into the soil. Sendi et al. (2013) reported that the replacement of 40% of SMC for Peat moss has been effective in increasing the yield, number of leaves and LAI of broccoli. However, Arthur et al.

(2012) showed that applying SMC to sandy soil has no significant effect on number of leaves or height of tomato plants. Vermicomposting has advantages over normal composting due to the interaction of earthworms and microorganisms in a non-thermophilic process. Higher plant-available forms of nutrients, such as nitrates and phosphates (Arancon et al., 2008), and greater cation exchange and water holding capacity (Hatamzadeh, 2011; Arancon et al., 2008; Azarmi et al., 2008; Atyieh et al., 2000) make VC as an effective medium in organic vegetable production. In both years VC was less yield-promoting compared to the other treatments, but with regard to the lower rate of application its efficiency has been more per unit applied composts. Arancon et al. (2003) showed that treatments with VC significantly produced higher yield and DM in tomato and pepper production in comparison with plots treated with inorganic fertilizer.

The fact that almost similar yield levels could be achieved despite the reduced amount of compost indicates valuable hint for sustainable production techniques. Nkebiwe et al. (2016) illustrated that placement of fertilizer in close distance to the plant root has increased tomato yield compared to broadcast of fertilizer. This is relevant with our finding when deep placement of compost did not significantly reduce tomato production. In our second study, due to closer distance of VC to plant roots, the level of application was reduced down to two thirds of the regular application of VC (2, 4, 6 t ha^{-1} vs. 3, 6, 9 t ha^{-1}, respectively). The results of this study showed that treatments with R and U method of application have produced higher yield compared to the other treatment in both years.

There are various studies indicating that higher rates of VC (30 % and more) in the media have increased yield of tomato and other crops (Hatamzadeh et al. 2011; Arancon et al. 2008; Gutiérrez-Miceli et al. 2007). These findings are in line with our results which indicate that higher rates of VC produce higher yield (Table 3.3). In this work, yield and DM increased in treatments with higher rates of VC and U application, as result of compost availability around the root area. That may be due to the higher availability of organic matter in rhizosphere, which could increase the water holding capacity of soil and increase yield performance (Azarmi et al. 2008; Gutierrez-Miceli et al. 2007). Treatments with U method of application show a higher DM in the second year of up to 15 %.

6. 2. Nutrient uptake and use efficiency

Sustainable production requires high nutrient use efficiency, in order to produce more yields with minimal environmental damages (Gliessman 2014). Higher available nutrients could increase yields; however the risk of losing nutrients also increases. Therefore, efficient fertilizer application is a need (Yang et al. 2017). Nkebiwe et al. (2016) showed that fertilizer placement in a relevant close distance to the plant root is an effective method to increase the nutrient uptake. Studies showed that, we cannot expect a large response to plant growth with compost application in a short period of time because compost is not a rich medium for available N. On the other hand, there are evidences indicating that compost can improve soil organic matter under long-term fertilization (Abbasi et al. 2002; von Fragstein and Schmidt 1999). On average, biologically active soils contain two million living creatures per gram of soil, which have an important role on soil fertility (Sylvia et al., 2005). There is evidence which illustrates that VC can increase root growth as a result of improving the soil environment (Padmavathiamma et al. 2008). In our study, treatments with the new method of VC application (U) showed a higher N uptake in both years as a result of an increase of microorganism growth in the rhizosphere, which may be attributed to higher availability of N in the soil and consequently enhance N uptake (Joshi et al. 2015; Padmavathiamma et al.

2008). In another study on different Amaranthus species, the results showed that using VC have increased the biomass production and yield by providing the nutrients required for them (Uma and Malathi 2009). Another study also indicated a significant increase in the yield and quality of fructan in garlic with the application of VC. They found that VC has increased non-structural carbohydrates such as fructan, by accelerating the bulb formation and their prolonged filling period (Argüello et al. 2006).

Different studies are demonstrating that VC can improve P uptake and K uptake. In our third study, treatments with the new method of VC application showed a higher P and K uptake, however, these differences were not significant (Table 3.4). Consequently, availability of VC around the root can enhance root development and available P. Heydari and Slehi (2017) illustrated that application of 15 % VC in the medium increased phosphorous uptake in (*Stachys pilifera* L.). In this regard, it has been reported that by adding compost to a cultivating system, the soil humus contributes to covering the surface of the particles and prevents the phosphorus fixation. Also, the phosphorus in VC, which is gradually mineralized and absorbed by the plant, is effective in increasing phosphorus uptake by the plant. Moreover, the availability of K in the forms which are more readily available in the soil could cause an increase in K uptake for the crop. The higher availability of K for tomatoes can be portrayed by an increase in the cation exchange capacity (CEC) by using organic fertilizers (Jeyabal and Kuppuswamy 2001).

In this study, we found a negative relationship between NUE and a higher rate of fertilizer application. Similar to the results for N, a higher rate of VC decreased PUE and KUE. This study demonstrated that different methods of application had a clear impact on nutrient use efficiency (Table 3.5). By improving the availability of nutrients in rhizosphere, the use efficiency of nutrients increases in less quantities of fertilizer application (Rengel and Damon 2008). The specific surface area of VC is very high; therefore its ability to absorb and maintain nutrients is high as well. The nitrate, as well as the exchangeable phosphorus, potassium, calcium and magnesium presented in VC, are in available forms (Edwards and Neuhauser 1998).

6. 3. Suppressive against soil-borne disease

The use of composts from residual biomass has been of growing interest for many scientists and researchers. Our study confirmed the suppressive action of composts on fungal pathogen *Pythium ultimum* (Ebrahimi et al. 2018). High biotic activities in compost cause the disease suppression nature of this substance (Szczech 1999). This is in line with our findings on the pathogen suppressive properties of compost. Different studies show that sterilizing or heating compost can reduce its disease suppressive properties (Szczech 1999; Reuveni et al. 2002; Noble and Coventry 2010).

There are different aspects effecting antagonistic characteristics of composts, such as the decomposition level of organic matter, the inclusion rate in soil or the ingredient of compost. As the decomposition level of organic matters increases, the corresponding levels of deterioration in composts increase (Noble and Coventry 2005). The decomposition level of organic matter increases the number of antagonistic micro-organisms; therefore the level of suppression will increase (Coventry et al. 2002). Coventry et al. (2002) showed up to a 50 % infection reduction for (*Sclerotium cepivorum*) in onion field.

Different studies have shown that composts could control *Pythium spp*., although the level of suppression varied due to several inoculation rates, different compost materials and methods of preparation (Ebrahimi et al. 2018). As previously shown in this study, all compost extracts were suppressive against pathogen. However, HC illustrated a higher suppression against *Pythium* for in vitro test. This finding was relevant to that of Pane et al. (2011), where HC could control *P. ultimum* and *Sclerotinia minor* at the same time up to 60 %. Markakis et al. (2016) showed that VC and HC water extracts have anti-fungal activities. Also, we found that a higher concentration of compost in the liquid is more effective on disease inhibition. This finding is similar to that of Szczech (1999), which showed that a higher concentration of VC in potting media (30 %) decreased the disease incidence of *Fusarium wilt* of tomato.

The greenhouse experiments had similar results. Different types of composts showed an antagonist effect against pathogen in pea plants. In in vivo study, all composts were virtually suppressive against *P. ultimum* at the same level with an infection rate of 5 %. Studies indicated the suppressive effects of compost are biological rather than chemical (Szczech 1999; Yogev et al. 2009; Noble and Coventry 2005). Compost has different biological mechanisms to control pathogens (Noble and Coventry 2005), such as producing anti-biotic, competition for nutrients, acting as a parasite against pathogens, activating of disease resistance genes in plants and enhancing disease resistance by improving plant nutrition (Noble and Coventry 2005; Bonanomi et al. 2007; Pane et al. 2011; Suárez-Estrella et al. 2013; Yu et al. 2015).

Table 4.1 shows, that there is no big difference in nutritional values between HC and VC, although the EC level is almost double in HC than VC (5.4 and 2.8 dS m^{-1}, respectively). A lower EC can provide a better basal respiration rate (BRR) for the pots with this medium. There are different studies that found a positive correlation between BRR and disease suppression in the soil (Veeken et al. 2005; Ghini et al. 2016). We are able to replace more compost in potting media when BRR is higher. Therefore, VC has a great advantage to be replaced with peat or other media in pot production systems which will increase the level of suppression against soil borne diseases in the growing medium. Markakis et al. (2016) illustrated that low pH value, as well as phenolic substances, ammonia and volatile fatty acids, all have suppressive effects on fungal pathogens. In this experiment, the difference in pH cannot explain suppression of the pathogen while *P. ultimum* are active in a wide range of pH levels. Hadar and Mandelbaum (1986) reported that *P. ultimum* oospores germinate at a range of pH level from 4.5 to 7.5.

Additionally, FM weight showed significant differences among composts and control pots. The results showed that HC and SMC produced similar fresh biomass in all infection levels, which indicates that compost had a positive effect against the pathogen. Moreover, the FM in control pots with a 5 % infection rate (1.7 g) shows that HC and VC at the same level of infection (2.9 and 4.9 g, respectively) have significantly produced more FM (Figure 5.4). Figure 5.3 and 5.4 show that pots with HC and no infection, not only had low infection index (1.2), but a low FM (3.3 g) production as well. However, this pattern did not occur in VC. The relative advantage of VC to HC in plant growth is due to the production of humic acid and other growth stimulants, such as plant growth hormones, during the process of vermicomposting by microorganisms. Overall, this result in increased biomass, added microbial activity and biodiversity, and improved soil fertility (Uma and Malathi 2009).

6.4. Outlook

These studies contribute to the understanding of the effects of different soil conditioners and their method of application on yield production of organic tomato that help to design practical and effective strategies to improve agro-ecosystems. However, some unresolved issues and future challenges need to be acknowledged:

1. Most importantly, it is crucial to better understand the underlying mechanisms which explain how microorganisms respond to different soil conditioners.

2. The effect of different methods of compost placement was found. Nevertheless, it is strongly recommended to conduct similar studies for different crops with different root system in different soil conditions.

3. It has been shown that tomato yield can change depending on the management strategy. It is recommended to conduct an environmental and financial cost and benefit evaluation study with regard to the U method of VC application.

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Chapter VII

Conclusion

7. Conclusion

This project presented us with the opportunity of carrying out a comprehensive review of the different types of soil conditioners, with the aim to improve organic production in semi-arid regions, such as the North East of Iran. Furthermore, we could evaluate the antagonistic effects of different composts from bio-wastes on *Pythium ultimum.*

The results of the field trial indicated that different types of fertilizers, rates and methods of application could impact the yield in organic tomato production. Under the climatic condition of the experiment CM seems to be more effect in 2014 or as effective in 2015 than other soil conditioners. In this experiment, we observed a good production potential for HC and SMC as two different soil conditioners produced from bio-wastes and industrial by-product could increase organic tomato production. It is recommended to wash SMC before applying due to its high EC level. We found that VC was less promoting in tomato yield production compared to the other composts however, with regard to the lower rate of application; its efficiency should be taken into account. The assessment of dry matter illustrated that CM is again, most promoting, followed by the other composts.

The second trial (chapter 3) was dedicated to the aspect of three placement method which was investigated by the single use of VC. This trial showed that our novel method of application (U) could achieve similar yield, DM, N and K uptake as well as higher N, P and K use efficiency despite the reduced amount of VC. This indicates valuable hints for sustainable production techniques. Deep placement of composts should be facilitated by adequate agricultural machinery when agricultural practice is not only labor-dominated. Besides, VC can be a good solution to manage the amount of fertilizer utilization due to its potential to be located at the nearest distance of rhizosphere tomato plant, while our novel method of placement could increase yield and DM by improving nutrient use efficiency.

This work could confirm that compost materials are effective mediums to suppress *P. ultimum*. All compost extracts were effective by *in vitro* test on *P. ultimum* mycelium, although HC were significantly more suppressive among all compost extracts in petri dish trials. In *in vivo* test with *Pisum sativum* indicated that VC have different inhibition capabilities against *P. ultimum* in various infection levels, while both HC and SMC showed similar pattern in suppression. Due to lower EC level in VC, the pea growth was less afflicted than after HC and SMC treatments even though the suppressive effect of the two mentioned composts were more pronounced. As many studies indicated, high level of humic acid and growth stimulants in VC could create an advantage in soil fertility and biomass production for this soil conditioner.

Important outcomes of the thesis are:

1. There is no significant difference in yield production between treatments with compost application however, CM seems to be more effective (in 2014) or as effective (in 2015) than other composts in the Iran's climatic condition. (Q1)

2. The method of placement should be selected based on the rate and type of compost. Broadcast application is more effective for SMC, VC and HC as compared to row placement (in 2014). (Q2)

3. Deep placement of VC could achieve similar yield, DM, N uptake and K uptake as well as higher N, P and K use efficiency. Due to close distance to plant roots, the rate

of application was reduced down to two thirds of regular application of VC in Iran. (Q3)

4. All compost extracts are effective against *P. ultimum* mycelium, although HC were significantly more suppressive among all compost extracts. It is found that a higher concentration of compost in the liquid and a shorter extraction period (7 days) were more effective in pathogen inhibition. (Q4)

To conclude, the study demonstrated that composts can be a good solution to manage industrial and municipal wastes by using their potential for agricultural production and soil improvement. Also, it is important to choose soil conditioners based on their chemicophysical and biological characteristics. Thus, applying more effective methods of placement can improve nutrient consumption and reduce fertilizer application. Deep placement of composts can be facilitated by adequate agricultural machineries to reduce the need for labor force to implement these methods.

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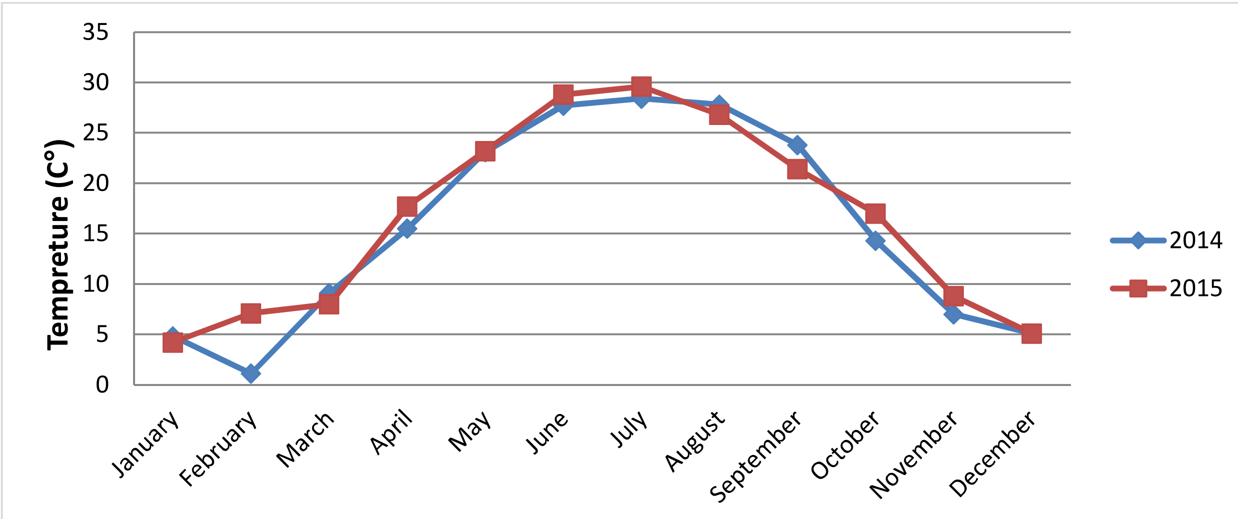
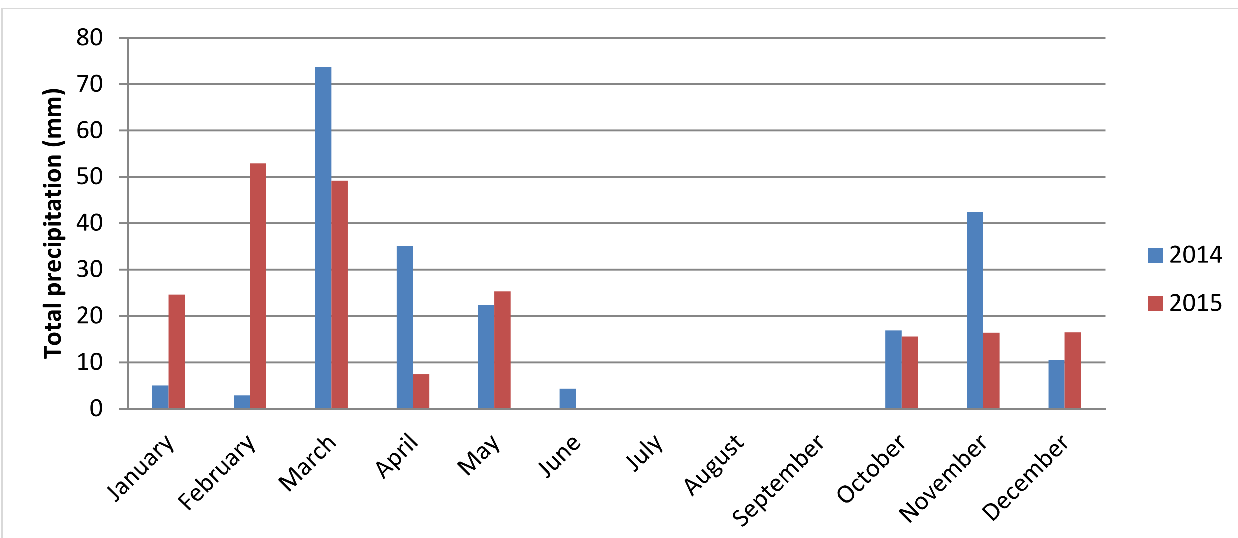
Thank you

8. Appendix

Figure 8. 1: Average temperature and total precipitation in both years





“Es ist nicht genug zu wissen, man muß es auch anwenden; es ist nicht genug zu wollen, man muß es auch tun“

Goethe