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DEPARTMENT OF BIOLOGY

GROWTH RESPONSES OF TOMATO (*SOLANUM LYCOPERSICUM* L.) TO INOCULATION OF *ARBUSCULAR MYCORRHIZAL FUNGI* AND *TRICHODERMA HARZIANUM* AND APPLICATIONS OF BIOCHAR AND COMPOST IN THE PRESENCE OF *FUSARIUM OXYSPORUM FORMAE SPECIALES LYCOPERSICI* UNDER GREEN HOUSE, HAWASSA UNIVERSITY, ETHIOPIA

BY

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March 2024

HAWASSA, ETHIOPIA

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ADVISOR's APPROVAL SHEET

This is to certify that Thesis entitled "***GROWTH RESPONSES OF TOMATO (SOLANUM LYCOPERSICUM L.) TO INOCULATION OF ARBUSCULAR MYCORRHIZAL FUNGI AND TRICHODERMA HARZIANUM AND APPLICATIONS OF BIOCHAR AND COMPOST IN THE PRESENCE OF FUSARIUM OXYSPORUM F.SP. LYCOPERSICI PATHOGEN IN THE GREEN HOUSE, HAWASSA UNIVERSITY, ETHIOPIA*****"*** submitted in partial fulfillment of the requirements for the Master's with specialization in **Applied Microbiology,** the graduate program of **Department of Biology,** and has been carried out by **BELETECH HABTE AWANO (GpApMiR/0001/14)** under my /our supervision. Therefore, I recommend that the student has fulfilled the requirements and hence thereby can submit the Thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by ***Beletech Habte*** have read and evaluated his/her thesis entitled "***GROWTH RESPONSES OF TOMATO (SOLANUM LYCOPERSICUM L.) TO INOCULATION OF ARBUSCULAR MYCORRHIZAL FUNGI AND TRICHODERMA HARZIANUM AND APPLICATIONS OF BIOCHAR AND COMPOST IN THE PRESENCE OF FUSARIUM OXYSPORUM F.SP. LYCOPERSICI PATHOGEN IN THE GREEN HOUSE HAWASSA UNIVERSITY, ETHIOPIA*** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Sciences in Applied Microbiology.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMF	Arbuscular mycorrhizal fungi
ANOVA	analysis of Variance
BIO	Biochar
C	Control
CEC	Cation Exchange Capacity
Comp	Compost
CRD	Completely randomized design
DS	Diseases severity
EC	Electrical conductivity
F.o.f.sp.l	Fusarium oxysporum formae speciales. Lycopersici
IM	Inorganic matter
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
MD	Mycorrhizal dependency
NPSB	Nitrogen, Phosphorus, Sulfur, Boron
OM	Organic matter
Pc	Pieces
PDA	Potato dextrose agar
PDA	Potato dextrose agar
Pt	Pot
SNA	Synthetic nutrient agar
SNNP	Southern Nation Nationalities and People
SOM	Soil organic matter
T.h	Trichoderma harzianum

ABSTRACT

*Tomatoes **(Solanun lycopersicum)** are one of the most widely cultivated vegetable crops in Ethiopia. Tomato yields in smallholder cropping systems are below the potential of the crop, due to pests and diseases. Therefore, the objective of this research is to study the effect of inoculation of Arbuscular mycorrhizal fungi (AMF) and Trichoderma harzianum and compost and biochar amendments on tomato biomass, fruit yield and control of Fusarium oxysporum f. sp. lycopersici pathogen under Hawassa University greenhouse. The plants were grown in plastic pots filled with sterilized soils, arranged in a fourteen treatments including the control. A completely randomized design was used and growth measurements and disease severity assessment were taken after 15, 30, and 45 days of transplantation for all growth parameters including fruit yield and effect of the pathogen were measured. During early days of growth for treatments AMF+Fusarium and AMF+Trichoderam was recorded the highest height, leaf area and stem collar diameter for Galilea variety and variable values for ROMA V.F.N variety. When compared to plants treated with F.oxysporum f.sp.l alone and control, improvement in the various growth parameters was recorded in the plants treated with AMF, T. harzianum, biochar, and compost sole and combined. Better fruit yield and pathogen resistance was recorded for Roma variety. In addition to growth parameters all AMF inoculated treatments demonstrated root colonization, and sporulated. Nutrient uptake was enhanced in all treatments except for sole Fusarium and control treatments. Mycorrhizal dependency was better for sole AMF inoculation treatment in both varieties. Disease severity was lower in ROMA variety while Galilea variety was found to be more susceptible to Fusarium pathogen. Accordingly, significant fruit loss was recorded for Galilea variety. AMF and Trichoderma inoculation and application of biochar and compost has improved performance of the two tomato varieties. In addition, it was recorded that ROMA variety is much more resistant to Fusarium pathogen as inoculated with the two bio-inoculants, which indicates that different varieties show different resistance to Fusarium pathogen. Therefore, when growing tomato it is recommended to select the appropriate bio-pesticides like that of AMF and T. harzianum and appropriate variety of tomatoes. Finally, as this study focused on only two tomato varieties and two bio-inoculants, wide coverage of other bacterial and fungal inoculants production and application in the small holder farms is also recommended.*

Key words: Arbuscular mycorrhizal Fungi (AMF), Biochar, Compost, Disease severity, *Fusarium oxysporum*, inoculation, Root colonization, spore density, *Trichoderma harzianum*

1. INTRODUCTION

1.1 Background Information

Among vegetables, tomato (*Solanum Lycopersicon*) belongs to the family Solanaceae is one of the world's major vegetables with a total area of 4.4 million ha and production of 115 million metric tons (Worku and Sahe, 2018). Tomatoes are grown for home consumption, and are important cash crops to both smallholders and medium scale commercial farmers. In Ethiopia, Oromia region constitutes the largest share of tomato production followed by Southern Nation Nationalities and People (SNNP) and the two regions contribute about 70% of the country's tomato production (the reporter Ethiopia, 2022). Even though agroecology of Ethiopia is suitable for tomato production, its annual yield could not exceed 34, 947 per year metric ton which is very small compared to other African countries (Aynalem, 2022) while neighboring Kenya producing 1056.18 million tons per year (Ofori *et al*., 2022).

Major factors that decline its production are biotic and abiotic stress. Furthermore, among biotic stress, *fusarium wilt* caused by *Fusarium oxysporum* is one of the most damaging soil borne diseases of tomato causing heavy economic losses on the plant grown (Worku and Sahe, 2018). On the other hand, abiotic factors resulting production loss include disproportional chemical fertilizer utilization, poor soil fertility management practices, and low organic fertilizer adoption trends (Aynalem, 2022). To counteract aforementioned challenges, techniques that significantly minimize ill effects of biotic and abiotic factors while keeping environmental safety become a hot research topic and therefore significant studies have been carried out. Among the ways to achieve high productivity of healthy, safe and tasty food, the use of beneficial micro-organisms as biostimulants is the most promising one compared to artificial agrochemicals; an environment-friendly approach. Therefore, the effects of microbes that can act as a pesticide and

herbicide (i.e. biocontrol) while improving soil fertility (i.e. bio fertilizers) are common approach to improve growth and productivity of tomato (Szczałba *et al*., 2019). One of such approaches is application of Arbuscular mycorrhizal fungi and *T. harzianum* as a bioinoculant and biocontrol respectively. Arbuscular mycorrhizal fungi (AMF) create symbiosis with the plant and improve mineral absorption while *T. harzianum* is an effective biological control agent, inducing the defensive response of plants and stimulates plant growth (Wanjiku *et al.*, 2021).

Another input essential for regulating nutrients in soil is biochar. It is a kind of charcoal produced from wooden biomass at low level or in the absence of oxygen (pyrolysis or charring) used for soil improvement, can sequester carbon in soil for long duration and thus decreases greenhouse gas emissions from agriculture (Mohawesh *et al.,* 2018).

Likewise, adding biochar to soil can improve its chemical, biological, and physical characteristics as well as boost nutrient availability by lowering nutrient leaching. According to Tripura, (2022), it additionally facilitates the chemical and biological breakdown of pesticide residues. It also has the ability to lower soil bulk density, raise soil water retention capacity, improve pH and cation exchange capacity (CEC), and improve soil water retention. According to Herrmann *et* a*l.*, (2019), it prevents some foliar and soil-borne infections and raises the pH of acidic soils while also increasing agricultural production. These extra characteristics imply that adding biochar to the soil as an amendment could improve its agronomic productivity.

Another serious concern in conventional farming is excessive application of inorganic fertilizers to increase crop production. However, along term usage of inorganic fertilizer could reduce soil fertility and crop productivity (Hashimi and Habibi, 2021). Therefore, use of compost improves the chemical and physical characteristics of the soil, thereby increasing the growth and yield

characters of crop (Dang *et al.*, 2022). Therefore, in recent years' soil quality and its importance for sustainable agricultural development has received growing attention as soil chemical and physical properties directly affect plant production (Adugna, 2016).

Organic farming system aims in producing healthy food and sustaining healthy ecosystems. In this farming system farmers use compost, green manure, and crop rotation including legumes instead of chemical fertilizers to maintain soil fertility and high yield (Baghdadi *et al.*, 2018). Studies show that compost applications can increase soil organic matter (SOM) and crop yields and sustain soil fertility as well (Pepper *et al.*, 2014).

Furthermore, harnessing the potential of soil microorganisms such as AMF and *T. harzianum* as biofertilizers to reduce the application of inorganic fertilizers and as biopesticides to reduce the application of hazardous pesticides in the production of food crops and vegetables is the growing biotechnological approach. Besides, the application of organic matter in the form of compost, and biochar supplement the soil environment with necessary nutrients and improve the soil structure.

1.2 Statement of the Problem

In Ethiopia, reliance on chemical fertilizers, a lack of biocontrol-based disease management plans, and environmental conditions are the primary factors influencing production and hampering the ability to satisfy consumer demands. Furthermore, an increasing tomato consumption combined with unfavorable climatic conditions and devastating plant pathogens necessitates development of urgent mitigation strategies that can boost production while improving fruit quality in Ethiopia. From the surveyed literature, for example, in (Alehegn *et al*., 2022; Getachew & Gemechu, 2019; Worku & Sahe, 2018), the *Fusarium oxysporum* that cause *fusarium wilt* reduces tomato production by 80-100 % if no control measures are taken. Hence, controlling this pathogen becomes an urgent research issue to sustain tomato production targets of agricultural sector. To enhance tomato yield while controlling disease requires a combination of possible control measures such as cultural, biological and use of botanicals.. Specifically, exploiting microbes as bio-controllers and bio-fertilizers and enriching the soil by organic soil amendments creates a conducive symbiotic rhizosphere around the plants. However, the combined effect of mycorrhizal inoculation, *Trichoderma*, biochar, and compost application in tomato growth, productivity and pathogen inhibition potential is not well researched in Sidama Regional State and elsewhere.

Therefore, this research aims to investigate the effects of AMF and *T. harzianum* inoculation and application of biochar and compost in enhancing growth and controlling tomato disease in the greenhouse of Hawassa University.

1.3 Objectives

1.3.1 General Objective

The general objective of this research work is to investigate growth responses and diseases resistance ability of tomato to inoculation of AMF and *T. harzianum* and applications of Biochar and compost in the presence of *Fusarium oxysporum* f.sp. *Lycopersici* pathogen under greenhouse condition.

1.3.2 Specific Objectives

To achieve the main objective of the research the following specific objectives are set out.

- To compare the effect of bio-inoculation, application of biochar, and compost on tomato plant during growing time intervals.
- To evaluate the impact of *T. harzianum*, AMF, and biochar on growth and yield of tomato in a greenhouse conditions.
- To investigate the effect of *T. harzianum* and AMF inoculation on pathogen resistance of tomato plant.
- To evaluate the efficacy of *T. harzianum* and AMF inoculation and application of biochar and compost on AMF root colonization, spore density, and mycorrhizal dependency of the plants.
- To investigate effect of bio-inoculation, application of biochar, and compost on plant nutrient uptake

1.4 Research Questions

- What are effects of bio-inoculation, application of biochar, and compost on tomato plant during growth durations?
- What is the impact of *T. harzianum*, AMF inoculation and biochar application on growth and biomass yield of tomato in a greenhouse conditions?
- Does *T. harzianum* and AMF inoculation and application of compost and biochar reduce pathogen infestation of tomato plant?
- How *T. harzianum* and AMF inoculation and application of biochar and compost application on improved AMF root colonization and spore density in tomato plant?
- Do bio-inoculation, application of biochar and compost improve plant nutrient uptake?

1.5 Significance of the study

The responses of tomato to inoculation of AMF and *T.harzianum*, as well as applications of biochar, and compost in the presence of *Fusarium oxysporum* f.sp. *Lycopersici* in the green house, is evaluated and investigated in this study. As a result, the findings of this study contribute to the resilience of the farming system, farmers, and the environment by reducing the use of inorganic fertilizers and pesticides with residual effects that may jeopardize human and environmental health. Finally, the findings of this study can be used as a juncture point for environmentalists, agricultural sector, researchers as well as government to draft new policies as its significant contribution.

1.6 Scope of the study

This research work targets on the study of responses of tomato to inoculation of AMF and *T.harzianum* while providing soil amendments compost and biochar in presence of *F.oxysporum.f.sp.l* under green house. Hence, its study scope do not encompasses field level based investigations. For the investigation purpose, even though numerous tomato varieties exist in our country, Ethiopia, only two predominant tomato varieties were chosen as a candidate. Their performance investigation focused on plant growth, nutrient uptake, pathogen inhibition, and yields per plant for two widely adopted tomato varieties. Other phenotypic and genotypic assessment variables are out of the bound of this research.

1.7 Limitation of the study

As the study focus on impact of selected parameters on plant is the main goal; their influence on each other before applying to the plant need to be studied. Variable environmental elements may make it difficult to transfer results from controlled greenhouses surroundings to field situations. To transfer to realistic farming system, constraints for significant field testing, scalability of results could be hindrance of implementation of this findings on the realistic situations.

2. LITERATURE REVIEW

In this chapter review of existing works on tomato productivity, applications of bio controllers and biofertilizers is presented. To provide an overall progress made yet and the research gaps are also pointed out.

2.1 Tomato (*Solanum lycopersicum L.*)

Tomato is originated in Peru of South America and name of crop came from the Aztec word "Tomato"(Abreu et al., 2008). Early domestication was undertaken by the Native Americans. The first encounter with tomato by Europeans appears to be during a voyage by Cortez in 1519, when he acquired some tomato plants in Mexico (Saavedra*et al.*, 2017). The crop is of recent origin and first report of tomato was from Italy in 1544 (Razdan, 2006). Later spread was fast and the crop is grown throughout the length and breadth of the world. Tomato planting practices introduction dates in Ethiopia is between 1935 and 1940 (Asfaw, 2021).

Tomato occupies a prime position in list of protective foods since it is a rich source of minerals like calcium (48 mg / 100g), sodium (12.9 mg), and copper (0.19 mg). It also consists of vitamins(A, C, B, complex (thiamine)), essential amino acids, and healthy organic acids like citric, formic, and acetic acids (Guo*et al*., 2021).Tomato is a good appetizer and its soup is a good remedy for preventing constipation (Pepper*et al.*, 2014).

Tomato yields in smallholder cropping systems are generally far below the potential of the crop, due to low quality seeds, poor crop husbandry and pests and diseases (Chehri, 2016).The average yield of tomato in Ethiopia is low (8 ton ha-1) compared with world average yields of 34 ton ha-1 (FAO, 2008). This may be related to limited access and use of improved commercial tomato varieties, adaptation and poor production management. As a result of these, different

experiments were conducted in regions and across regions by researchers and higher learning institutions. Under open field and greenhouse condition at JUCAVM, tomato varieties Marglobe and Moneymaker in greenhouse showed the highest total fruit yield per plant (Getachew and Gemechu, 2019)

Tomato production in greenhouses has attracted attention in recent years, based on the perception that greenhouse tomatoes can be more profitable than agronomic crops or horticultural crops in the open field (Medina Saavedra*et al.,* 2017)

2.2 Arbuscular Mycorrhizal (AM) Fungi

The term "mycorrhiza" was first coined by Albert Bernhard Frank to describe the symbiotic association of plant roots and fungi. Mycorrhiza literally means "fungus root" (Frank, 2005).Mycorrhiza results from mutualism between roots of higher plants and certain fungi. These fungi in soil are ubiquitous throughout the world and form symbiotic relationships with the roots of most terrestrial plants (Pepper *et al*., 2014). Therefore, it could be said that mycorrhizal association is almost universal phenomenon in plant kingdom (Bagyaraj, 2011). The most common mycorrhizal association occurring in crops important in agriculture and horticulture is the arbuscular type 'fungus roots' biotic association of plant roots and fungi.

AMF belongs to an endomycorrizas from the *Glomales* order. It is one of the beneficial microbiotas which has symbiotic association with most of the plants in agroforestry *(Diagne et al.*, 2020). Both organisms establish a specialized connection in which a bidirectional transfer of nutrients occurs, the host supplies carbohydrates to the fungus, while the fungus transport nutrients such as P, Ca, Cu, and Zn that the plant requires with help of ramifying fine absorbing hyphae (Mahdi *et al*., 2010). This association allows the plant to increase size, mass, seed

production, resistance to pests, and drought allowing them to guarantee their establishment and success in disturbed site (Szczałba*et al.*, 2019).

AMF helps plants to cope with biotic and abiotic stresses such as salinity, drought, extreme temperature, heavy metal, diseases, and pathogens (Begum *et al.*, 2019). For abiotic stresses, the mechanisms of adaptation of AMF to these stresses are generally linked to increased hydro mineral nutrition, ion selectivity, gene regulation, production of osmolytes, and the synthesis of phytohormones and antioxidants. Regarding the biotic stresses, AMF are involved in pathogen resistance including competition for colonization sites and improvement of the plant's defense system (Diagne *et al.*, 2020).

AMF may both assist host plants in the up-regulation of tolerance mechanisms and prevent the down-regulation of key metabolic pathways (Turrini*et al.*, 2018). AMF, being natural root symbionts, provide essential plant nutrients to host plants, thereby improving growth and yield under unstressed and stressed regimes (Mohandas, 2012).

The role of AMF as a bio-fertilizer can potentially strengthen plants' adaptability to changing environment(Sasvári *et al.*,2012). Application of AMF increased growth due to improved phosphorous and micronutrient uptake in the host tomato plant (Mwangi *et al.*,2011).

2.3 *Trichoderma*

Trichoderma spp. (perfect stage: Hypocrea) are a widely studied filamentous ascomycetous fungus used as a biocontrol agent against major phytopathogens(Nafady et al., 2022). In addition to acting as direct biological control agents, they also act as plant growth promoters, by an indirect biological control mechanism (Lima et al., 2022). Because of these, many products

containing *Trichoderma* strains are used to improve seed health, providing better development of roots and aerial parts of plants (Pandey*et al*.,2021).

They comprise different economically important species, such as. *T. harzianum, T. asperellum, T. viride, T. atroviride, T. virens, and T. reesei* (Povedae*t al.,* 2019).They are an omnipresent mycoflora and major colonizers of numerous soils in all the ecosystems and different agroclimatic zones (Aynalem, 2022). These species are known for their ability to colonize cellulosic materials and, in the rhizosphere of plants, can induce systemic resistance against plant pathogens(Wanjiku*et al.,* 2021).

Trichoderma produces a variety of molecules that can be used in different combinations depending on the target namely be the competitive micro-organism or the host plant(Sani *et al.*, 2020). Mechanisms of anti-pathogen activity *Trichoderma* include antibiosis, covering production and secretion of compounds inhibiting phytopathogens such as lipolytic, proteolytic, pectinolytic and cellulolytic enzymes, which degrade pathogen cell walls (Awad-Allah et al., 2022).*Trichoderma* also induce antioxidant enzymes in plants under stress(Galindo et al., 2018). Investigations into the effects of the *T. harzianum* against *R. solani* in tomato plants showed that the protection provided by *Trichoderma* was associated with increasing activities of ascorbate peroxidase, guaiacol peroxidase, superoxide dismutase and catalase at the early stage after pathogen challenges (Mironenka *et al.*, 2021).

By virtue of their high antagonistic and mycoparasitic potential, some Trichoderma strains encompass the ability to decrease the severity of plant diseases by inhibiting plant pathogens, mainly in the soil or on plant roots(Wanjiku *et al*., 2021). They do control a wide range of plant pathogens, including fungi, bacteria, oomycetes, and even viral diseases, through elicitation of

induced systemic resistance or localized resistance. They have antagonistic effects on soil borne fungal plant pathogens belonging to different groups and also foliar fungal plant pathogens (Galindo *et al.*, 2018). They are well known as a proficient biocontrol agent because of their high reproductive capability, ability to stay alive under very adverse conditions, effectiveness in nutrient utilization, ability to alter the rhizosphere, sturdy aggressiveness against plant pathogens, and efficiency in promoting plant growth and defense mechanisms (Fraceto *et al.*, 2018).

According to (Mwangi *et al.*, 2011) *T. harzianum Rifai* have been known to show antagonism to various root pathogens such as *Pythium spp., Rhizoctonia spp, and Fusarium spp*. The best way to control the disease is by selecting resistant varieties of tomatoes (Ayana and Gabrekiristos, 2022).*T. harzianum* establishes well in the rhizospheric region and assists the progress of the positive interaction with plants because of the availability of fungal prey and root-derived nutrients (Cubillos-Hinojosa*et al*., 2009). Also some rhizosphere-competent Trichoderma strains have been shown to have direct effects on plants increasing their growth potential and nutrient uptake, (Ozbay and Newman, 2004) and stimulation of plant defenses against biotic and abiotic damages (Khan*et al*., 2017).

Abiotic stresses, like heat, drought, cold and salinity cause serious losses in crop plants. Studies performed (Poveda *et al.*, 2019) tomato seeds treated with *T. harzianum* germinated faster than untreated ones under osmotic, salt or suboptimal temperature stress conditions. The researchers in (Awad-Allah *et al.*, 2022) showed that effective applications of *Trichoderma* isolate especially *T. viride* and *T. harzianum* are antagonistic against the *F. solani* pathogen which cause *Fusarium wilt* disease; while simultaneously promoting the growth and development of cherry tomatoes.

2.4 Compost

Long term usage of inorganic fertilizer could reduce soil fertility and crop productivity. Hence, compost or organic matter becomes more preferable. Compost consists of the relatively stable decomposed organic materials resulting from the accelerated biological degradation of organic materials under controlled, aerobic conditions (Adugna, 2016). The decomposition process converts potentially toxic or putrescible organic matter into a stabilized state that can improve soil for plant growth. Advantages of compost includes addition of nutrients to soils, increasing SOM, improving water holding capacity and other physical properties of soil such as bulk density, water retention, and penetration resistances (Dang *et al.*, 2022). By playing these roles it improves both the chemical and physical characteristics of the soil, thereby increasing the growth and yield characters of crops (Baghdadi *et al.*, 2018). By applying an adequate amount of chemical fertilizer in combination with organic fertilizers has shown an improvement in plant growth as well as yield in tomato according to (Hashimi, 2021). As pointed out in (Adugna, 2016), soil organic matter contains more than 95% of N and S as well as up to 25% of P nutrients in non-cultivated soils.

Proper application of compost can increase the activities of soil microorganisms and enzymes and soil available nutrient contents (Agegnehu, 2022). Due to its multiple positive effects on the physical, chemical and biological soil properties, compost contributes to the stabilization and increase of crop productivity and crop quality (Ali Salim *et al.*, 2017).

Long-term field trials proved that compost has an equalizing effect of annual/seasonal fluctuations regarding water, air and heat balance of soils, the availability of plant nutrients and thus the final crop yields (Meresa and Gebremedhin, 2020). For that reason, a higher yield safety can be expected compared to pure mineral fertilization.

2.5 Biochar

Biochar is a short form of coal that refers to the solid product of bio-organic materials (biomass) produced by thermal pyrolysis under the circumstance of little or no oxygen. It is defined as an organic, low-density, carbonaceous product obtained from the pyrolysis of organic materials under limited oxygen conditions, where coproduced biogas and bio-oils can be used for energy (Paz-Ferreiro *et al.*, 2014).

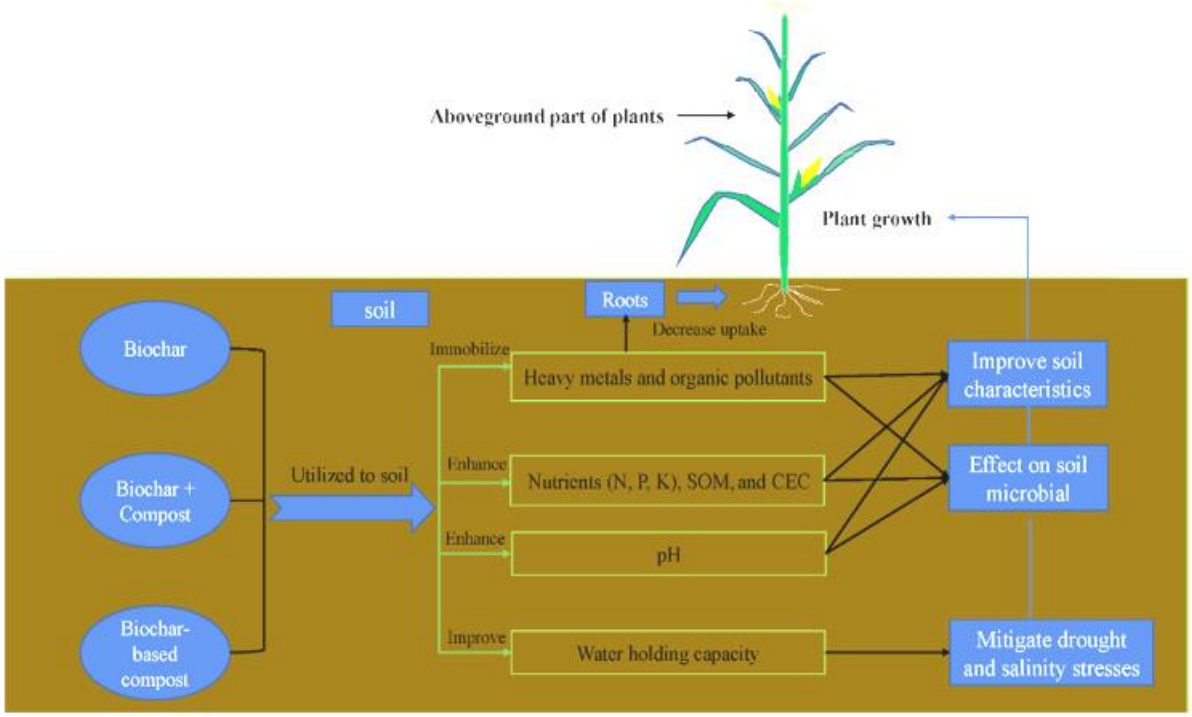

Figure 1. Effects of Biochar in plant growth (Paz-Ferreiro *et al.*, 2014)

The application of biochar in degraded soil can change the physicochemical properties of the soil, increase the nutrient availability by reducing nutrient leaching, and promote the chemical and/or biological degradation of pesticide residues as shown in Figure 1. In (Singh *et al.*, 2022), from a meta genesis analysis of 59 literature published between 2012 and 2021, summarized that biochar increased soil pH, cation exchange capacity, and organic carbon by 46%, 20%, and 27%, respectively, with greater effects in coarse and fine-textured soils. It is claimed that application

of biochar improves soil fertility, fertilizer use efficiency and crop productivity, particularly when biochar is combined with organic amendments such as compost (Agegnehu, 2022).

Similarly, Almaroai & Eissa (2020) reported the effect of biochar on yield and quality of tomato grown on a metal contaminated soil. In our country's context (Garamu Urgessa, 2021) studied an impact of different source and rates of biochar application on the yield and yield components of mungbean on the acidic soil in western Ethiopia

Biochar can improve the hydrolysis reactions of urea and the oxidizing ability of soil microorganisms by increasing the activity of urease and catalase (Yusif *et al.*, 2019). The biochar addition increases the P available for plant growth due to increased phosphatase activity, and improves soil nutrients by increasing the abundance of soil microbial (fungi, bacteria, and actinomycetes).

The application of biochar as a soil amendment to the soil can improve soil biological characteristics by enhancing soil microbial functional activity and changing the community structure (Conversa *et al*., 2015). Two-year greenhouse experiments containing six biochar levels and two nitrogen fertilizer application rates (190 and 250 kg ha−1) were conducted, improved the nitrogen and phosphorus uptake by tomato plants and enhanced the photosynthetic traits of tomato leaves, stomatal conductance, transpiration rate and chlorophyll which lead to the highest gains in tomato yield ,even when the applied nitrogen fertilizer was significantly reduced (Guo *et al.*, 2021).

2.6 Interaction between *T. harzianum* and AMF

Detailed understanding on interactions of the two species as part of ecosystem processes is essential for obtaining the maximum benefit for plant growth and health in the context of soil-plant system sustainability. The character of AMF, TR and plant interactions are sustainable and ecological in agriculture because these organisms are safe for humans, crop plants and agricultural systems (Szczałba *et al.*, 2019).

Production of the tomato is commonly affected by different diseases such as early blight pathogen (*Alternaria solani), Furasium* wilt and root rot to name a few. For example in (Ayana and Gabrekiristos, 2022) tried to evaluate the efficacy of some five fungicides with the objectives to assess in vitro efficacy of fungicides on the growth and sensitivity of pathogens, *in vitro* tolerance of pathogens to fungicides, and their effectiveness as potential foliar sprays against *A. solani*. From this evaluation researchers observed the significant percentage reduction in the growth of *A. solani* record with Orozole 25 EC followed by Agro Laxyl MZ 63.5 WP respectively resulting in 100% and 56.5% mycelia growth inhibitions.

Authors (Nzanza *et al.*, 2012) assessed Mycorrhizal and *Trichoderma* root colonization, vegetative growth, fruit yield and quality of tomato under field conditions in two cycles: 2008-2009, and 2009-2010 growing season in South Africa and generated their conclusion by stating: *T. harzianum*-inoculated plants had more than 85% root colonization and AMF-inoculated plants had root colonization above 20%, their uninoculated counterparts had root colonization of less than 10% and 1%, respectively .and the shoot to root ratio was unaffected by the combined treatment. Similar to this, the AMF alone or in combination with *T. harzianum* increased tomato early output by 70% and 64%, respectively, during the first and the second tomato seed growing seasons.

In fact, most of the increased yield associated with AMF was either due to its potential to alleviate stress such as severe drought, salinity, or disease incidence (Begum *et al.*, 2019). For example, AMF increased fruit yield of salt stressed tomato plants but not that of non-stressed plants (Nzanza *et al.*, 2012) whereas observed higher yields in AMF-inoculated plants than in uninoculated plants. According to (Kabdwal *et al*., 2019) survey revealed that occurrence of late blight, early blight, stem rot, and wilt diseases causing an average loss of 80% to tomato. To counter this diseases, *Trichoderma harzianum* (Th43), *Pseudomonas fluorescens* (Pf173), Jas mycorrhiza (AMF), and the fungicide (Mancozeb) in different combinations applied through soil application, seedling treatment and foliar spray were evaluated for growth promotion and disease control in tomato at experimental and farmers' fields

2.7 Interaction between Biochar and Microorganisms

Due to high thermal production process biochar is usually considered as free from indigenous microbial community. However, its addition to soil induces important traits to soil microbes hence to crops enhancing yields, develops resistance to plant pathogens, and improve quality. According to researchers in (Singh *et al.*, 2022) biochar prepared at lower pyrolytic temperatures (<500 °C) had a greater effect on microbial diversity (both bacterial and fungal), with more diverse bacterial populations in medium and coarse textured soils, while fungal diversity increased in fine textured soils (Ding *et al.*, 2022).

In Sani *et al* (2020) the growth, yield, and antioxidant properties of tomatoes, as well as their mineral composition, were analyzed. From the analysis they have showed that the combined application of Trichoderma and biochar increased the growth attributes positively and produced 101.45% and 11.33% higher yield compared to half dose and standard dose of N-P-K, respectively. The combination *Trichoderma* and biochar has improved soil fertility, nutrient

uptake and promoted the growth of rhizosphere fungal and bacterial populations, which combined resulted in higher tomato yields, antioxidants, and minerals (Simiele *et al.*, 2022) Therefore, the co-application of Trichoderma and biochar with a 50% dose of N-P-K can be considered an effective technique for the sustainable production of tomato with higher yield and superior quality (Sani *et al.*, 2020).

Some reports emphasize that biochar amendments can increase AMF % root colonization in plant roots(Elmer and Pignatello, 2011)grown in acidic soils (Yamato *et al.*, 2006). Improved colonization was also found due to decreased infection of plant pathogens after addition of AMF and biochar as activated carbon similar to biochar. Inhibited colonization after biochar amendment might be due to improved availability of P (Warnock *et al*., 2007).

2.8. *Fusarium oxysporum f. sp. Lycopersici*

F. oxysporum is a widespread soilborne plant pathogen, which causes diseases such as vascular wilt and crown and root rot (Worku and Sahe, 2018). The species delimitation has been defined according to morphological and physiological characteristics; with strains of *F. oxysporum* classified into formae speciales on the basis of pathogenicity on a particular host plant and races based on differences in virulence to given host cultivars (Hibar *et al.*, 2007). There are over 120 described formae speciales and races (Reads, 2018).One of these formae speciales is *Fusarium oxysporum* Schlect f. sp. radicis-lycopersici Jarvis and Shoemaker, which causes *Fusarium* crown and root rot of tomato.

Fusarium wilt of tomato caused by *Fusarium oxysporum* f. sp. *Lycopersici*, is one of the most prevalent, serious diseases of tomato (Reis *et al.*, 2005). It is also on economically important wilting pathogen of tomato in Iran (Chehri, 2016). The pathogen occurs throughout most tomato-growing areas worldwide causing a vascular wilt that can severely affect the crop (Moretti *et al*.,

2008) and the disease is considered as one of the main soil-borne systemic diseases. It causes significant losses in tomato production both in greenhouse and field–grown tomates (Ozbay and Newman, 2004).Several disease management strategies are available e.g. cultural technique, biological control, resistant cultivars, crop rotation and chemical control. Resistant cultivars are the most effective measure of controlling *Fusarium wilt* (Mwangi *et al.*, 2011). Alternative methods of controlling the disease have to be explored inclusive of biological control methods. Adding biocontrol agents directly to the roots is an efficient and inexpensive means to provide a more vigorous transplant with disease protection when it is transplanted in the field rot (Worku and Sahe, 2018). *T.harzianum,* that are common inhabitants of the rhizosphere are biological control organisms against *F. oxysporum f. sp.lycopersici* and also have been known to provide plant growth promotion (Wanjiku *et al*., 2021).

3 MATERIAL AND METHODS

3.1 Description of the study area

Hawassa University Main Campus is located north of Hawassa on the highway that connects to Addis Ababa, the capital city, with the southernmost town of Moyale on the Kenyan border in the Ethiopian rift valley, 275Km south of Addis Ababa and lies between $7^0 3' 1.35'' N$ latitude and $38^0 29' 43.81'' E$ longitudinal with an altitude of about 1736 meters above sea level. The research was conducted at Hawassa university research village under greenhouse that found the eastern corner of the main campus.

3.2 Collection of experimental samples

Tomato seed variety of Roma V.F.N and Galilea obtained from the southern agricultural research center were used as experimental plants. The AMF; mixtures of *Gigaspora rosea* and *Rhizophugus clarus* were obtained from Hawassa University, Department of biology, isolated and identified from Sidama agroforestry (Dobo *et al.,* 2018). The biocontrol fungi *T. harzanium* was obtained from Addis Ababa University, previously isolated and preserved in the University laboratory. *Fusarium oxysporum* f.sp. *Lycopersici* pathogen was isolated from Hawassa University research field from tomato plants that has shown signs of wilting and has a brown discoloration of vascular vessels. Compost was obtained from the nearby smallholder farms, and wood biochar obtained from the market.

To produce AMF inoculum, seeds of *Sorghum bicolor* was collected from the southern agricultural research center. For the greenhouse trials, 180 Kg soil sample was collected from 4 locations in Hawassa University research field at 0-20 cm depth. After collection, the soil sample was steam sterilized using autoclave at $121^0 C$ and 15Lb pressure for 15 minutes. The soils were left for a period of one week to allow for escape of volatile poisonous substances produced

during process of sterilization and samples were dried in a glass house. Then, the samples were pooled and collected in alcohol sterilized poly ethylene plastic bags for their process in green house condition.

3.3 Experimental Design

The greenhouse experiments were set up in a completely randomized design (CRD), with 14 treatments (including the control) replicated three times (Table 1). The treatments include AMF, *T. harzianum* and *F.oxysporum.f.sp.l* inoculation; biochar and compost application and their combination as shown in Table 1.

Table 1 Treatments in the experimental design.

Tomato	Treatments	Replication
Pt_1	Sole AMF	3
Pt_2	Sole *T. h*	3
Pt_3	Sole Compost	3
Pt_4	Sole Biochar	3
Pt_5	AMF+ *T.h+ F.o.f.sp.l*	3
Pt_6	AMF+Comp+ *F.o.f.sp.l*	3
Pt_7	*T.h+ F.o.f.sp.l*	3
Pt_8	AMF+ *F.o.f.sp.l*	3
Pt_9	AMF+Bio+ *F.o.f.sp.l*	3
Pt_{10}	AMF+*T.h*+comp+ *F.o.f.sp.l*	3
Pt_{11}	AMF+T.h+Bio+ *F.o.f.sp.l*	3
Pt_{12}	AMF+*T.h*+Bio+Comp+ *F.o.f.sp.l*	3
Pt_{13}	*F.o.f.sp.l*	3
Pt_{14}	Control	3

Key: Pt=pot treatment, AMF=Arbuscular mycorryzal fungi, *T.h=Trichoderma harzanium*, Bio=Biochar, Comp=Compost, *F.o.f.sp.l=Fusarium oxysporum formae speciales lycopersici* C=control

3.4 Preparation and Germination of tomato seeds

Tomato seeds of cultivar Galilea and Roma V.F.N were surface sterilized in 1% solution of sodium hypochlorite for 30 seconds and rinsed thoroughly several times with distilled water; and then dried with sterile blotting paper. The seeds were then germinated in 15 x 20 x10 cm trays containing sterilized sand.

Twenty-day-old tomato seedlings, two per pot, were transplanted into plastic pots containing 2 kg sterilized sand-clay-loam soil and each treatments.

3.5 Preparation of Inoculants

3.5.1 AMF Inoculum

AMF inoculums production is carried out in association with the host plant *Sorghum bicolor* in pot culture, as methods for the production of AMF in the artificial media is not yet established. A mixture of AMF previously isolated were multiplied on the roots of maize plants.

The plants were allowed to grow for 45 days after which the fine roots were persevered, substrate containing root fragments, mycelium, and spores were collected, and air dried and ultimately used as a crude inoculum. Then, the seedlings of tomato were transplanted with mycorrhizal inoculums (100 g) containing the Sorghum root fragments, mycelium, and spores in plastic pots containing 2 kg soil. The spore count in the crude inoculums was 255/100 g dry soil.

3.5.2 Trichoderma harzianum inoculum

The *T.harzianum* isolate was obtained from Addis Ababa University. The isolate was cultured on PDA at 25^0C for 4 days. 39 g of PDA powder was weighed and dissolved into 1 liter of distilled water and stirred using a magnetic stirrer in a mild temperature until the mixture dissolved. The

mixture was then autoclaved at 121°C and 15 lb pressure for 30 minutes *(Xue et al.,* 2021). A sterile sharped, straight inoculating wire was used and gently scratched on the grown colony formed from the former petri dish and transferred to the new PDA media petri dish in zigzag drag pattern and then incubated in inverted position at 25 °C for seven days. After seven days of incubation, *T. harzianum* spores were collected by topical scratch and addition of sterile distilled water and filtered through sterilize gauze. The obtained concentration was adjusted to 10^6 spores/ml according to (Cubillos *et al.,* 2009). In 2 kg pots full of sterilized soils 50 ml of *T. harzianum* is immersed and then transplanted.

3.5.3 Preparation of Fusarium oxysporum f.sp. Lycopersici

Fusarium oxysporum f.sp. *Lycopersici* was isolated from diseased tomato plants that has shown signs of wilting and has a brown discolouration of vascular vessels. The roots were cleaned, and cut into 1 cm long pieces using a sterile blade. The pieces were sterilized using 0.5% sodium hypochlorite solution for 30 seconds to remove surface contaminants, then rinsed in sterile distilled water, and dried using sterile filter paper. Then, the pieces were plated on PDA for seven days at room temperature (22-23^{0}C). To suppress bacterial contamination, an antibiotic chloramphenicol was added to media at a concentration of 0.5 mg per liter of molten PDA. Colonies with colony morphology of *Fusarium* was sub cultured for seven days on synthetic nutrient agar (SNA) that allows sporulation of *Fusarium*. A portion of mycelia were picked and stained with lactophenol and the fungus was identified according to (Nelson*et al.,* 1983).An agar block of the pathogen was preserved on PDA in universal bottle at 4^{0}C.

The spores were collected by topical scratch and addition of sterile distilled water, and filtered through sterilize gauze. The obtained concentration was adjusted to 10^6 spores/ml according to

(Cubillos *et al*., 2009). In 2 kg pots full of sterilized soils 50 ml of the pathogen is immersed and then transplanted.

3.6 Preparation of Amendments

3.6.1 Application of compost

Before transplanting the seedlings, compost (about 250 g) was added to each pot based on treatment allocation. Pots with a capacity of 2kg were filled with sterile soil (2:1 soil: sand ratio). The composite (farmyard manure combined with agricultural waste such as straw, grass, and root crops such as enset) was applied in appropriate pots according to the predetermined design.

3.6.2 Application of Biochar

Biochar to be applied as one of the treatments prepared from commercially available charcoalprepared from unknown woody plants was purchased from the local vendors and mixed with the soil for each pots. It is applied at 250 g for each treatment allocated after being ground using a laboratory mortar and pestle.

3.7 Pot experiment and measurement of parameters

The pots were arranged in a CRD with three replications. The experiment was started on April of 2015 E.C in the greenhouse of Hawassa University, main campus. The seedlings were grown for about 20 days; then transplanted to the plastic pots. After 15, 30, and 45 days of transplantation different growth parameters were measured; shoot height (cm) measured one inch above the soil surface to the tip of the young shoot; leaf area is measured by centimetre(cm) and multiplied by a correction factor 0.58 (LA= L x W x 0.58); and stem diameter (mm) is measured using the sliding micrometre. After 90 days of growth, plants were carefully uprooted from the pots; and

the shoots, root and soil samples were collected. Shoots, roots, and yields are separated. Roots were washed with tap water to remove adhering debris, oven-dried at 72 ^{0}C for three days; and then weighed using the digital balance repeatedly until constant weight.

3.7.1 AMF Spores extraction from the pot experiment

For the investigation of the spore density in the greenhouse pot experiments, 100g soil samples were taken from each treatment after the experiment and mixed in a two-litter capacity beaker containing 1.5 litres of water. The soil in the water was stirred vigorously by hand and then allowed to settle. The suspension was then sieved with sieves having a mesh size of 500µm, 106µm, and 50µm, following the wet sieving and decanting method (Gerdemann & Nicolson, 1963). From the last one (50µm) samples were transferred to four 250ml centrifuge tubes with a fine stream of water from a wash bottle and centrifuged at 2000rpm for five minutes and removed the supernatant. Then, it was suspended in 60% sucrose solution and was thoroughly mixed and centrifuged at 2000rpm for 1 minute and poured the supernatant through the smallest mesh sieve (50µm) and spores were rinsed with tap water and transferred to petri-dishes and then the spores of the samples were observed under a stereomicroscope(Gerdemann & Nicolson, 1963).

3.7.2 Mycorrhizal colonization

Root colonization by AMF was assessed on root samples by clearing them with 10%(w/v) KOH at 90^{0}_{C} for 1-2 hours and acidify in 1% HCl for 1hrand then stained them with 0.05% trypan blue, according to(Phillips and Hayman, 1970). The AMF fungal structures were observed under a compound-light microscope (Olympus-bx51) at 200 to 400-fold magnification. Fungal

colonization was estimated using the magnified intersection method of (Gonigle *et al*., 1990) as total root length colonization.

RLC= 100[(G-N)/G], the percentage of root length colonized by hyphae only, hyphal colonization HC= 100(H/G), the percentage of root length colonized by arbuscules, arbuscular colonization, AC= 100(A/G) and the percentage of root length colonized by mycorrhizal vesicles, vesicular colonization VC= 100(V/G). RLC, N, A, V and G are designated as RLC, (total root length colonization), N (no fungal structure), A (arbuscules), V (vesicles) and G (total intersection) respectively. All were quantified by examining 100 intersections per sample.

3.7.3 Effect of treatments on fruit yield

In this research, two tomato varieties (Galilea and Roma.V.F.N) recommended for rift valley ecology were selected and an experiment was conducted under green house to evaluate the effect of treatments on fruit yield. After 90 days the fruit was harvested and the yields were measured by two parameters of weight either marketable (the absence of defects, skin and flesh color) or non-marketable (having defects, skin and flesh color) using digital balance (g/plant).

3.7.4 Disease Severity (DS)

Disease severity assessment was done 15 days after transplanting when symptoms of infection were observed. Such symptoms included clearing of the veins and drooping of petioles followed by yellowing of lower leaves. From each pot one plant is selected at random marked with pieces of string that was infected with *Fusarium oxysporum formae speciales lycopersici* pathogenand used to evaluate disease severity after every 3 weeks up to 9weeks. Wilt severity was determined using a modification of a scale by (Wanjiku *et al.*,2021). This was based on the wilt severity rated as follows; (% of shoot wilted, using a scale of 0-5 where, 0=No symptoms, 1=one leaf wilted (1%-25%), 2= 2 or 3 leaves wilted (26%-49%), 3=half plant wilted (50%-74%), 4= all leaves wilted (75%-100%), 5=Plant dead).

3.8 Soil physicochemical properties

The soil sample for the pot experiment was collected from Hawassa University research village, and air-dried at room temperature for three weeks and passed through a 2mm sieve and preserved until analysis. Soil analysis was undertaken at Hawassa University, College of Agriculture following standard procedures and methods. Soil texture was analyzed following the hydrometric method after removing organic matter using H_2O_2 and dispersing the soils with sodium hexametaphosphate (Black *et al.*, 1965).Soil organic matter is determined by the Walkley-Black oxidation method(Jackson *et al*., 1973). Total nitrogen is determined by using the Kjeldahl distillation method and available phosphorus is determined using Olsen's extraction method (Olsen, 1982). The soil pH value also measured by potentiometrically in 1:2 soil water suspensions with a standard glass electrode pH meter (Van Reeuwijk, 2002). Electrical conductivity is determined by 1:2 soil: water extract. Exchangeable potassium, magnesium, and calcium is determined by Melich-3 methods (Mehlich, 1984).

3.9 Nutrient Content

Plant tissue analysis was conducted at Debrzeit agricultural research laboratories following standard procedures. The concentration of nitrogen in the samples was determined using an element analyzer based on the Dumas principle (LECO CN). For the plant tissue concentration of other elements, dried sample (500mg) was digested in a tri-acid (HNO_3 + $HClO_4$ + H_2SO_4) mixture (Nabrzyski & Gajewska, 1998). The K content in the digest was measured using atomic absorption spectrometry (Varian SpektrAA 300) (Beaty & Kerber, 1993). The P content in the plant tissues was analyzed by the vanadomolybdate method after the wet digestion followed by photometry (Varian DMS 200) (Cavell, 1955).

3.10 Data analysis

Analysis of variance (ANOVA) was carried out with the SPSS software package (version 25.0)

4 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Soil physicochemical properties

In this section, the performance assessment results from the two tomato varieties were presented. To provide an overall outlook, the utilized soil physicochemical analysis is presented in subsection 4.1.1 before delving into in the detail. Then, the plants performance measurements and their descriptions are discussed in subsequent subsections.

Table 2 displays outcome of the soil analysis. The soil has pH value of 5.8 at a depth of 0–20 cm, indicating a slightly acidic nature based on its physicochemical characteristics. The N, P, OC, EC, Ca, Mg, K, and Mg amount in the soil were 0.31%, 24.6 mg/kg,1.54%,72.2 µS/cm, 43.21 mg/kg, 28.33 mg/kg, and 2.55 mg/kg, respectively. The soil has a sandy-clay-loam texture. The amount of all nutrients in the trial soil is ideal for tomato growth.

Table 2 Soil physicochemical properties of experimental site before greenhouse experiment

Sample	pH	TN%	TP(mg/kg)	OC%	EC(µS/cm)	Ca mg/kg	Mg mg/kg	K mg/kg	Sand	Silt	Clay
Soil sample used for greenhouse experiment	5.8	0.31	24.6	1.54	72.2	43.21	28.33	2.55	48 %	18 %	34 %
									Sandy Clay Loam		

4.1.2 Effect of AMF and T.h inoculation and application of biochar and compost with and without F.o.f.sp.l pathogen on tomato growth parameters.

Effect of AMF, *T.h* inoculation, application of biochar and compost with and without *F.o.f.sp.l* pathogen on height of variety Galilea with three intervals of growth (15, 30, and 45 days) is shown in Figure *2*. In comparison to other combined and sole treatments, the tomato plants within the three time intervals *T.h+F.o.f.sp.l* had the highest mean height (45 cm) in 15 days and its highest mean height (75 cm) in 30 days interval; whereas AMF+ *F.o.f.sp.l* treatments highest mean height value (102 cm). The plants treated with the *F.o.f.sp.l* pathogen (pt13) were found to have the lowest mean height across the three patterns.

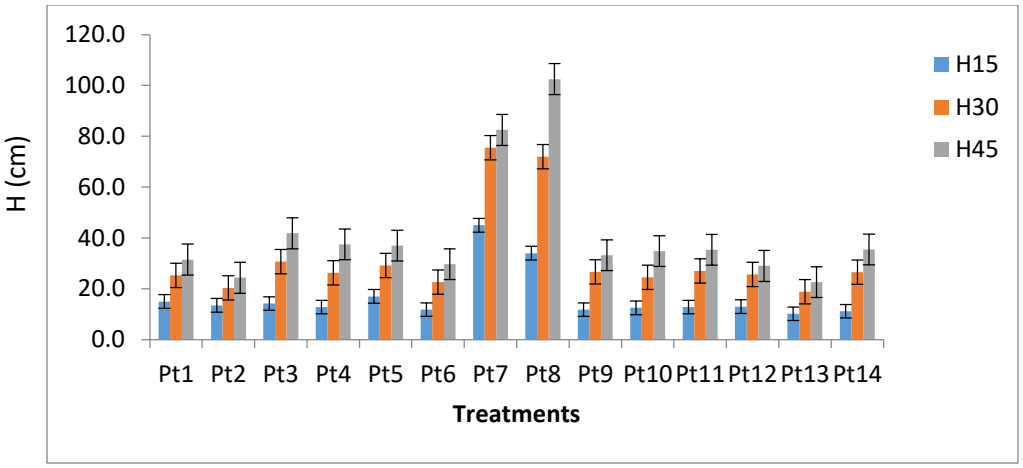

Figure 2 Microbial inoculation and application of sole & combined compost and biochar in the presence of *F.o.f.* on H of Galilea variety.

Key: *Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}-F.o., Pt_{14}. Control. F.O-Fusarium oxysporum, H-height*

The role of AMF and *T.h* inoculation and application of biochar and compost with and without *F.o.f.sp.l* pathogen on leaf area (LA) expansion of Galilea with three patterns (15, 30, and 45 days) was also indicated in Figure *3*. It was observed that AMF+*F.o.f.sp.l* treatment shown the highest mean LA of 38 cm2, 88.5 cm2, and 67.3 cm2 within growth intervals of 15, 30, and 45 days respectively. The *T.h. + F.o.f.sp.l* treatment's corresponding values were 25 cm^2, 28.3 cm^2, and 35cm^2 as a successor of AMF plant's LA expansion. According to the findings of this study for plants treated with *F.o.f.sp.l* pathogen was recorded the lowest mean on LA of the three growth intervals.

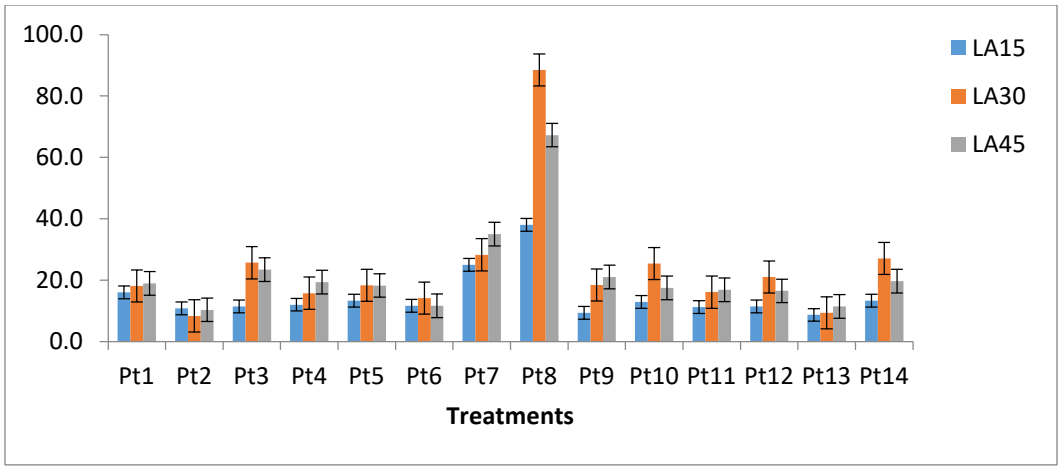

Figure 3 Microbial inoculation and application of sole & combined compost and biochar in the presence of *F.o.* on LA of Galilea variety.

Key: *Pt_1.Sole AMF, Pt_2.Sole T. h , Pt_3.Sole Compost, Pt_4.Sole Biochar, Pt_5.AMF+ T.h+ F.o, Pt_6.AMF+Comp+ F.o., Pt_7.T.h+ F.o., Pt_8.AMF+ F.o., Pt_9.AMF+Bio+ F.o., Pt_{10}.AMF+T.h+comp+ F.o., Pt_{11}.AMF+T.h+Bio+ F.o., Pt_{12}.AMF+T.h+Bio+Comp+ F.o., Pt_{13}.F.o., Pt_{14}. Control. F.O-Fusarium oxysporum, LA-leaf area*

Effect of AMF and *T.harzianum* inoculation and application of biochar and compost with and without *F.o.f.sp.l* pathogen on stem diameter (SD) of tomato (Galilea) with three (15, 30 and 45) duration was illustrated on Figure 4. According to this findings, AMF inoculation resulted in the highest SD (18.2 cm) followed by T.h+*F.o.f.sp.l* inoculated treatment (14.5 cm) throughout the assessment intervals. Compared to other treatments and the control for plants treated with *F.o.f.sp.l* pathogen (Pt13) was recorded the lowest SD (3.42 cm).

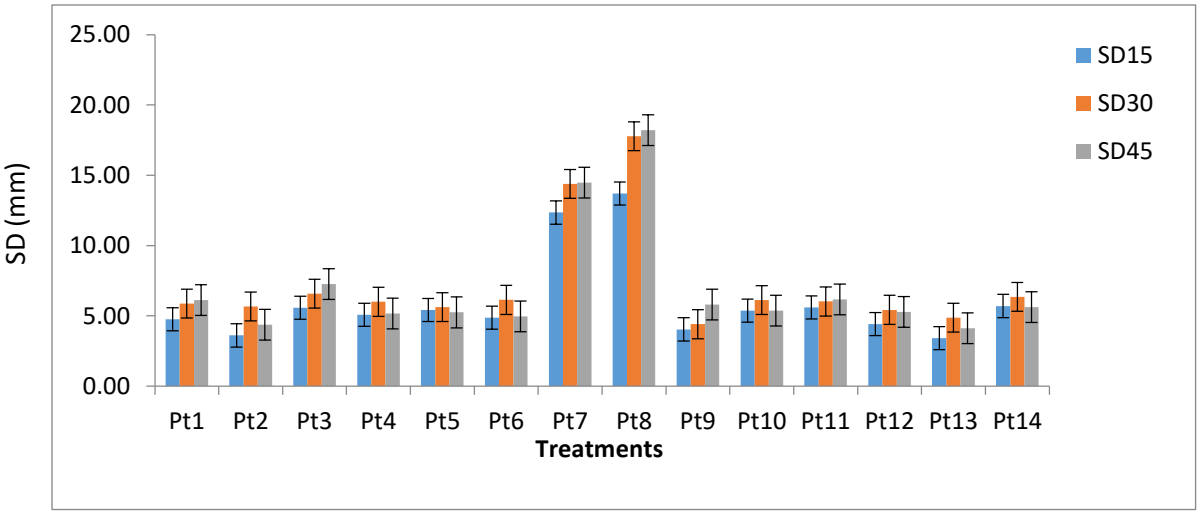

Figure 4. Microbial inoculation and application of sole & combined compost and biochar in the presence of *F.o.* on SD of Galilea variety.

Key:*Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}-F.o., Pt_{14}- Control, F.O-Fusarium oxysporum, SD-stem diameter,.*

Similarly, the effect of AMF and *T.h* inoculation and application of biochar and compost with and without *F.o.f.sp.l* pathogen on height of tomato (Roma.V.F.N) with three patterns (15, 30 and 45 days after transplantation) was showed on Figure 5. According to this findings, the highest mean height of *T.h+F.o.f.sp.l* was recorded in 15 and 30 days (16.33 cm and 37.5 cm respectively) but overtaken by AMF+Comp+*F.o.f.sp.l* treatment within 45 days of development stages resulted the highest mean plant height (51 cm) compared to other treatments and the control.

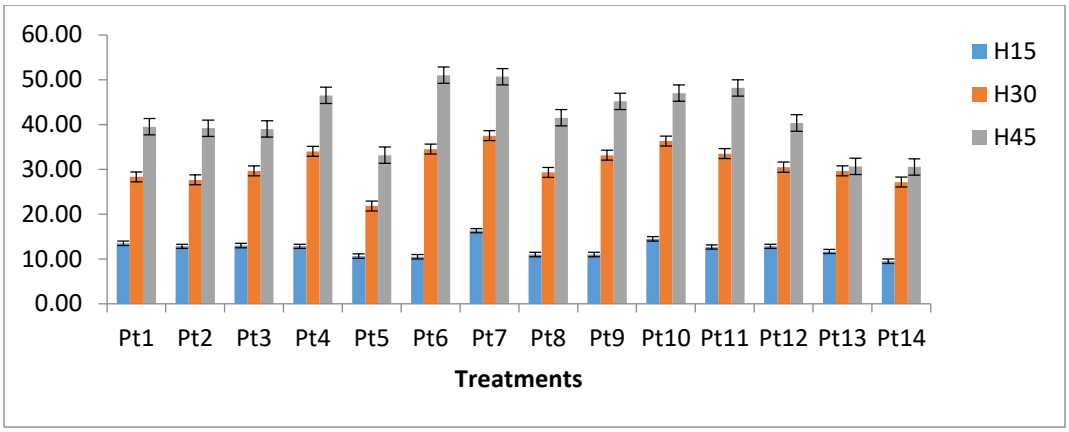

Figure 5 Microbial inoculation and application of sole & combined compost and biochar in the presence of *F.o.* on H of Roma.V.F.N variety.

Key:*Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}-F.o., Pt_{14}-Control F.O-Fusarium oxysporum, H-height.*

Effect of AMF and *T.h* inoculation and application of biochar and compost with and without *F.o.f.sp.l* pathogen on LA of tomato (Roma.V.F.N) with three patterns (15, 30 and 45) was indicated onFigure 6. The mean LA were highest in plants treated with sole AMF in 15 days but in 30 days sole biochar recorded highest mean of LA compared to all treatments. The study show the combination of AMF+*T.h* +Bio + *F.o.f.sp.l* were highest mean within 45 days of time.

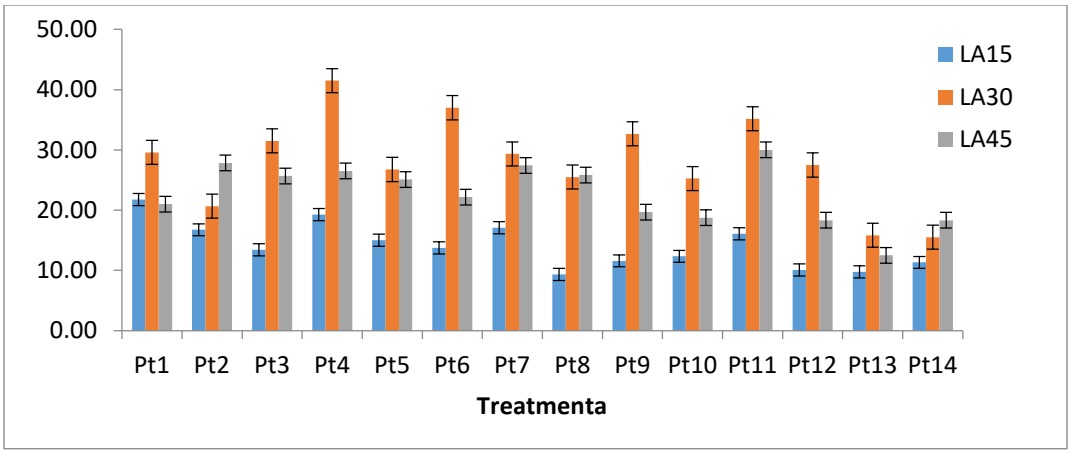

Figure 6 Microbial inoculation and application of sole & combined compost and biochar in the presence of *F.o.* on LA of Roma.V.F.N variety.

Key: *Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}-F.o., Pt_{14}- F.O-Fusarium oxysporum, LA-leaf area, Control.*

Figure 7 shows the impact of AMF and *T.harzianum* inoculation, as well as the application of compost and biochar with and without the *F.oxysporum.f.sp.l* pathogen, on the SD of tomato (Roma V.F.N) at three intervals of fifteen days (15, 30, and 45). The study's conclusions indicate that, after 15 days, *T. h + F.o.f.sp.l* had the highest mean SD; however, after 30 days, only AMF+Bio+ *F.o.f.sp.l* had the highest mean SD when compared to other treatments. Sole biochar had the highest standard deviation in 45 days, with sole AMF coming in second. When compared to other treatments and the control, Roma V.F.N. treated with the *F.oxysporum.f.sp.l* pathogen exhibits the lowest mean of SD in all parameters.

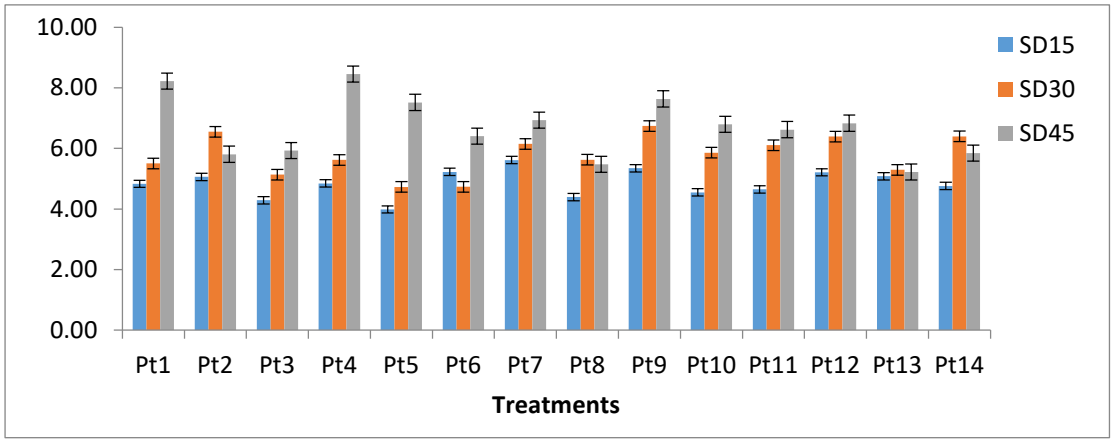

Figure 7 Microbial inoculation and application of sole & combined compost and biochar in the presence of *F.o.* on SD of Roma.V.F.N variety.

Key: *Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}-F.o., Pt_{14}-Control F.O-Fusarium oxysporum, SD-stem diameter,*

4.1.3 Effect of AMF and *T. harzianum* inoculation and applications of sole and combined Biochar and Compost in the presence of *F. oxysporum.f.sp. Lycopersici* pathogen on

Table 3 shows how the growth parameters of the tomato variety Galilea vary in a greenhouse setting at 45 days for stem diameter, height, and other parameters. When compared to plants treated with *F. oxysporum f.sp. Lycopersici* pathogen alone, an improvement in the various parameters was seen in the plants treated with arbuscular mycorrhizal fungi, *T. harzianum*, biochar, and compost combined with or without *F.oxysporum.f.sp.Lycopersici* pathogen and control. Additionally, it was noted that there were significant differences in the treatment effects on the plants at ($P<0.05$).

As a result, the plants inoculated with compost had the highest height values (41.83 cm), followed by those treated with biochar (37.50 cm) and AMF combined with *T.harzianum* and *F.oxysporum.f.sp.Lycopersici* (37.00 cm) in comparison to the control (35.50 cm) and the pathogen alone (22.66 cm) inoculation. Compost also had the largest leaf area (23.41±3.58) and steam diameter (7.27±1.03) when compared to other treatments. AMF combined with *F. oxysporum.f.sp.l.Lycopersici* came in second (22.41±3.53), followed by AMF combined with *T. harzianum.* Biochar, and *F.o.f.sp.l* (6.16±0.55). As a result, the plants inoculated with compost had the highest height values (41.83 cm), followed by those treated with biochar (37.50 cm) and AMF combined with *T. harzianum* and *F. oxysporum.f.sp. Lycopersici* (37.00 cm) in comparison to the control (35.50 cm) and the pathogen alone (22.66 cm) inoculation. Compost also had the largest leaf area (23.41±3.58) and steam diameter (7.27±1.03) when compared to other treatments. AMF combined with *F. oxysporum.*f.sp. *Lycopersici* came in second (22.41±3.53), followed by AMF combined with *T. harzianum*, Biochar, and *F.o.f.sp.l* (6.16±0.55).

Table 3 (Mean±SEM) Growth and biomass response of tomato (Galilea) with inoculation of AMF and *T. harzianum* and applications of sole and combined Biochar and Compost in the presence of *F.oxysporum f.sp. Lycopersici* pathogen

Treatmen	H(cm)	LA(cm2)	SD(mm)	SWW(g)	SDW(g)	RWW(g)	RDW(g)
Pt_1	31.67±0.16^{abcd}	15.1±3.61^{abc}	5.60±0.73^{bc}	101.00±78.56^{a}	14.00±9.01^{a}	20.00±6.02^{a}	2.33±0.88^{bc}
Pt_2	24.33±1.42^{cd}	10.33±0.33^{c}	4.37±0.17^{cd}	128.33±115.83^{a}	15.66±13.67^{a}	17.66±8.68^{a}	4.66±0.66^{a}
Pt_3	41.83±5.17^{a}	23.41±3.58^{a}	7.27±1.03^{a}	70.66±31.69^{a}	15.00±4.35^{a}	16.33±6.17^{a}	1.66±0.33^{bc}
Pt_4	37.50±2.92^{ab}	19.33±3.40^{abc}	5.17±0.30^{bcd}	115.66±101.66^{a}	17.33±13.38^{a}	18.00±8.32^{a}	2.66± 0.88^{b}
Pt_5	37.00±3.90^{ab}	18.25±1.75^{abc}	5.25±0.10^{bcd}	90.00±71.05^{a}	13.66±9.68^{a}	9.66±2.84^{a}	1.66±0.33^{bc}
Pt_6	29.66±1.48^{bcd}	11.66±1.66^{bc}	4.97±0.13^{bcd}	24.00±8.00^{a}	4.00±1.52^{a}	11.33±1.33^{a}	1.66±0.33^{bc}
Pt_7	27.50±1.25^{bcd}	11.66±1.76^{bc}	4.82±0.21^{bcd}	11.66±1.20^{a}	2.66±0.33^{a}	14.00±5.85^{a}	2.33±0.88^{bc}
Pt_8	34.16±6.49^{abc}	22.41±3.53^{a}	6.06±0.49^{ab}	27.00±9.53^{a}	7.33±3.33^{a}	14.33±5.60^{a}	2.00±0.57^{bc}
Pt_9	33.16±7.37^{abcd}	21.00±7.54^{a}	5.80±0.61^{bc}	30.00±19.50^{a}	6.66±2.72^{a}	8.66±5.36^{a}	1.50±0.76^{bc}
Pt_{10}	34.83±2.02^{abc}	17.50±1.44^{abc}	5.36±0.22^{bcd}	22.33±8.41^{a}	6.33±0.66^{a}	11.66±6.22^{a}	1.33±0.33^{bc}
Pt_{11}	35.33±3.60^{abc}	16.83±2.04a^{bc}	6.16±0.55^{ab}	48.00±27.62^{a}	27.62±4.72^{a}	19.33±4.25^{a}	2.66±.88^{b}
Pt_{12}	29.00±6.04^{bcd}	16.50±2.92^{abc}	5.27±0.26^{bcd}	17.33±6.83^{a}	3.66±1.20^{a}	10.66±4.09^{a}	1.83±0.72^{bc}
Pt_{13}	22.66±0.44^{d}	11.41±2.48^{bc}	4.13±0.65^{d}	8.66±2.40^{a}	3.33±2.02^{a}	5.00±1.15^{a}	0.50±0.00^{c}
Pt_{14}	35.50±2.36^{abc}	19.66±2.16^{ab}	5.63±0.8^{bc}	27.33±7.53^{a}	8.00±2.08^{a}	19.66±3.84^{a}	3.00±0.57^{ab}

Key: *Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}- Fusarium oxysporum, Pt_{14}-control, H-height, LA-leaf area, Sd-stem diameter, SWW-shoot wet weight, SDW-shoot dry weight, RWW-root wet weight, RDW-root dry weight. In columns,* superscripts with dissimilar letters show significant relationship between treatments atp<0.05.

Tomato (Roma.V.F.N) growth and biomass response to AMF and *T. harzianum* inoculation, as well as Biochar and Compost applications, and their combinations in the presence of *F.oxysporum f.sp. Lycopersici* pathogen is shown in Table 4. This study found that plants inoculated with AMF+Comp+ *F.o.f.sp.l* (51.00±5.61) had the highest height, followed by *T. harzianum*+ *F.o.f.sp.l* (50.66±3.08), when compared to other treatments and control plants. AMF+*T. harzianum*+Bio+ *F.o.f.sp.l* had the highest leaf area (30.00±3.46), followed by sole *T. harzianum* (27.83±7.32) among treatments and control. Biochar (8.45±1.39) had the highest diameter compared to steam, followed by AMF (8.22±1.79) and control treatments. Plants inoculated with *T. harzianum* + *F.o.f.sp.l* had the highest shoot and root wet and dry weights (104.66±32.89, 67.33±10.34, 20.00±6.00, 11.33±1.33) compared to other treatments and controls. Plants treated with *F. oxysporum.f.sp. Lycopersici* had the lowest results in all.

Table 4 (Mean±.SEM) Growth and biomass response of tomato (Roma.V.F.N) with inoculation of AMF and *T. harzianum* and applications of Biochar and Compost in the presence of *F.oxysporum f.sp. Lycopersici* pathogen

Treatments	H(cm)	LA(cm2)	SD(mm)	SWW(g)	SDW(g)	RWW(g)	RDW(g)
Pt_1	39.50± 1.89^{abc}	21.00±3.57^{ab}	8.22±1.79^{a}	78.66±23.84^{abcd}	17.33±3.84^{ab}	60.00±22.03^{ab}	10.66±5.66^{a}
Pt_2	39.16±4.17^{abc}	27.83±7.32^{a}	5.80±0.86^{bc}	31.33±3.71^{de}	6.33±0.88d^{e}	21.00±4.61^{de}	2.66±0.88^{bc}
Pt_3	39.00±4.85^{abc}	25.66±8.19^{a}	5.92±0.48^{bc}	98.33±12.46^{ab}	18.33±2.33^{ab}	55.66±9.33^{abc}	4.33±0.66^{bc}
Pt_4	46.50±5.79^{a}	26.50±0.50^{a}	8.45±1.39^{a}	71.33±24.39^{abcde}	14.66±4.09^{abcd}	39.33±9.90^{bcd}	4.33±1.20^{bc}
Pt_5	33.16±3.60^{bc}	25.08±5.43^{ab}	7.51±0.99^{ab}	35.33±9.40^{cde}	6.33±1.33^{de}	23.33±4.84^{de}	3.00±1.15^{bc}
Pt_6	51.00±5.61^{a}	22.16±1.16^{ab}	6.40±0.50^{abc}	60.00±9.07^{abcde}	12.00±3.21^{abcde}	24.66±6.22^{de}	3.33±0.66^{bc}
Pt_7	50.66±3.08^{a}	27.41±70.62^{a}	6.93±0.18^{abc}	104.66±32.89^{a}	20.00±6.00^{a}	67.33±10.34^{a}	11.33±1.33^{a}
Pt_8	41.50±4.07^{abc}	25.83±4.51^{a}	5.47±0.62^{bc}	50.00±11.84^{bcde}	10.00±2.30^{bcde}	44.00±13.65^{abcd}	7.33±3.17^{ab}
Pt_9	45.16±3.56^{ab}	19.66±2.60^{ab}	7.63±0.47^{ab}	64.66±12.34^{abcde}	11.33±2.02^{abcde}	23.66±1.33^{de}	3.66±0.33^{bc}
Pt_{10}	47.00±4.25^{a}	18.75±0.72^{ab}	6.79±0.05^{abc}	83.33±27.55^{abc}	15.00±4.61^{abcd}	23.33±4.91^{de}	3.00±0.57^{bc}
Pt_{11}	48.16±4.25^{a}	30.00±3.46^{a}	6.62±0.25^{abc}	82.66±20.67^{abcd}	16.66±4.66^{abc}	33.66±4.25^{cde}	4.33±0.33^{bc}
Pt_{12}	40.33±1.45^{abc}	18.33±0.83^{ab}	6.83±0.13^{abc}	45.66±10.34^{cde}	7.66±1.85^{cde}	21.66±4.48^{de}	2.66±0.33^{bc}
Pt_{13}	30.66±4.70^{c}	12.50±0.28^{ab}	5.22±0.19^{c}	26.33±11.02^{e}	5.00±2.00^{e}	10.66±2.72^{e}	1.00±0.00^{c}
Pt_{14}	30.54±5.84^{c}	18.33±0.83^{b}	5.84±0.32^{bc}	42.00±10.69^{cde}	9.33±1.45^{bcde}	23.00±5.68d^{e}	3.00±0.57^{bc}

Key: *Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}- Fusarium oxysporum, Pt_{14}-control, H-height, LA-leaf area, Sd-stem diameter, SWW-shoot wet weight, SDW-shoot dry weight, RWW-root wet weight, RDW-root dry weight. In columns,* superscripts with dissimilar letters show significant relationship between treatments atp<0.05.

4.1.4 The effect of AMF and *T. harzianum* inoculation and applications of Biochar and Compost combined or not with *F. oxysporum f.sp. Lycopersici* pathogen on yield of two tomato varieties

Table 5 shows the effect of AMF and *T. harzianum* inoculation, as well as the use of Biochar and Compost in combination or not with the *F. oxysporum* f.sp. *Lycopersici* pathogen, on marketable and non-marketable tomato (Galilea) yields. This study found that plants treated with sole compost (148.00±53.61 & 33.00±33.00) were the most marketable, followed by sole biochar (121.00±94.50 & 9.66±9.66) when compared to other sole and combined treatments and the control. In this variety, the treatment AMF+ *F. o*.f.sp.l (46.66±9.52) had higher marketable yields than *T. harzianum*+ *F. o*.f.sp.l (12.33±1.33), but neither treatment had Non-marketable yield.

In comparison with the three and four combination, including control and *F.o.f.sp.l;* AMF+Bio+ *F.o.f.sp.l* (70.00±61.22) resulted in the highest marketable yields. According to these findings there was no marketable yields with tomato plants treated with *F.oxysporum* f.sp. *Lycopersici.*

Table 5 Mean fruit Yield of tomato (Galilea variety) with microbial inoculations and application of Biochar and Compost with or without presence of *F.oxysporum f.sp. Lycopersici* pathogen.

Treatments	**Yields**	
	Marketable(g)/pot of plant	**None Marketable(g)/pot of plant**
Pt_1	50.66±36.70^{abc}	0.00±0.00^{b}
Pt_2	4.00±4.00^{c}	0.00±0.00^{b}
Pt_3	148.00±53.61^{a}	33.00±33.00^{a}
Pt_4	121.00±94.50^{ab}	9.66±9.66^{ab}
Pt_5	65.00±46.54a^{bc}	0.00±0.00^{b}
Pt_6	36.33±13.09^{bc}	0.00±0.00^{b}
Pt_7	12.33±1.33^{bc}	0.00±0.00^{b}
Pt_8	46.66±9.52^{abc}	0.00±0.00^{b}
Pt_9	70.00±61.22^{abc}	0.00±0.00^{b}
Pt_{10}	40.33±9.52^{abc}	0.00±0.00^{b}
Pt_{11}	34.66±6.17^{bc}	0.00±0.00^{b}
Pt_{12}	23.00±16.09^{bc}	0.00±0.00^{b}
Pt_{13}	0.00±0.00^{c}	2.66±2.66^{b}
Pt_{14}	46.33±15.81^{abc}	0.00±0.00^{b}

Key:*Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}- Fusarium oxysporum, Pt_{14}-control,.In columns,* superscripts with dissimilar letters show significant relationship between treatments at p<0.05.

Marketable and N. Marketable yields of Tomato (Roma.V.F.N) with inoculation of the AMF, *T. harzianum* and application of Biochar and Compost combined or not with *F. oxysporum f.sp. Lycopersici* pathogen was illustrated in.

Table 6. The highest Marketable yields were observed in plants treated with sole compost (249.66±108.94), followed by *T.h+F.o.f.sp.l* (190.66±63.83) compared to other combined and sole treatments and control. According to this findings *T. harzianum+F.o.f.sp.l* (190.66±63.83) was highest compared to AMF+*F.o.f.sp.l*(71.33±22.10) treated plants.In combination with three

treatments AMF+Bio+*F.o.f.sp.l*(142.00±47.17) was highest than AMF+Comp+*F.o.f.sp.l* (128.00±35.23) and AMF+ *T.h*+*F.o.f.sp.l* (69.66±9.35).

Incomparisonof the fourcombinations AMF+*T.h*+Bio+*F.o.f.sp.l* (183.66±25.84) was highest than AMF+*T.h*+comp+*F.o.f.sp.l* (166.33±68.48) and control. According to the findings of this study tomato plants treated with sole and combined treatments except *F.o.f.sp.l* has the highest marketable yields than control plants. None marketable yields were observed only in tomato plants treated with *F. oxysporum.f.sp*. *Lycopersici*.

Table 6. Mean weight fruit yield of tomato (Roma V.F.N variety) with microbial inoculations and application of Biochar and Compost with or without *F.oxysporum* f.sp. *Lycopersici* pathogen

Treatments	**Yields**	
	Marketable(g/plant)	**None Marketable(g/plant)**
Pt_1	113.33 ± 28.91^{bcd}	0.00 ± 0.00^{b}
Pt_2	62.33 ± 16.49^{bcd}	0.00 ± 0.00^{b}
Pt_3	249.66 ± 108.94^{a}	0.00 ± 0.00^{b}
Pt_4	115.66 ± 45.93^{bcd}	0.00 ± 0.00^{b}
Pt_5	69.66 ± 9.35^{bcd}	0.00 ± 0.00^{b}
Pt_6	128.00 ± 35.23^{abcd}	0.00 ± 0.00^{b}
Pt_7	190.66 ± 63.83^{ab}	0.00 ± 0.00^{b}
Pt_8	71.33 ± 22.10^{bcd}	0.00 ± 0.00^{b}
Pt_9	142.00 ± 47.17^{abcd}	0.00 ± 0.00^{b}
Pt_{10}	166.33 ± 68.48^{abc}	0.00 ± 0.00^{b}
Pt_{11}	183.66 ± 25.84^{ab}	0.00 ± 0.00^{b}
Pt_{12}	112.33 ± 22.22^{bcd}	0.00 ± 0.00^{b}
Pt_{13}	25.33 ± 9.49^{d}	1.6667 ± 1.66^{a}
Pt_{14}	50.00 ± 21.93^{cd}	0.00 ± 0.00^{b}

Key:*Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}- Fusarium oxysporum, Pt_{14}-control, H-height, LA-leaf area, Sd-stem diameter, SWW-shoot wet weight, SDW-shoot dry weight, RWW-root wet weight, RDW-root dry weight.In columns,* superscripts with dissimilar letters show significant relationship between treatments at $p<0.05$.

4.1.5 Root colonization and spore density

Root colonization and spore density percentage of the two varieties of tomato inoculated as Sole AMF and combined with other treatments was indicated in Table 7. There were significant differences in percentage among the various treatments sole and combined. The percentage of

root colonization of AMF inoculated treatments sole and combined ranged from 85%(AMF+ *T.h*+ *F.o.f.sp.l* and AMF+*T.h*+Comp+Bio+*F.o.f.sp.l*) inoculation to 70% in AMF+*F.o.f.sp.l,* AMF+Comp+ *F.o.f.sp.l,* AMF+*T.h*+comp+*F.o.f.sp.l*and AMF+*T.h*+Bio+*F.o.f.sp.l*for Galilea variety. Whereas, for Roma.V.F.N variety the highest root colonization was observed in the combined inoculation of AMF+*T.h*+comp+*F.o.f.sp.l* (88%). The highest spore density values were60 spores/100gm dry soil in sole AMF, followed by combined AMF+Bio+ *F.o.f.sp.l* 40 spores/100gm dry soil in Galilea tomato variety. Also,44% and 36% were observed in sole AMF and combined AMF+Bio+ *F.o.f.sp.l* in Roma.V.F.N respectively.

Table 7 Tomato plant percent root colonization and spore density with the inoculation of the sole AMF and combined or not with other treatments

Treatments	**Galilea**				**Roma.V.F.N**			
	AC	**VC**	**RLC**	**SD**	**AC**	**VC**	**RLC**	**SD**
Sole AMF	25	45	80	60	35	30	85	44
AMF+ *F.o.f.sp.l*	15	25	70	36	30	23	80	26
AMF+ *T.h*+ *F.o.f.sp.l*	25	35	85	22	30	30	78	20
AMF+Comp+ *F.o.f.sp.l*	15	34	70	32	20	26	82	22
AMF+Bio+ *F.o.f.sp.l*	25	42	80	40	28	38	85	36
AMF+*T.h*+comp+*F.o.f.sp.l*	24	28	70	26	40	21	88	28
AMF+*T.h*+Bio+*F.o.f.sp.l*	20	25	70	28	30	35	85	32
AMF+*T.h*+Comp+Bio+*F.o.f.sp.l*	30	40	85	30	20	20	70	30

Key: AMF-arbuscular mycorrhizal fungi, *T.h-Trichoderma harzianum,* Comp-Compost, Bio-Biochar, *F.o.f.sp.l-Fusarium oxysporum f.sp. Lycopersici*.

4.1.6 Tomato tissue nutrient uptake

According to this study total N, P, Ca, Mg and K accumulation in the shoot after 45 days in tomato above ground tissue is presented in Table 8. Total N, P, Ca, Mg and K accumulation in the shoot dry matter was significantly different between the two varieties, the treatments and the control. The studied nutrient contents in variety Galilea were significantly

increased by treatments of AMF+*T.h*+Bio+Comp+*F.o.f.sp.l* in almost all except calcium and potassium. The highest (4.3%) and the lowest (1.92%) calcium is recorded in a treatment inoculated with AMF+com+*F.o.f.sp.l* and amended by biochar respectively. Potassium content ranged from (2.97 %) in sole *T. harzianum* to 1.85% in *F.* f.*sp.l.* In findings of this study this variety treated with *F.o.f.sp.l* pathogen were lowest in all treatments except sole biochar (1.92%) and the combined treatment AMF+Bio+ *F.o.f.sp.l (*2.03%) corresponding to the nutrient calcium. In this study all nutrient contents of the control plants were highest compared to the *F.o.f.sp.l* pathogen inoculated plants.

Table 8. Tomato plant nutrient uptake (Galilea)

Treatments	**Av.N%**	**Av.P%**	**Ca%**	**Mg%**	**K%**
Pt_1	0.25	0.54	4.00	1.05	2.80
Pt_2	0.23	0.62	4.19	1.06	2.97
Pt_3	0.22	0.71	4.22	1.14	2.96
Pt_4	0.10	0.55	1.92	1.12	2.60
Pt_5	0.10	0.55	4.11	1.02	2.22
Pt_6	0.12	0.49	4.02	1.0	2.05
Pt_7	0.20	0.62	4.21	1.20	2.50
Pt_8	0.25	0.76	4.30	1.25	2.55
Pt_9	0.10	0.58	2.03	1.25	2.70
Pt_{10}	0.35	0.85	3.5	2.10	2.35
Pt_{11}	0.34	0.78	3.22	1.99	2.44
Pt_{12}	0.36	0.88	3.6	2.24	2.40
Pt_{13}	0.09	0.32	2.88	1.0	1.85
Pt_{14}	0.15	0.43	3.10	1.55	2.01

Key: Pt_1-Sole AMF, Pt_2-Sole T. h , Pt_3-Sole Compost, Pt_4-Sole Biochar, Pt_5-AMF+ T.h+ F.o, Pt_6-AMF+Comp+ F.o., Pt_7-T.h+ F.o., Pt_8-AMF+ F.o., Pt_9-AMF+Bio+ F.o., Pt_{10}-AMF+T.h+comp+ F.o., Pt_{11}-AMF+T.h+Bio+ F.o., Pt_{12}-AMF+T.h+Bio+Comp+ F.o., Pt_{13}- Fusarium oxysporum, Pt_{14}-control.

The studied nutrient contents in tomato (Roma.V.F.N) were illustrated in Table 9. The highest nutrient contents were recorded by the combination of all treatments (AMF+T.h+Bio+Comp+ *F.o.f.sp.l*) except calcium and potassium. The studied nutrient contents were lowest in tomato

plants infected with *F.o.f.sp.l* pathogen compared all treatments except sole biochar and the combined treatment AMF+Bio+ *F.o.f.sp.l* regarding to calcium. The highest percentage of calcium was observed in plants treated with AMF+Com+*F.o.f.sp.l* (4.33%) and the lowest were in sole biochar (1.90%). According to K content the highest was recorded by plants treated by sole *T.harzianum* (3.10) followed by sole compost (2.98%).

Table 9. Tomato plant nutrient uptake (Roma.V.F.N)

Treatments	**Av.N%**	**Av.P%**	**Ca%**	**Mg%**	**K%**
Pt_1	0.29	0.58	4.13	1.06	2.83
Pt_2	0.26	0.66	4.22	1.08	3.10
Pt_3	0.26	0.73	4.25	1.17	2.98
Pt_4	0.14	0.57	1.90	1.16	2.62
Pt_5	0.15	0.57	4.13	1.15	2.25
Pt_6	0.16	0.52	4.05	1.13	2.18
Pt_7	0.23	0.65	4.24	1.23	2.54
Pt_8	0.27	0.78	4.33	1.28	2.58
Pt_9	0.15	0.61	2.05	1.28	2.73
Pt_{10}	0.49	0.87	3.53	2.13	2.37
Pt_{11}	0.47	0.81	3.26	2.12	2.47
Pt_{12}	0.50	0.90	3.62	2.27	2.43
Pt_{13}	0.12	0.35	2.91	1.13	1.87
Pt_{14}	0.18	0.46	3.13	1.58	2.04

Key: *Pt_1.Sole AMF, Pt_2.Sole T. h , Pt_3.Sole Compost, Pt_4.Sole Biochar, Pt_5.AMF+ T.h+ F.o, Pt_6.AMF+Comp+ F.o., Pt_7.T.h+ F.o., Pt_8.AMF+ F.o., Pt_9.AMF+Bio+ F.o., Pt_{10}.AMF+T.h+comp+ F.o., Pt_{11}.AMF+T.h+Bio+ F.o., Pt_{12}.AMF+T.h+Bio+Comp+ F.o., Pt_{13}. Fusarium oxysporum, Pt_{14}-control. In columns,* superscripts with dissimilar letters show significant relationship between treatments at $p<0.05$.

4.1.7 Mycorrhizal Dependency

The mycorrhizal dependency of treatments of the two tomato varieties are indicated in Table 10. More than 70% of global plants are dependent on mycorrhizal association, but their association varies with specific plant and the mycorrhizal species involved in the association.

In this study, sole AMF and combined treatments AMF+*T.h*+Bio+*F.o.f.sp.l* showed highest mycorrhizal dependency in both varieties compared to other treatments. The findings indicate that tomatoes treated with all combination doesn't show MD at all.

Table 10. Mycorrhizal dependency of tomato plants

Treatments	**MD (%)**	
	Galilea	**Roma V.F.N**
Sole AMF	42.85	46.16
AMF+ *F.o.f.sp.l*	-9.14	6.7
AMF+*T.h*+ *F.o.f.sp.l*	41.43	-47.39
AMF+Comp + *F.o.f.sp.l*	-100	22.25
AMF+Bio+ *F.o.f.sp.l*	-20.12	17.65
AMF+*T.h*+Comp+*F.o.f.sp.l*	-26.38	37.8
AMF+*T.h*+Bio+*F.o.f.sp.l*	71.03	43.99
AMF+*T.h*+Bio+Comp+*F.o.f.sp.l*	-118.57	-21.8

Key: *MD-Mycorrhizal dependency, AMF-arbuscular mycorrhizal fungi, T.h-Trichoderma harzianum, Comp-Compost, Bio-Biochar, F.o.f.sp.l-Fusarium oxysporum f.sp. Lycopersici*

4.1.8 Disease Severity of tomato plants

The percentage of microbial inoculation and application of compost and biochar in the presence of *F.o.f.sp.l* pathogen on disease severity (DS) of the two varieties of tomato plants were studied. The study of microbial inoculation and application of compost and biochar on diseases severity of tomato plants (Galilea) were illustrated in Table 11. According to this findings the inoculation

of the bio-control fungi (*T. harzianum*) decrease the disease severity in the three patterns of time compared to all other treatments, followed AMF+ *T.h+ F.o.f.sp.l* and (AMF+ *F.o.f.sp.l*) respectively. The three combination (AMF+ *T.h+F.o.f.sp.l)* decrease DS compared with AMF+Comp+*F.o.f.sp.l*, AMF+Bio *F.o.f.sp.l.* The findings showed that plants infected with *F.o.f.sp.l* almost all died compared with inoculation of other treatments and the control.

Table 11. Mean of effect of microbial inoculation and application of compost and biochar on diseases severity of tomato plants (Galilea)

Treatments	**DS(15)**	**DS(30)**	**DS(45)**
AMF+ *F.o.f.sp.l*	1.00 ± 0.00^{bc}	2.00 ± 0.00^{bcde}	2.66 ± 0.33^{abcd}
T.h+ F.o.f.sp.l	0.66 ± 0.33^{bc}	1.33 ± 0.33^{cde}	1.66 ± 0.33^{cd}
AMF+ *T.h+ F.o.f.sp.l*	1.33 ± 0.33^{bc}	1.33 ± 0.33^{cde}	2.33 ± 0.66^{bcd}
AMF+Comp+ *F.o.f.sp.l*	1.66 ± 0.33^{abc}	2.66 ± 0.33^{abc}	3.33 ± 0.33^{abc}
AMF+Bio+ *F.o.f.sp.l*	2.00 ± 0.00^{ab}	3.33 ± 0.33^{ab}	4.00 ± 0.00^{ab}
AMF+*T.h*+comp+*F.o.f.sp.l*	2.00 ± 0.57^{ab}	2.66 ± 0.33^{abc}	3.00 ± 0.57^{abcd}
AMF+*T.h*+Bio+ *F.o.f.sp.l*	$1.33\pm0\ .33^{bc}$	2.00 ± 0.00^{bcde}	3.66 ± 0.33^{abc}
AMF+*T.h*+Bio+Comp+ *F.o.f.sp.l*	1.66 ± 0.66^{abc}	2.33 ± 0.33^{abcd}	2.66 ± 0.33^{abcd}
F.o.f.sp.l	$3.33\pm0\ .33^{a}$	4.00 ± 0.00^{a}	4.66 ± 0.33^{a}
Control	1.00 ± 0.00^{bc}	1.33 ± 0.33^{cde}	1.66 ± 0.33^{cd}

Key: *DS-Diseases severity*. In columns, superscripts with dissimilar letters show significant relationship between treatments at $p<0.05$; $p<0.01$and $p<0.001$. *In columns*, superscripts with dissimilar letters show significant relationship between treatments at $p<0.05$.

The effect of microbial inoculation and application of compost and biochar in the presence of *F.o.f.sp.l* on diseases severity of tomato plants (Roma.V.F.N) indicated in Table 12. The findings reflected that the inoculation of *T. harzianum* highly suppress the pathogen *F.o.f.sp.l in* all patterns of time compared to other treatments and the control. The combined inoculation of AMF and *T. harzianum* also have high potential to suppress *F. oxysporum.f.sp.l*, compared to all other combined treatments and the control. The study resulted that Roma. V.F.N infected with *F.o.f.sp.l* totally die in the last two durations.

Table 12. Mean of effect of microbial inoculation and application of compost and biochar on diseases severity of tomato plants (Roma. V.F.N)

Treatments	**DS(15)**	**DS(30)**	**DS(45)**
AMF+ *F.o.f.sp.l*	0.33±0.33^{bc}	1.33±0.33^{bcde}	1.66±0.33^{cdefg}
T.h+ F.o.f.sp.l	0.00± 0 .00 ^{c}	0.66±0.00^{cde}	1.00±0.00^{efg}
AMF+ *T.h+ F.o.f.sp.l*	0.66±0 .33^{bc}	1.33±0.33^{bcde}	1.66±0.33c^{defg}
AMF+Comp+ *F.o.f.sp.l*	1.33±0 .33^{abc}	2.66±0.33^{abc}	3.33 ±0.33^{abcd}
AMF+Bio+ *F.o.f.sp.l*	1.33±0 .33^{abc}	2.66±0.33^{abc}	3.33±0.33 ^{abcd}
AMF+*T.h*+comp+*F.o.f.sp.l*	2.00±0.57^{ab}	2.33±±0.33^{abcd}	3.00±0.00^{abcde}
AMF+*T.h*+Bio+ *F.o.f.sp.l*	1.33±0 .33^{abc}	1.66±0.33^{bcde}	2.66±0.33^{abcdef}
AMF+*T.h*+Bio+Comp+ F.*o.f.sp.l*	1.66±0.66^{abc}	2.00±0.33^{bcde}	2.33±0.33^{bcdefg}
F.o.f.sp.l	3.00±0.33^{a}	4.33±0.33^{a}	4.66±0.33^{a}
Control	0.66±0.33^{bc}	1.33±0 .33^{bcde}	1.33±0.33^{defg}

Key: DS-Diseases severity. In columns, superscripts with dissimilar letters show significant relationship between treatments at p<0.05; p<0.01and p<0.001. *In columns*, superscripts with dissimilar letters show significant relationship between treatments at p<0.05.

4.2 Discussion

In alignment with the major goal of this thesis work, the role of *T. h*arzianum, AMF, compost, and biochar as major treatments in combination and/or sole on pathogen inhibition, root colonization, yield, growth, and nutrient uptake parameters were investigated for two tomato varieties. First, to figure out the main contribution of each treatment throughout the plant life cycle sole treatments are independently applied to the plant and corresponding data were recorded. An improvement of the different parameters was observed in the plants treated with the arbuscular mycorrhizal fungi, *T. harzianum*, biochar, and compost in combined with or not to *F. oxysporum f.sp. Lycopersici* and compared to the control.

Time-interval based observation of the growth parameters was conducted for each variety at three different growth intervals of 15, 30, and 45 weeks, as shown in Figures 2 to 7.

According to Getachew and Gemechu, (2019) all growth parameters are different with varieties. This is observed in the current findings. When compared to other treatments and the control, *T.h+ F.o.f.sp.l* records the highest mean height during the 15 and 30 days in Galilea's growth. Within 15 days the two varieties provided with only AMF are crucial in the case of LA at this time. This is because, according to research by Guo *et al*. (2021), AMF is active in the early stages of plant colonization to increase nutrient uptake and improve photosynthetic traits of tomato leaves. It also increases stomatal conductance, transpiration rate, and chlorophyll, all of which contribute to the plant's growth. In the case of sole compost, time prolongations within 30 and 45 days improve more plant growth parameters. This is related to the decomposition process, which transforms potentially toxic or putrescible organic matter into a stabilized state that can enhance the soil for plant growth. In a similar vein, in Galilea, the stem diameter increases with compost over time.

Within 15 days, *T. harzianum + F.o.f.sp.l* increases the stem diameter and height in the case of Roma V.F.N. This is in line with research by Morinenka *et al.* (2021) which found that *T. harzianum's* effects on tomato plants were linked to early-stage increases in the activities of ascorbate peroxidase, guaiacol peroxidase, superoxide dismutase, and catalase. With AMF+ Comp, AMF+Bio + *T. harzianum*, and sole biochar, respectively, height, leaf area, and stem diameter are increased over the course of 45 days.

Individual applications of AMFs, *T.harzianum*, compost and biochar had positive effects on tomato growth, shoot, root, and total biomass, plant height, stem diameter, leaf area, and the majority of nutrient content in shoots. Compost consists of the relatively stable decomposed organic materials resulting from the accelerated biological degradation of organic materials under controlled, aerobic conditions (Adugna, 2016). The decomposition process converts

potentially toxic or putrescible organic matter into a stabilized state that can improve soil for plant growth. Adequate use of compost has been shown to have many advantages, including adding an array of nutrients to soils, increasing SOM, improving water holding capacity and other physical properties of soil such as bulk density, penetration resistance (Dang*et al*,, 2022) and relates positively to crop production (Oldfield *et al.*, 2020). In the current study, application of compost as a soil amendment strategy have shown better performance in tomato growth parameters as compared with the control and sole application treatments.

So that, the highest values of plant height (41.83±5.17 cm), leaf area (23.41±3.58 cm^2), steam diameter (7.27±1.03 mm), 148 g $plant^{-1}$ marketable yield, and 0.28 % P and 0.96 % K increment in nutrients uptake were recorded within the plants treated with compost followed by those treated with biochar with corresponding values of 37.50±2.92cm 19.33±3.40 cm^2,5.17±0.30 mm,121 $gplant^{-1}$, and 0.12 % P, 0.6 % K increment compared with control for Galilea variety. Application of compost displays the highest portion of P (0.71 %) and Ca (4.22%) among other nutrients as can be referred from Table 8. Improvement of P enhanced the photosynthetic traits of tomato leaves, stomatal conductance, transpiration rate and chlorophyll which lead to the highest gains in tomato yield (Guo *et al.,* 2021). These findings suggest that use of compost and biochar minimizes the sorption and leaching of nutrients in the soil which coincides with the findings of (Agegnehu, 2022) that compost and biochar applications on the soil resulted increment in plant nutrient uptake, growth, and yield.

This impact emanates from the boosting the exchangeable cations that can bind nutrient cations hence more available for uptake by plants (Guo *et al*., 2021). The results also significantly show Similarity for the Roma V.F.N.

Biochar used as an amendment, could have a promoting effect on plant growth and productivity as an indirect consequence of its positive effect on water holding capacity and pH enhancement, increased nutrient availability, organic carbon, and exchangeable cations(Simiele *et al.*, 2022).

Growing medium pH is an important characteristic in terms of nutrient availability and, in turn, plant growth. Growing substrates with a high cation exchange capacity can hold or bind nutrient cations; thus, nutrients are retained rather than leached and, therefore, more available for uptake by plants (Guo *et al*., 2021).

Biochar can improve the hydrolysis reactions of urea and the oxidizing ability of soil microorganisms by increasing the activity of urease and catalase (Yusif *et al*., 2019). The biochar addition increases the P available for plant growth due to increased phosphatase activity, and improves soil nutrients by increasing the abundance of soil microbial (fungi, bacteria, and actinomycetes).

The combined effect of biochar and AMF on plant growth may vary for different biochar types (i.e., biochar feedstock and production temperature) and application rates (Koide, 2017). For example, biochar produced from leaves improved soil P availability more than that produced from woodchip biochar (Zhou *et al.*, 2020), and biochar produced at a higher temperature increased AMF root colonization and spore germination more than that produced at a lower temperature, due to polycyclic aromatic hydrocarbons (PAHs) produced by biochar at low temperatures (Dunuweera *et al*., 2021).

According to (Sunusi Abdu Yusif and Dare, 2016) and (Warnock *et al.*, 2007) biochar application decrease in AM root colonization, this might be due to improved availability of P. Contrast to this another authors (Elmer and Pignatello, 2011) and (Yamato *et al.*, 2006) reported

that biochar amendments can increase AMF root colonization and spore density in plants grown in acidic soils. Improved colonization was also found due to decreased infection of plant pathogens after addition of AMF and biochar (Ding *et al*., 2016).

As a result of changes in soil properties and alterations in soil microbial activities, the current study demonstrates similar findings with that biochar in combination with AMF resulted vital for AMF spore density and root colonization compared with other combined treatments. Furthermore, for both tomato varieties, AMF+Biochar+Fus greatly raises marketable yields.

AMF transport nutrients that the plant requires with the help of ramifying fine absorbing hyphae (Mahdi *et al.*,2010).This association allows the plant to increase size, mass, seed production, resistance to pests, and drought allowing them to guarantee their establishment and success in disturbed site (Szczałba *et al*., 2019).

AMF helps plants to cope with biotic and abiotic stresses such as salinity, drought, extreme temperature, heavy metal, diseases, and pathogens (Begum *et al.*, 2019). For abiotic stresses, the mechanisms of adaptation of AMF to these stresses are generally linked to increased hydro mineral nutrition, ion selectivity, gene regulation, production of osmolytes, and the synthesis of phytohormones and antioxidants (Mohandas, 2012). Regarding the biotic stresses, AMF are involved in pathogen resistance including competition for colonization sites and improvement of the plant's defense system (Diagne *et al.*, 2020). In the current study inoculation of AMF significantly increase plant growth parameters, yield, and colonization by AMF and mycorrhizal dependency and have greater potential to suppress *Fusarium oxysporum* wilting pathogen of in the two varieties of tomato.

In the current study, the combined effect of AMF and compost on tomato growth and biomass productivity and production outperformed the control in Roma V.F.N. In case of Galilea some modifications are obtained. Authors (Getachew and Gemechu, 2019) observation showed variation of parameters scale are due to the variety type. In most cases, our findings indicate that sole application of compost increase growth and bio-mass yield than with the combination of AMF and compost. The AMF colonization and mycorrhizal dependency also decrease in combined inoculation, this is because AMF functions became more vigorous when OM concentrations in the soil were low, and the rate of AMF colonization decreased as OM concentrations increased.

Plants may suppress AMF development when they obtain sufficient nutrients through their own root system from compost (Grman, 2012). As a result, the suppressed AMF contributed less to production, which may indirectly limit SOM benefit delivery because AMF can enhance SOM decomposition (Gui *et al*., 2017).

T.harzianum have the ability to colonize cellulosic materials and, in the rhizosphere of plants, can induce systemic resistance against plant pathogens (Wanjiku *et al.*, 2021). Mechanisms of antipathogen activities are antibiosis, secretion of pathogen inhibiting compounds (lipolytic, proteolytic, pectinolytic and cellulolytic enzymes), which degrade pathogen cell walls (Awad-Allah *et al.*, 2022), induction of antioxidant enzymes in plants under stress (Galindo *et al., 2*018). Mironenka *et al.* (2021) investigated that effect of *T. Harzianum* inhibiting pathogen of tomato plants was associated with increasing activities of ascorbate peroxidase, guaiacol peroxidase, superoxide dismutase and catalase at the early stage after pathogen challenges.

T. harzianum is an important disease prevention target in this study, as shown in Tables 11 and 12 for both tomato varieties. Based on the comparison of the two varieties, it has completely avoided the disease incidence in Roma.V.F.N. This finding is agreed with (Ayana and Gabrekiristos, 2022), the best way to control the disease is by selecting resistant varieties of tomatoes. In addition, biocontrol fungi have a significant positive effect on plant growth, shoot and root wet and dry weights, nutrient uptake, and yield when compared to the control. However, the results showed that the scale and magnitude differed for both varieties, depending on the type of variety resistance (Getachew and Gemechu, 2019).

Furthermore, plants treated with *T. harzianum* and AMF had a lower percentage of infection than AMF-treated plants. In this scenario, other plant growth parameters and productivity are depicted in plants treated with both AMF and *T. harzianum*, as compared to each treatment and the control. The combined inoculation also resulted in high AMF root colonization. The findings are consistent with what Begum *et al*. (2019) observed as having the potential to alleviate disease incidence stress. Furthermore, combined inoculation of these fungi can increase tomato production and nutrient uptake in both varieties when compared to a control.

The treatment *T. harzianum* and AMF either individually or when combined together significantly lower disease severity in tomato plants, this findings corresponding to the findings of (Mwangi *et al.,* 2011) observed that tomato plants treated with both *T.harzianum* and AMF generally lower disease severity.

In this study, we analyzed for the first time the simultaneous use of compost, biochar, *T. harzianum* and AMF. The combination of AMF+*T. harzianum*+Biochar+compost+*F.o.f.sp.l* demonstrated the highest nutrient uptakein case of N, P and Mg compared to other inoculants

and control and also showed comparable performance in tomato growth and biomass productivity in both varieties in the current study. The percentage of spore density was lower in both varieties, and the plant's mycorrhizal dependency became completely negative as nutrients improved. This result, combined with (Grman, 2012), indicates that plants suppress AMF development when they obtain sufficient nutrients.

Fusarium oxysporum f.sp. Lycopersici pathogen occurs throughout most tomato-growing regions worldwide causing a vascular wilt that can severely affect the crop (Moretti *et al*., 2008) and the disease is considered as one of the main soil-borne systemic diseases. It causes significant losses in tomato production (Ozbay and Newman, 2004). The current study has shown that the inoculation with *T. harzianum* and AMF has reduced the impact of Fusarium oxysporum wilt. But it has also had a noticeable effect on the Galilea variety's fruit yield. *Fusarium oxysporum* pathogen effect is totally inhibited in the ROMA V.F.N. case, and no non-marketable yield is produced.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Improving soil characteristics and controlling plant pathogens via combined utilization of microbes and soil amendments has been widely recommended agricultural practices from both sustainable development and natural resource conservation perspectives. In this thesis work, the effect of inoculation of AMF and *T. harzianum* as bio-controller/fertilizer and while supplying compost and biochar as soil amendments on two tomato varieties is assessed. The performance assessment was carried out in terms of plant biomass, fruit yield, nutrient uptake, and *Fusarium oxysporum f. sp. lycopersici* pathogen withstanding capacity in the greenhouse.

From the overall plant growth performance characteristics throughout growth stages early days of growth for treatments AMF and its combination with *T. harzianum* was recorded the highest height, leaf area, and stem collar diameter for both varieties despite a slight difference per variety. In addition, better fruit yield and pathogen resistance was recorded for Roma variety, which provides a clue for different varieties show different resistance to wilting pathogen showing variety level investigations before concluding potential direction for extending these findings further.

The application of compost and biochar as a soil amendment resulted increment in plant nutrient uptake, plant growth parameters and yield. This study in disease prevention target demonstrated, *T. h*arzianum plays a vital role for both tomato varieties. In addition to this it has positive effect on plant biomass growth, nutrient up take and yield compared to the control. But different scale and magnitudes are observed for both varieties, this is based on the type of variety resistance. Similarly, combined with biochar resulted vital for root colonization, spore density and yields for both tomato varieties in this study. Inoculation of *Fusarium oxysporum f.sp. Lycopersici*

pathogen depressed both tomato varieties in all parameters. Combined inoculation of AMF and *T. harzianum* and amendment with biochar and compost improved growth, biomass yield, and nutrient uptake in the greenhouse in these findings.

5.2 Recommendation

On the basis of findings of this study the following recommendations are forwarded:

- Using bio controller and biofertilizers are recommended rather than using synthetic fertilizers.
- To enhance the rate of biomass productivity, all growth parameters and yield, use of compost and biochar are recommended.
- It is recommended to conduct additional research using disease-resistant varieties to achieve the target.

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APPENDIX

Appendix 1 Raw data of the thesis work

Table 13 Height, Steam diameter, and Leaf area of Galilea

Treatments	H(cm)15	H30	H45	LA(cm2)15	LA30	LA45	SD(mm)15	SD30	SD45
Sole AMF	13.5	24	31.5	12.5	13.75	15.4	4.42	5.4	5.25
	13	22.5	32	11.25	12.5	10	5.02	5.41	4.54
	16.5	26.5	31.5	19.5	22.5	22.5	5.1	6.34	7.02
AMF+ *F.o.f.sp.l*	10	20.5	26	16.5	21	22.5	4.53	5.17	5.08
	11	30	47	9	52.5	28.5	4.75	7.02	6.68
	13	21.5	29.5	12.5	15	16.25	4.42	5.59	6.44
Sole *T.harzianum*	16.5	25	25.5	12.5	11	11	3.51	6.66	4.25
	15	21.5	26	11	9	10	3.93	5.46	4.72
	9	14.5	21.5	9	5	10	3.4	4.88	4.14
T.harzianum +*F.o.f.sp.l*	16	37	30	9	12	11	4.01	5.03	4.41
	15	20	26.5	9	11	15	4.59	4.4	4.92
	14	18.5	26	7	5.25	9	3.75	4.96	5.15
AMF+*T.h*+ *F.o.f.sp.l*	14.5	25	30	13.75	22.5	21	5.6	5.48	5.44
	16.5	28	37.5	12.5	16.25	15	5.13	4.95	5.23
	20	34.5	43.5	13.75	16.25	18.75	5.54	6.45	5.08
Biochar	13	29.5	36.5	13.5	22.5	18.75	5.2	5.87	5.78
	14.5	26.5	43	10	13.75	25.5	4.94	6.48	4.78
	11	23	33	12.5	11	13.75	5.12	5.66	4.96
Compost	13	25.5	31.5	12.5	35	27	5.27	5.84	5.69
	15.5	35	47.5	13.75	24.5	27	6.12	6.61	9.22
	14	31.5	46.5	8	17.5	16.25	5.33	7.31	6.91
AMF+Bio+ *F.o.f.sp.l*	14	27	34	10	15	30	4.38	4.18	5.85
	12	24	45.5	10	16.25	27	4.72	5.16	6.85

	9.5	29	20	8	24	6	3.03	3.89	4.72
AMF+Comp *F.o.f.sp.l*	11	20	27.5	12	10	10	4.46	5.82	4.71
	14	25.5	32.5	11	16.25	15	5.05	5.92	5.07
	10.5	22.5	29	12	16.25	10	5.11	6.68	5.14
AMF+*T.h*+Bio+*F.o.f.sp.l*	14	31	42.5	9	18.75	20	5.18	5.88	6.7
	13	25	32.5	13.75	17.5	13	5.51	5.98	5.06
	11.5	25	31	11	12	17.5	6.13	6.22	6.73
AMF+*T.h*+comp+*F.o.f.sp.l*	12	22	34.5	10	10	20	5.29	5.88	5.23
	15	24.5	31.5	15	16.25	15	6.75	6.43	5.06
	10.5	27	38.5	13.75	50	17.5	4.1	6.06	5.81
AMF+*T.h*+Comp+Bio+*F.o.f.sp.l*	13	23	31.5	12.5	16.25	11	5.42	5.95	5.11
	12	23	17.5	8	28	17.5	4.42	4.65	4.91
	14	31	38	13.75	18.75	21	3.4	5.69	5.8
F.o.f.sp.l	10	15	22	8	9	16.25	2.91	4.29	4.36
	10.5	23.5	22.5	9	11	10	3.63	5.06	5.14
	10	18	23.5	9	8	8	3.73	5.26	2.89
Control	12	25.5	36.5	13.75	40	24	5.02	6.29	5.55
	11.5	26.5	31	12.5	22.5	17.5	5.9	6.42	5.01
	10	27.5	39	13.75	18.75	17.5	6.19	8.1,6.96	6.34

Table 14 Height, Steam diameter, and Leaf area of Roma. V.F.N

Treatments	H(cm)15	H(cm)30	H(cm)45	LA(cm^2)15	LA(cm^2)30	LA(cm^2)45	SD(mm)15	SD(mm) 30	SD(mm) 45
Sole AMF	14.5	31.5	36	24	25.5	18.75	5.18	5.76	6.45
	13.5	24.5	40	18.75	20	16.25	4.62	5.32	6.41
	12.5	29	42.5	22.5	43.25	28	4.69	5.43	11.8
AMF+ *F.o.f.sp.l*	10	27.5	42.5	11	34.5	27	4.64	4.63	5.25
	10.5	25	34	6	12	17.5	4.11	5.66	4.52
	12.5	35.5	48	11	30	33	4.43	6.59	6.65
Sole *T.harzianum*	13.5	24.5	35.5	13.75	13	24	4.54	6.17	5.36
	9.5	24	34.5	11	17.5	17.5	5.16	7.34	4.58
	15.5	34.5	47.5	25.5	31.5	42	5.48	6.13	7.48
T.harzianum +*F.o.f.sp.l*	17	34.5	46	15	24	16.25	5.46	5.79	6.64
	17	42	56.5	13.75	40.25	24	6.08	7.14	6.88
	15	36	49.5	22.5	23.75	42	5.31	5.52	7.27
AMF+*T.h*+ *F.o.f.sp.l*	11	26.5	37.5	13.75	18.75	16.25	4.78	5.18	5.54
	9	22	36	16.25	36	24	3.97	5.4	8.71
	12	17	26	15	25.5	35	3.21	3.6	8.3
Biochar	11.5	26	35	28	30	25.5	4.66	6.17	9.94
	15	41	51	18.75	45.5	27	5.35	5.48	9.74
	12	35	53.5	11	49	27	4.52	5.21	5.67
Compost	16	33	45.5	13	20	18.75	4.95	6.41	5.93
	11	26	29.5	11	36	42	3.19	3.14	6.76
	12	30	42	16.25	38.5	16.25	4.72	5.85	5.09
AMF+Bio+ *F.o.f.sp.l*	11	30.5	40	10	33.25	15	5.85	6.89	6.78
	11.5	38.5	43.5	13.75	28.75	20	5.47	6.83	8.43
	10.5	30.5	52	11	36	24	4.71	6.5	7.69
AMF+Comp *F.o.f.sp.l*	9	28.5	43.5	8.25	21	22.5	4.81	4.22	5.43
	10	34	47.5	18	42	24	5.45	5.37	6.69

	12.5	41	62	15	48	20	5.41	4.61	7.09
AMF+*T.h*+Bio+*F.o.f.sp.l*	13	30.5	45.5	12	35	30	5.32	6.57	6.77
	12.5	33	42.5	17.5	28.5	24	4.68	6.28	6.97
	12.5	37	56.5	18.75	42	36	3.94	5.46	6.12
AMF+*T.h*+comp +*F.o.f.sp.l*	14.5	31.5	38.5	12	18.75	17.5	4.73	6.05	6.81
	15	38	51	12	30	18.75	4.5	5.64	6.69
	14	39.5	51.5	13	27	20	4.42	5.88	6.89
AMF+*T.h*+comp+ Bio+*F.o.f.sp.l*	12	28.5	38	10	30	17.5	5.79	6.8	6.68
	13.5	33	43	12	27	20	4.37	6.63	6.72
	13	30	40	8.25	25.5	17.5	5.47	5.74	7.09
F.o.f.sp.l	11.5	35.5	25	8.25	16.25	13	4.61	4.94	5.06
	12	25.5	27	12	16.25	12.5	5.56	5.03	5
	11.5	28	40	9	15	12	5.07	5.9	5.6
Control	10	27	34	12.5	14	17.5	4.7	6.2	5.6
	9	31	38.5	9	10	17.5	4.19	6.49	5.44
	9.5	23.5	19.14	12.5	22.5	20	5.39	6.5	6.5

Table 15 Pathogen influence on tomatoes

Treatments	**Galilea**			**Roma.V.F.N**		
	PI (15)	PI (30)	PI (45)	PI(15)	PI (30)	PI (45)
Sole AMF	0	1	1	0	1	1
	0	1	2	0	0	1
	0	0	0	0	0	0
AMF+ *F.o.f.sp.l*	1	2	3	0	1	2
	2	2	3	1	1	1
	1	2	2	0	2	2
Sole *T.harzianum*	0	1	2	0	0	1
	0	0	1	0	0	0
	0	0	0	0	0	0
T.harzianum+*F.o.f.sp.l*	1	2	2	0	1	2
	1	1	1	0	0	0
	0	1	2	0	1	1
AMF+*T.h*+ *F.o.f.sp.l*	1	1	3	0	1	2
	1	1	1	1	1	1
	1	2	3	1	2	2
Biochar	1	2	3	1	2	3
	1	2	4	1	2	2
	1	3	4	1	3	3
Compost	1	2	3	1	3	3
	2	3	3	1	2	2
	1	1	2	0	1	1
AMF+Bio+ *F.o.f.sp.l*	2	4	4	1	3	4
	2	3	4	1	3	4
	2	3	4	2	2	2
AMF+Comp *F.o.f.sp.l*	2	3	3	1	3	4
	2	3	4	2	2	3
	1	2	3	1	3	3
AMF+*T.h*+Bio+*F.o.f.sp.l*	2	2	4	2	2	3
	1	2	3	1	1	2
	1	2	4	1	2	2
AMF+*T.h*+comp+*F.o.f.sp.l*	1	2	2	1	3	4
	2	3	3	2	3	3
	3	3	4	3	1	2
AMF+*T.h*+Comp+Bio+*F.o.f.sp.l*	1	2	3	1	3	3
	3	3	3	3	1	2
	1	2	2	1	2	2
F.o.f.sp.l	4	4	4	3	4	5
	3	4	5	3	4	4
	3	4	5	3	5	5
Control	1	1	2	1	2	2
	1	2	2	0	1	1
	1	1	1	1	1	1

Key;PI=Pathogen influence, *F.o.f.sp.l=Fusarium oxysporum formae speciales lycospersic, T.h=Trichoderma harzianum*

Table 16 Gelilea

reatments	SWW(g)	SDW(g)	RWW(g)	RDW(g)	Yield	
					Marketable	N. Marketable
Sole AMF	258	32	15	2	122	
	28	6	13	1	30	
	17	4	32	4	0	
AMF+ *F.o.f.sp.l*	16	4	6	2	47	
	46	14	25	1	63	
	19	4	12	3	30	
Sole *T.harzianum*	360	43	35	6	12	
	13	3	8	4	0	
	12	1	10	4	0	
T.harzianum +F.o.f.sp.l	14	3	25	4	15	
	11	3	12	1	11	
	10	2	5	2	11	
AMF+*T.h*+ *F.o.f.sp.l*	14	3	4	2	15	
	232	33	12	2	158	
	24	5	13	1	22	
Biochar	13	6	14	3	26	
	319	44	34	1	310	29
	15	2	6	4	27	
Compost	20	8	7	2	42	
	129	23	14	2	215	99
	63	14	28	1	187	
AMF+Bio+ *F.o.f.sp.l*	11	5	1	0.5	18	
	69	12	19	1	192	
	10	3	6	3	0	
AMF+Comp *F.o.f.sp.l*	40	7	14	2	62	
	16	2	10	2	28	
	16	3	10	1	19	
AMF+*T.h*+Bio+*F.o.f.sp.l*	25	7	22	3	44	
	103	18	25	4	37	
	16	2	11	1	23	
AMF+*T.h*+comp+*F.o.f.sp.l*	39	7	24	1	54	
	16	5	7	1	22	
	12	7	4	2	45	
AMF+*T.h*+comp+Bio+*F.o.f.sp.l*	11	3	12	3	15	
	10	2	3	0.5	0	
	31	6	17	2	54	
F.o.f.sp.l	10	3	5	0.5	0	
	4	7	7	0.5	0	8
	12	0	3	0.5	0	
Control	42	12	27	4	76	
	17	5	14	2	22	
	23	7	18	3	41	

Table 17 Roma V.F.N

Treatments	SWW(g)	SDW(g)	RWW(g)	RDW(g)	Yield	
					Markatable	N.Markatable
Sole AMF	50	23	40	5	75	
	60	19	104	5	95	
	126	10	36	22	170	
AMF+ *F.o.f.sp.l*	49	14	54	7	60	
	30	6	17	2	40	
	71	10	61	13	114	
Sole *T.harzianum*	24	5	13	3	35	
	34	6	21	4	60	
	36	8	29	1	92	
T.harzianum +*F.o.f.sp.l*	141	8	58	10	225	
	39	26	88	14	67	
	134	26	56	10	280	
AMF+*T.h*+ *F.o.f.sp.l*	24	5	33	3	51	
	28	5	18	1	78	
	54	9	19	5	80	
Biochar	32	7	55	6	56	
	66	16	42	5	85	
	116	21	21	2	206	
Compost	78	16	73	3	204	
	121	16	41	5	457	
	96	23	53	5	88	
AMF+Bio+ *F.o.f.sp.l*	46	8	21	3	88	
	88	15	25	4	236	
	60	11	25	4	102	
AMF+Comp *F.o.f.sp.l*	42	7	20	4	146	
	67	11	37	4	60	
	71	18	17	2	178	
AMF+*T.h*+Bio+*F.o.f.sp.l*	63	12	28	5	208	
	61	12	31	4	132	
	124	26	42	4	211	
AMF+*T.h*+comp+*F.o.f.sp.l*	30	7	17	2	30	
	98	15	20	4	246	
	122	23	33	3	223	
AMF+*T.h*+Comp+Bio+*F.o.f.sp.l*	25	4	13	3	74	
	55	9	24	3	151	
	57	10	28	2	112	
F.o.f.sp.l	12	3	16	1	19	
	19	3	9	1	13	
	48	9	7	1	44	5
Control	28	7	34	2	21	
	35	9	20	3	36	
	63	12	15	4	93	

Appendix 2 pictures prepared during the thesis work

Figure 8 AMF Inoculum preparation (left), Drying the AMF inoculum (middle), and seeds of tomato (right)

Figure 9 Germinated seeds (left), Transplanted 20 days old tomato seedlings (middle), and After 15 days of transplantation (right)

Figure 8 preparation of planting pots

Figure 9 spores used

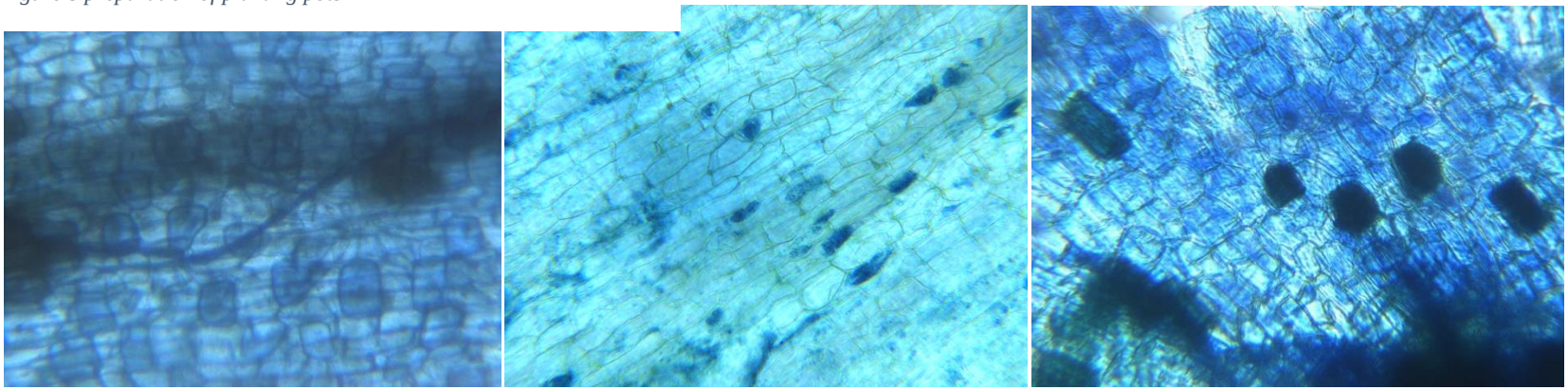

Figure 10a. AMF root colonization

Figure 11 Isolated of F.oxysporum.f.sp.l (left) and T.harzianum isolate (right)