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Production of Vegetable Crops by Using Arbuscular Mycorrhizae

Ozlem Altuntas

Abstract

In modern agriculture, application of beneficial microorganisms has become more reliable and alternative source to reduce the application of pesticides. Several studies demonstrate that the beneficial microorganisms like arbuscular mycorrhizal (AM) fungi, *Pseudomonas* species, *Trichoderma* species etc. increase the plant growth and their and also improve the quality of soil. Additionally, these microorganisms increase the resistance of host plants against biotic and abiotic stresses. In the present chapter; vegetable crops in horticultural systems were focused. Most of the vegetable crop form symbiotic relationship with mycorrhiza acting as a bridge for the flow of energy and matter between plants and soils. The symbiotic relationship includes most species of vegetables and some species of fungi that have great relevance to soil ecosystem functions, especially nutrient dynamics, microbial processes, plant ecology, and agriculture. AMF can improve the nutrient and water uptake, induce tolerance of abiotic and biotic stress of their host plants. In the sustainable agriculture, the association of soil microorganisms with plant roots can also be exploited and in this way improve plant growth and productivity under normal and stressful environment. As a result, mycorrhizae improves plant growth, root structure development and crop yield and quality in almost any ambient condition. In addition, another benefit of mycorrhizae is that plants are resistant to diseases. it is concluded that arbuscular mycorrhizal infused pepper seedlings have high yield and quality. And also arbuscular mycorrhizae can be recommended for high yield and quality crop.

Keywords: Arbuscular mycorrhiza, vegetables, plant growth, nutrient uptake, yield

1. Introduction

Industrialization and rapid population growth, especially after World War II, caused significant environmental problems around the world. Among these problems, the most significant one was the hunger. In order to overcome this problem, different opinions have been put forward. One of them was to acquire new areas to agriculture while the other was to obtain maximum yield per area. Since the first suggestion was not easy to practicable, second one shined out as an important opportunity. As the world population grows, providing the necessary food for people to feed will increase the demand for agricultural production, which will be the biggest challenge facing agriculture. To meet this challenge, there is a need to focus on the soil biological system in the farmed land and the agricultural ecosystem as a whole. When we look at the current situation; although the food produced is not insufficient, there is a problem in distributing it to the regions in need. As a result of the problem arising from this distribution injustice (there are regions with hunger

problems in the world), it has led to high input agriculture and green revolution for higher yields. In the green revolution, high inputs were used for high efficiency, injustice in the distribution of products to the world continued, while there was an excess of wasted food in some regions, the need for food continued in hungry regions. However, the constant and alarming increase of the human population still threatens the world's food security. Therefore, it is thought that a second green revolution will be needed to increase food production by about 50% in the coming years [1, 2]. Moreover, the use of chemical fertilizers has theoretically reached its maximum use and there will be no yield increase due to the use of fertilizers [3, 4].

It is becoming increasingly clear that while increasing the yield by applying more chemical fertilizers to the soil, the soil and plants cannot maintain a healthy production for a long time. Because indiscriminate and over-application of chemical fertilizers poses a danger to human and environmental health, agronomists have sought alternative strategies that can ensure productivity while maintaining soil health. This new concept of agriculture, often referred to as "sustainable agriculture", requires agricultural practices that are environmentally friendly and maintain the long-term ecological balance of the soil ecosystem. In this context, the use of biofertilizers (beneficial microorganisms) in agriculture constitutes an environmentally friendly alternative to other applications of mineral fertilizers. Continuous investigation of the natural biodiversity of soil microorganisms and optimization of microbial interactions in the rhizosphere are prerequisites for the development of more efficient microbial inoculants. In agricultural production, in addition to providing sufficient food for the increasing human population, the quality of agricultural products, healthy, ecologically compatible, environmentally friendly techniques are increasing. Application of beneficial microorganisms, is an important techniques that improve the ecosystem, soil and human health.

For example, excessive use of nitrogen fertilizers causes nitrate accumulation, especially in green leaf-eaten crops, and contamination of groundwater by leaching of nitrogen fertilizers. The reduction or replacement of chemical fertilizers with the use of beneficial microorganisms has been proven by studies [5–7]. Since beneficial microorganisms fulfill important ecosystem functions for plants and soil, both healthy and high quality agricultural production and reduction of chemical input use can also play a key role in preventing yield reduction [8–13]. Moreover, in modern agriculture, many plant species traditionally produced due to the use of chemicals are susceptible to diseases. Stimulation of plant growth and crop protection can be improved by the direct application of a number of microorganisms known to act as bio-fertilizers and/or bio-preservatives. In addition, the production of metabolites related to root development and pathogen control (phytohormones, antimicrobials, antibiotics) and their direct effects on some metabolic activities, plant nutrients and water can be counted as their most obvious benefits. Although it has been repeatedly demonstrated over the last 150 years that bacteria and fungi promote plant growth and suppress plant pathogens, this knowledge has not been extensively used in agricultural biotechnology [14].

The second most common microorganism in the soil is fungus. It is the most preferred and studied group of soil fungi, which are mostly related to photosynthetic plants as mycorrhizal symbiotics. Mycorrhizae represent a vital component in plant ecosystems: They are widely distributed in natural and agricultural environments and are found in more than 80% of land plants, liverworts, ferns, woody gymnosperms and angiosperms and grasses. Providing an effective nutrient and water uptake, resulting in increased yield and resistance to environmental stresses (biotic and abiotic) most land plants need to be associated with mycorrhizal fungi. The use of plant - mycorrhiza symbiosis in natural and agronomic environments has high environmental and economic value. Mycorrhiza; It is a term derived from the Greek

words mykes and rhiza, meaning mushroom and root respectively [15]. It was first used in 1885 by Albert Bernhard Frank. Mycorrhiza expresses a symbiotic life between soil fungi and plant roots [16]. Arbuscular mycorrhiza (AM) replaced the earlier term “vesicular–arbuscular mycorrhiza” (VAM) because not all endomycorrhizae of this type develop vesicles, but all form arbuscules.

Mycorrhizae are found in many environments and their ecological success is due to their wide variety. About 6000 species of mycorrhizal species in *Glomeromycotina*, *Ascomycotina* and *Basidiomycotina* have been recorded, and the use of molecular techniques increases this number. The taxonomic position of plant and fungal partners defines the mycorrhiza species; for this the main distinction is between endomycorrhizae and ectomycorrhizae. With the symbiosis ectomycorrhizae (ECMs) in the roots of trees and shrubs, hyphae remain extracellular and cause significant changes in root morphogenesis. In addition, ectomycorrhizae cause only subtle changes in epidermal or cortical cells [17]. In the endomycorrhizae, namely the arbuscular (AMs), ericoid, and orchid mycorrhizae, hyphae penetrate the stem cells to form an intracellular symbiosis independent of the plant host. While AMs are common among various plant taxa [18], the ericoid and orchid mycorrhizae are restricted to the family Ericales and Orchidaceae, respectively [19]. Arbuscular mycorrhizal (AM) fungi improve soil structure and aggregate stability [20]. Therefore, it can be expected to increase water absorption and plant nutrient uptake by plants in the treated soil, which may increase plant growth [20, 21]. Arbuscular mycorrhizal (AM) fungi, which are in symbiotic relationship with the roots of the majority of land plants, increase the nutrient-absorbing root surface area in the host plant through external myceliums [22]. In other words, root surface area increase is that mycorrhizae develop an extramatric mycelium, which in turn increases the plant nutrient absorption sites of the roots [23]. Since arbuscular mycorrhizal fungi are obligate endosymbionts and live with carbohydrates derived from stem cells, all soil factors affecting plant growth and physiology will also alter fungal activity and thus affect the structure and functioning of bacterial communities [24]. It is now well understood that arbuscular mycorrhizal fungi alter root functions [25], alter the carbohydrate metabolism of the host plant, and affect rhizosphere populations [26]. Microorganisms in areas where hyphae of arbuscular mycorrhizal fungi extend may affect mycorrhizal functions such as nutrient and water uptake by arbuscular mycorrhizal fungi.

During intergenerational interactions, arbuscular mycorrhizal fungi improve the phosphate nutrition of plants by using the available phosphorus in the soil due to the large root surface area and high affinity phosphate uptake mechanisms created by the hyphae [27, 28]. The role of arbuscular mycorrhizal fungi in improving plant phosphate nutrition and their interactions with other soil biota has been investigated with reference to host plant growth, there is research on the organic acid production of arbuscular mycorrhizal fungi that can dissolve insoluble mineral phosphate [29, 30]. AMF has a number of well-documented effects on plant nutrition ([31], new literature), it is worth highlighting the potential role of AMF in micronutrient uptake in particular [32, 33] because of its important implications for the nutritional value of plant products. In addition, AMF potentially contributes to increased drought resistance of the crop by improving plant-water relationships through a variety of mechanisms [19]. In addition, AMF may interact with beneficial microorganisms such as phosphate-dissolving bacteria [34], with potential beneficial contributions to the nutrient cycle and plant nutrition. At the ecosystem scale, AMF gains importance with its effects on soil aggregation in soils where organic matter is the main binding agent. Soil aggregation has important implications for carbon storage [35, 36]. In addition to increasing water and nutrient intake in the soil, AMF, which provides carbon storage in the soil, is one of the main determinants of soil

quality. AMF plays important roles in agroecosystems, including the participation of extra radical mycelium in promoting soil aggregation. Among these functions is their role in soil aggregation, hypothesized to be partly mediated by a proteinaceous compound released by an actively growing AMF mycelium in the soil: glomalin [37, 38]. This proteinaceous compound, which was operationally identified and extracted from soil as glomalin-associated soil protein [39], is highly associated with an important soil parameter and total water stability [40].

In order to ensure desired yields in vegetable cultivation, chemical fertilizers are applied in excess amount. In addition, more fertilizer are used in greenhouse vegetable growing because of the 2–3 times higher yield and the longer production season. There is a greater need for farmyard manure in greenhouse and field vegetable growing than other production systems. However, it is quite hard to supply large quantities of farmyard manure. For this reason, the need for plant nutrition instead of organic fertilizer in the soil is generally provided by chemical fertilizers. It is known that mineral fertilizer applications, especially nitrogen, are washed from the soil profile and cause pollution in ground waters. It is also believed that chemical compounds contribute to the greenhouse effect and the ozone layer under certain conditions. As a result of these negativities, agricultural practices that are friendly to the environment and which do not disrupt the ecological balance into the soil have been needed. In this context, biological fertilizers, plant stimulants and biological pesticides have been considered as resources that are able to meet the nutrients needed by the plant. Microorganisms to be used as biological fertilizers; should be simple to apply cheap, have high metabolic activity and be able to store for a long time.

As mentioned earlier, the use of excessive agricultural inputs to solve the hunger problem, which is the result of increased population, corrupts food and living quality. For this reason, organic farming has become an important part of the world and researchers have done a lot of study on this subject. However, the limited agricultural inputs that can be used in organic farming make plant nutrition difficult in this production system. In this case, the use of bio-fertilizers for their many positive effects on plants can be an alternative solution for this problem. In this review, the use of mycorrhizae (one of bio-fertilizers) for different purposes in vegetable growing was considered.

Vegetables are an important source for human nutrition. Turkey's geographical conditions enable the cultivation of all kinds of vegetables [16]. Greenhouse vegetable production in the Mediterranean countries are an important agricultural sector. Open field vegetable cultivation requires a long vegetation period, and high yield requires more intensive use of fertilizers in the greenhouse cultivation. Useful soil microorganisms are destroyed during the disinfection of greenhouse pests. These microorganisms do not exist in soilless cultivation media.

2. Use of mycorrhiza in soilless vegetables cultivation in the greenhouses

The effect of mycorrhizal inoculation with two species (*Glomus clarum* and *Glomus caledonium*) and three different inoculation treatments (sowing, transplanting and sowing + transplanting) were applied on pepper hydroponically grown on perlite medium. *G. clarum* and *G. caledonium* increased 29% and 21% respectively with respect to the control plants (**Table 1**). *G. clarum* was more effective on pepper yield. As seen in the **Figure 1**, plant growth and development especially root growth was excellent in plants inoculated with mycorrhizae. Mycorrhizae treatments increased pepper yield [41].

Dasgan et al. [42] studied soilless grown tomatoes inoculated with mycorrhizae in a plastic greenhouse (**Figure 2**). The substrate 1:1 perlite + cocopeat and nutrient

Experiment	Control	<i>G. caledonium</i>	<i>G. clarum</i>
Sowing (S)	839.92	912.38	1071.25
Transplanting (T)	839.92	964.67	989.71
S + T	839.92	1076.58	1116.54

Table 1.
The effect of mycorrhizae on the yield of peper plants at spring season (g plant⁻¹).



Figure 1.
Effect of mychorrhiza on the growth of pepper plants.



Figure 2.
Effect of mychorrhiza on the growth of tomato plants.

solution (full strength nutrients, the nutrient solution contained 20% and 40% and 60% reduced nutrients) were used. The yield was increased by mychorrhizae. The mycorrhizae along with nutrient solution responded differently. The higher yield was obtained in 60% nutrient solution (Table 2).

Treatments	Total yield
100% nutrient + M	9.65 c
80% nutrient + M	11.65 b
60% nutrient + M	13.40 a
40% nutrient + M	11.15 b
P	0.0035
LSD 0.005	1.39

Table 2.
The effect of nutrients and mycorrhizae on the yield of tomato plants (kg m⁻²).

G. Fasciculatum was applied on tomato variety M19 and perlite was used as the substrate [43]. The mychorrizae use in soilless cultivation increases the tomato fruit yield. The highest yield (19.5 kg m⁻²) was produced with the treatment under Open (M+) system (**Table 3**). The mychorrizal colonization in the open or closed systems affected the tomato yield. Higher fruit production was found for the mycorrhizal versus the non-mycorrhizal plants in both closed and open systems. Closed (M+) plants and Open (M+) plants produced 6.7% and 5.0% of higher yields, respectively, than those of the Closed (M-) and Open (M-) plants.

Yilmaz and Gül [44] studied the effect of mycorrhizae and phosphorus on the growth of eggplant (**Figure 3**). The cultivar Phaselis F1, and *Glomus caledonium* and the pumice were used. Among the 3 different phosphorus (15, 30 and 45 ppm) treatment, 15 ppm enhanced the yield along with mycorrhizal inoculation (**Table 4**).

Mycorrhizae fertilizer under the trade name ‘Endo Roots Soluble’ (ERS) was used in the experiment. The seeds of squash were directly sown into the substrate of perlite-cocopeat mixture in 1:1 ratio and cocktail mychorrhiza which contained *Glomus aggregatum*, *Glomus clarum*, *Glomus deserticola*, *Glomus etunicatum*, *Glomus intraradices*, *Glomus mosseae*, *Glomus monosporus*, *Glomus brasilianum* and *Gigaspora* [45]. The highest yield was obtained from the cocktail mychorrhiza +nutrients solution(80%) (**Table 5** and **Figure 4**).

Dere et al. [46] investigated the growth of cantaloupe melon at reduced mineral nutrients and mycorrhizal treatments ((1)100% full nutrition(control), (2) 100% full nutrition+mycorrhiza, (3) 80% nutrition,(4) 80% nutrition+mycorrhiza (5) 60% nutrition (6) 60% nutrition+mycorrhiza (7)40% nutrition, (8) 40% nutrition+mycorrhiza) (**Table 6**).

Mycorrhizal inoculation is an important for sustainable agriculture, as like chemical and biological factors in the soil strongly influence nutrient management.

Treatments	Yield
Closed (– M)	16.8 b
Closed (+ M)	18.0 b
Open (– M)	18.5 ab
Open (+ M)	19.5 a
P	0.047
LSD 0.005	1.758

Table 3.
The effect of mycorrhiza on the yield of tomato plant (kg m⁻²) at colosed and open system.



Figure 3.
Effect of phosphorus and mycorrhiza on the soilless grown eggplant plants.

Treatments		1st year	2nd year
Mycorrhiza	—	4,67 b	4.88
	+		5.01
	LSD 0.05	0.22	ns
P doses	15 ppm	5.03	4.64
	30 ppm	5.09	5.25
	45 ppm	4.93	4.95
Mycorrhiza X P	- 15	4.51 d	4.33
	- 30	4.72 cd	5.42
	- 45	4.77 cd	4.89
	+ 15		4.95
	+ 30	5.46 ab	5.09
	+ 45	5.10 bc	5.00
	LSD 0.05	0.38	ns

Table 4.
The effects of phosphorus and mycorrhiza on the total yield of soilless grown eggplant plants (kg plant⁻¹).

Treatments	100% Nutrients	80% Nutrients	60% Nutrients
M +	383 b	1019	532
M -	797 a	984	598

Table 5.
The effect of mycorrhiza and reduced nutrients on the yield of squash plants under open soilless system (g m⁻²).



Figure 4.
Role of cocktail mycorrhiza on the summer squash plants in the greenhouse.

Treatments	Total yield
100% N + M	9.64 b
100% N	8.28 bc
80% N + M	12.44 a
80% N	8.33 bc
60% N + M	6.09 cd
60% N	5.72 d
40% N + M	6.11 cd
40% N	5.93 cd

N: Nutrition, M: Mycorrhiza. Different letters on a column indicate significant differences according to Tukey's test ($P \leq 0.05$).

Table 6.
Effect of mycorrhizae on total yield of melon in the reduced nutrient levels.

For sustainable nutrient and water management, soil and crop management can be improved by using selected mycorrhizal spores [47] or by producing mycorrhizal inoculated on seedlings [48].

3. Conclusion

The cultivation of vegetables is a very important in the agricultural sector. For healthy vegetables production, the organic farming is one of the ways to bring stability and sustainability to agriculture. The complete elimination of chemical fertilizers is not possible. But the biofertilizers may reduce the chemical inputs. Mycorrhizae increase the plant growth and yield by providing water and nutrients. In conclusion, the mycorrhizae are important for the growth of agricultural crops as well as the health of ecosystem. Mycorrhizae inoculated plants can easily adapt to greenhouse and field conditions.

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