26 Field Trials of Bioinoculants

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26.1 Introduction

The most widespread symbiotic association between micro-organisms and higher plants are arbuscular mycorrhizae (AM), which are present in a range of horticultural, agricultural and forestry plants. The term mycorrhiza, which literally means *fungus-root* (*myco*, fungus; *rhiza*, root), was first applied to fungus–tree associations described in 1885 by the German forest pathologist A.B. Frank. Mycorrhiza is a mutalistic symbiosis (non-pathogenic association) between soil-borne fungi and the roots of high plants. The symbiosis between fungi and plant root is a bi-directional movement of nutrients where carbon flows to the fungus and inorganic nutrients move to the plant, thereby providing a critical linkage between the plant root and soil in the rhizosphere. Mycorrhizal fungi usually proliferate both in the root and in the soil. In natural ecosystems, in nutrient-poor or moisture-deficient soils, nutrients taken up by the extrametrical hyphae can lead to improved plant growth and reproduction. Since mycorrhiza-inoculated plants take more nutrients, they are more competitive and better able to tolerate environmental stresses than non-mycorrhizal plants. It has been estimated that 90% of all plant species belong to genera that characteristically form mycorrhizae (Smith and Read 1997). Mycorrhizal infection occurs in 83% of dicotyledonous and 79% of monocotyledonous plants (Peterson et al. 2004).

A mycorrhizal root system seems able to selectively absorb phosphorus (P) from deficient soils (Fig. 26.1). In all these kinds of mycorrhiza, it is usual to find hyphal connections from the infected root into the soil. The hyphae may extend considerable distances (centimeters). The role of hyphae in mycorrhizal

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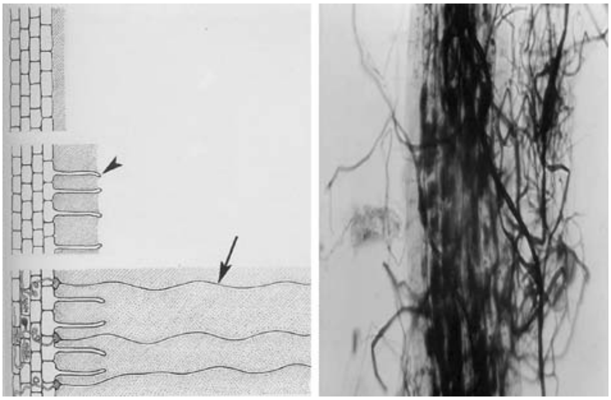

Fig. 26.1 The role of mycorrhizal hyphae on nutrient depletion zone (Peterson et al. 2004)

infection and nutrient uptake has not been studied intensively because a convenient technique was not developed until recently. It has been estimated that the amount of external hyphae is 80 cm/cm root length in onions (Sanders and Tinker 1973). However it is not easy to measure the amount of external hyphae formed in soil by mycorrhizal fungi.

26.2 Effect of Mycorrhizal Infection on Nutrient Uptake

AM infection can increase plant growth and nutrient uptake, especially an increase in P uptake by the host. The contribution of mycorrhizae is considered to be a function of an increase in P uptake due to mycorrhizal infection. Plant roots infected with AM fungi are known to have a higher P absorption ability compared with non-mycorrhizal plants in P-deficient soils (Abbott and Robson 1982).

Arbuscular mycorrhizal fungi (AMF) are generally known to benefit plant nutrient uptake such as P in soil of low fertility (Ortaş 2003). Mycorrhizal inoculation have a positive effect on maize plant P uptake, which was exhibited even when high level of P was applied; but high P fertilization reduced the degree of root colonization and also the quantity of external hyphae (Posta and Fuleky 1997).

In arid and semi-arid areas such as Turkey there are limitations on the amount of water used for plant cultivation and most of the soils are low in nutrient content, such as P, Zn and Fe, which are diffusion-limited in soils. Even if there were no deficiency of nutrient, there are several environmental stress factors such as temperature and, consequently, accumulation of salt in the soil due to evaporation. Thus there is a tendency to use the natural sources such as mycorrhizal fungi to reduce P fertilizer application and hence obtain better plant growth in nutrient-deficient soils. Also mycorrhizal inoculation reduces the quantity of P fertilizer normally required (Charron et al. 2001). Soil chemical and biological factors strongly affect P management. It seems to be very important to manage P in soil, since it is an ecological necessity for the future of soil quality.

For a given dry weight, mycorrhizal plants usually have higher P concentrations in their plant tissue than non-mycorrhizal plants (Stribley et al. 1980). How mycorrhizal plants obtain more P from soil than non-mycorrhizal plants is not yet fully understood. Several mechanisms have been proposed to define the AM effect on improving the absorption of available phosphate and these have been mentioned. Mycorrhizae may induce both quantitative and qualitative changes in plant P utilization (Smith and Read 1997). The amount of acid phosphatase present in AM hyphae (Tarafdar and Marschner 1994) and increased phosphatase activity of root surfaces as a result of infection (Allen et al. 1981) may liberate inorganic P from organic P sources, making P available for uptake. Tinker (1975) suggested that the roots of mycorrhizal plants may alter the rhizosphere chemistry by changing soil pH and may produce exudates such as organic acids which may increase the availability of phosphorus by liberating phosphate ions in the soil. There is still a wide gap in the understanding of the mechanisms involved in increased P availability in the soil by mycorrhiza-infected roots.

In addition to P, AM fungi enhance the acquisition of other nutrients, such as N and K, and immobile micro-nutrient cations, particularly Zn and Cu (Li et al. 1991).

Fries et al. (1998) tested the effect of different levels of P application on mycorrhizal formation and they found that under low P levels, a mycorrhiza-inoculated plant accumulated a greater amount of shoot dry weight, root P concentration and protein concentration than a non-inoculated plant. Medeiros et al. (1994) showed that mycorrhiza-inoculated plants had significantly higher uptake of P, K, Fe, and S than non-mycorrhizal plants. Plants colonized with AM fungi generally have greater growth and acquisition of mineral nutrients and often have a greater ability to withstand drought, compared with non-mycorrhizal plants (Al-Karaki and Clark 1998).

26.3 Effect of Soil Fumigation and Mycorrhizal Inoculation on Plant Growth Under Field Conditions

In the plain of Cukurova there is a serious problem with soil-borne disease such as plant parasitic nematodes, soil-borne plant pathogens, root-rot and some weed pests. Nearly 25% of yield reduction occurs from year to year. In order to prepare a safe seedbed and healthy yield, farmers are using a high amount of chemicals. Due to a combination of soil-borne pathogens, nematodes and weeds, soil fumigation with products such as methyl bromide (MeBr) has been essential for horticultural practice in this area. Since MeBr eliminates both desirable organisms such as arbuscular mycorrhizal fungi (AMF) and undesirable soil organisms, the plant growth and nutrient uptake, especially P and Zn uptake, have significantly declined.

Soil fumigation, as a partial soil sterilization, affects soil chemical properties in addition to the removal of viable mycorrhizal fungi and other micro-organisms. The fertility of sterilized soil may be different than non-sterile soil. Partial soil sterilization generally stimulates subsequent plant growth when compared with non-sterile soils (Ortaş et al. 2004). The main aim of partial soil sterilization in mycorrhizal studies is to eliminate indigenous mycorrhizal spores and pathogenic microbial activity in the soils, but this procedure often alters the chemical and biological properties of the soil.

Soil fumigation may have a dual effect on plant growth, such as increased growth by elimination of soil-borne pathogens, or conversely, stunted growth by exacerbation of existing P deficiency. As a result of reduction of mycorrhizal colonization in low-P soils with soil fumigation, there is a Br accumulation in the soil and plant uptakes in Br are more than ten times greater than control plants (Haas et al. 1987).

Since soil fumigation reduces useful organisms such as mycorrhizae, it is necessary to reinoculate mycorrhizae. Especially mycorrhiza-dependent plants need more mycorrhizal inoculation. It is very important to use mycorrhiza at least for horticulture plants which are transplanted to the soil as a seedling. It may be easy to produce mycorrhiza-inoculated seedlings.

For these reasons, several field experiments were set up to investigate the interaction effect of MeBr, mycorrhizae and P fertilizer on plant yield, growth, nutrient uptake and mycorrhizal formation. The aim of the research is to investigate the effect of MeBr, mycorrhizae and P fertilizer interaction on plant yield, growth, nutrient uptake and mycorrhizal formation. The overall results revealed that yields were lower in sterile (fumigated) plots than in the non-sterile (non-fumigated) ones. Conversely, MeBr application reduced yield compared with the non-fumigated one whether or not the plants were inoculated. As can be seen in Fig. 26.2, under field conditions, the yield of onion plants grown in the MeBr-treated plot was reduced. But mycorrhizal inoculation compensated the yield reduction, compared with the non-inoculated plots.

In this experiment rhizosphere soil was also used as a mycorrhizal source; and it was found that, under field conditions, indigenous mycorrhizal inoculation increased the onion yield in sterile plots. The interpretations of the results show that mycorhizal inoculation may have had some other benefits to the plant, such as protecting it against soil-borne pathogens and environmental stress.

The impact of mycorrhizal fungi is usually assessed by measuring plant growth and P uptake following inoculation of the fungi into sterilized soils (Hetrick et al. 1986). However, growth responses are erratic and sometimes occur when AMF are added to non-sterile soil (Ortaş et al. 1996). In some cases, the root colonization is less in non-sterile soil than in sterilized soil.

Farmers use MeBr before horticultural crops are planted, for the elimination of undesirable soil organisms. At the same time, they kill off all organisms. Since the organisms have a long-term effect on sustainability and quality of soil, it is

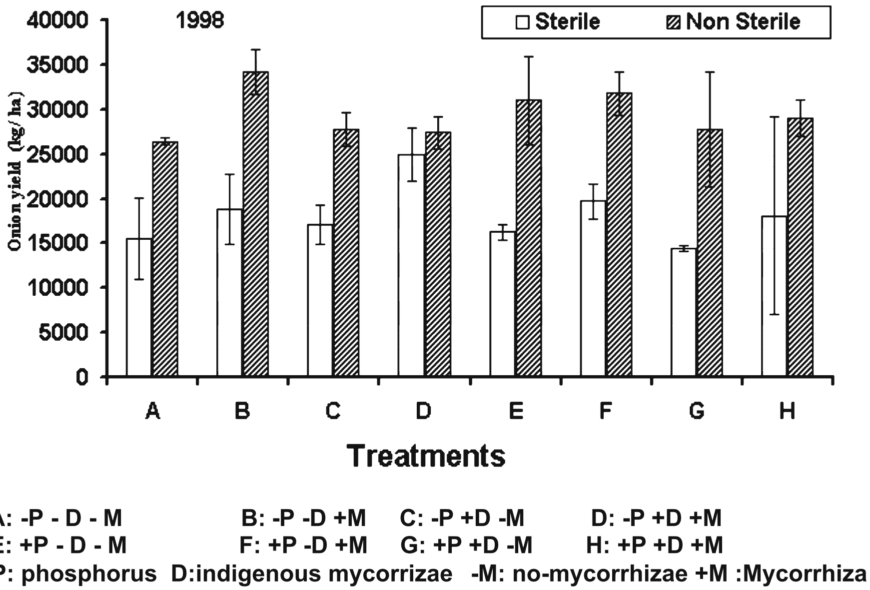

Fig. 26.2 Effect of MeBr on onion yield under field conditions with and without indigenous and selected mycorrhizae

sound to use alternative fumigant sources rather than MeBr. For example, using organic sources and mycorrhiza and their combination are alternative sources.

Ortaş et al. (2003) showed that AMF was very active in plants grown on non-fumigated soil and that AMF activity increased plant growth and nutrient uptake. In non-fumigated plots it seemed still that AMF were active since there was a high mycorrhizal infection.

Ortaş et al. (2003) showed that mycorrhizal inoculation increased plant yield significantly, compared with non-inoculated plants. When zero P was applied, the effect of mycorrhizal inoculation on plant yield was higher than yield increased with additional P application. When zero P was applied, mycorrhizal inoculation increased tomato yield up to 52%, eggplants up to 28% and pepper up to 36%, but with P addition, mycorrhizal inoculation increased yield up to 28%, 14% and 21%, respectively, compared with non-inoculated plants (Fig. 26.3). Mycorrhizal inoculation also increased plant zinc and copper uptake (Ortaş et al. 2003).

In fumigated plots P and Zn content reduced dramatically, which was related to a reduction in AMF colonization (Ortaş et al. 2003). Mycorrhizal inoculation increased the root Mn concentration but not the shoot Mn concentration.

It seems that plant yield supplied by mycorrhizal inoculation cannot be explained only by the effect of mycorrhizal inoculation on nutrient uptake. Olsen et al. (1999) found that mycorrhizal inoculation increased the pepper and tomato growth and they claimed that the growth response of vegetable crops grown within the greenhouse from colonization by an established mycorrhizal

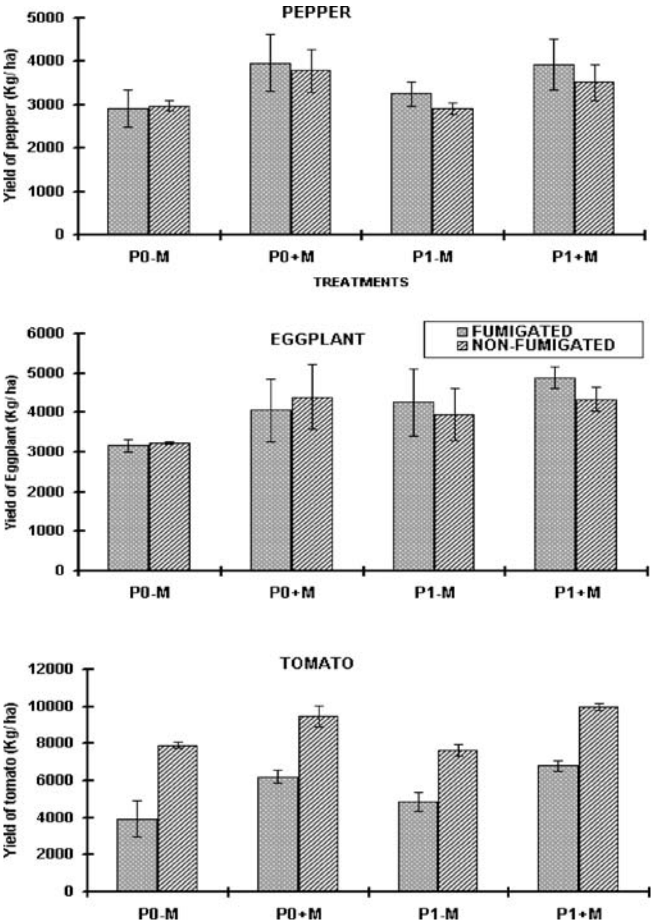

Fig. 26.3 The effect of MeBr and mycorrhizal inoculation on eggplant, tomato and pepper yields under field conditions

mycelium appeared to depend on a critical balance of P and C supply. Since the soil P level was medium and the plant P content had not been affected by mycorrhizal inoculation, it meant the soil P level was enough for both mycorrhizal and non-mycorrhizal plants. In the same field the experiment was repeated with several mycorrhizal inoculum for three years and the conclusion was that the effect of mycorrhizal inoculation on plant growth under field condition depends on year, and mycorrhizal inoculum potential.

It appears that there are some other benefits from mycorrhizae for horticultural plants, such as controlling disease and increasing plant resistance. We conclude that, although mycorrhizal inoculation increases some vegetable yield, this increase is not easily explained through a better nutrient uptake by AMF plants than by un-colonized plants. Mycorhizal inoculation may have some other benefits to plants, such as protection against soil-borne pathogens and environmental stress.

Most of these studies have been performed in the greenhouse under controlled conditions without the influence of complex interactions of other environmental variables. When bringing any mycorrhizal question to the field, one of the more difficult problems is the creation of a suitable non-mycorrhizal control, since a majority of plants is normally mycorrhizal. Fungicides can be useful in distinguishing the mycorrhizal effects on plants in the field from certain other influences.

Eggplant, tomato and pepper are among the most valuable vegetables grown for fresh-market production in Cukurova region, Adana-Turkey. Due to a combination of soil-borne pathogens, nematodes and weeds, the use of soil fumigation such as MeBr has been essential for horticultural practice in this area.

26.4 Effect of Mycorrhizal Inoculation on Plant Growth and Nutrient Uptake under Non-Sterile Field Conditions

Indigenous AM fungi have been found in most non-sterile soils and experimentally it has been shown that introduced mycorrhizal inoculum can infect the host plant under non-sterilized soil conditions (Abbott and Robson 1978). This treatment usually alters soil fertility as the result of an alteration of soil chemical and biological properties (Ortaş and Harris 1996). Although soil fumigations stimulate plant growth through eliminating the soil-borne pathogens and weeds, fumigation usually stunts plant growth due to a reduction in the viable AM population in low-fertility soils (Ellis et al. 1995).

At low-level P applications, sweet corn yield increased as a result of mycorrhizal inoculation (Fig. 26.4). Additionally, mycorrhizal inoculation increased

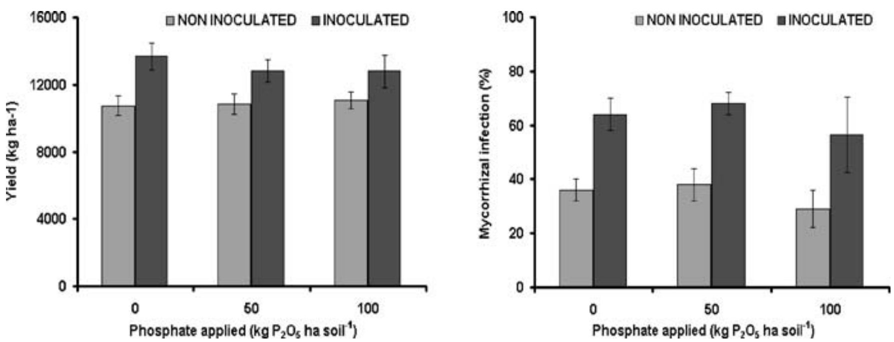

Fig. 26.4 The effect of different rates of P application (0, 50, 100 kg/ha P_2O_5) and mycorrhizal inoculation on sweet corn yield and root inoculation

Table 26.1 The effect of phosphorus application and mycorrhizal inoculation on N, P and K concentration (%) in shoots of sweet corn at silking. ± Standard error

Treatment	N	P	K
−Mycorrhizae			
P0	2.31±0.01	0.16±0.01	0.80±0.28
P1	2.44±0.02	0.20±0.00	0.90±0.14
P2	2.44±0.12	0.22±0.01	0.60±0.03
+Mycorrhizae			
P0	2.60±0.00	0.22±0.01	1.20±0.28
P1	2.84±0.12	0.23±0.01	1.30±0.14
P2	2.58±0.11	0.24±0.03	1.00±0.28

Table 26.2 The effect of phosphorus application and mycorrhizal inoculation on micronutrient content (Zn, Fe, Cu, Mn; mg/kg dry weight) in shoots of sweet corn at silking

Treatment	Zn	Fe	Cu	Mn
−Mycorrhizae				
P0	10.5±1.8	91.6±9.1	3.0±0.3	90.4±13.3
P1	14.5±2.1	103.2±2.0	3.8±0.8	92.9±9.8
P2	15.0±2.8	159.7±29.6	3.5±0.4	102.8±16.7
+Mycorrhizae				
P0	16.2±2.0	97.7±2.1	3.1±1.0	109.7±8.1
P1	15.8±0.8	109.7±12.0	4.0±0.3	100.4±11.0
P2	15.4±1.6	129.9±9.8	4.7±0.4	116.6±1.7

plant N, P, K concentrations significantly (Table 26.1). Furthermore, plant Zn and Mn concentrations increased; however, Fe and Cu concentrations remained the same during the experiment (Table 26.2). In non-inoculated plants, the P concentration of sweet corn shoots increased as the P fertilization increased, but in inoculated plants there was no significant increase. Mycorrhizal inoculation increased significantly root colonization but, with the higher P level addition, the extent of AMF colonization was reduced. It was concluded that, although soils have potential indigenous spores which can effectively infect plant roots, additional mycorrhizal inoculation increases root infection significantly and consequently increases plant nutrient uptake and yield.

As can be seen from Fig. 26.4, the increasing P addition also reduced the root infection, especially with 100 kg/ha P_2O_5 application. Our previous experiments also showed similar results in the same soil.

As can be seen from Table 26.1, mycorrhizal inoculation significantly increased sweet corn plant K content. It seems that the most important K uptake is by mycorrhizal inoculation. So far most work has focused on P uptake; however K is very important element in terms of plant quality (Ortaş and Sari 2003).

Under field conditions without using soil sterilization it is important to manage the indigenous mycorrhizae when the soil nutrients, especially phosphorus, are limited under the field conditions. For sustainable P management soil and crop management can help to get maximum benefit from indigenous mycorrhizae (Ortaş and Sari 2003). The research area was a preserved area for a long time and no pesticide and herbicide were used. So it was expected that the area is rich in soil biological fertility especially in indigenous mycorrhizae.

In order to see the effect of mycorrhizal inoculation on micro-nutrient uptake under field conditions a field experiment was set up in the Research Farm of the University of Cukurova, Faculty of Agriculture, Adana-Turkey. In this experiment onion, garlic, chickpea and horse bean plants were used as test plants. Cocktail mycorrhizae were used as mycorrhizae species.

Since chickpea and horse bean are nitrogen-fixing plants they take more micro-nutrient. Mycorrhiza inoculation significantly increased plant micro-nutrient uptake as well.

The results showed that, in mycorrhizal plots, the yields of onion, garlic, chickpea and horse bean plants was higher than in non-mycorrhizal plants (Table 26.3). Mycorrhizal inoculation increased the shoot Cu and Zn content (Table 26.4).

At the lowest P supply, shoot dry matter production was significantly depressed (Table 26.3). This decreasing effect of low P supply was particularly obvious when soils were sterilized and not inoculated with mycorrhizae. Inoculation of soil with mycorrhizae species significantly increased the plant growth and P uptake of plants, especially under low P supply (Table 26.3). In low P application, plant roots were strongly infected and consequently increased plant growth, but in high P level application there was a slight reduction in root infection. The results show that mycorrhizal inoculation is an effective practice for improving crop production in P-deficient soils.

In another experiment carried out under field conditions mycorrhizal inoculation was successfully applied in non-sterile soil conditions for wheat, which is a strategical plant for the region. During 1999 and 2000 a successive field

Table 26.3 Effect of mycorrhizal inoculation and P application on onion, garlic, chickpea and horsebean yield under field conditions

Treatment	Onion	Garlic	Chickpea	Horsebean
	Yield (kg/ha)			
−P−M	2812±200	4927±526	15 778±120	68 611±2585
+P−M	3229±210	9621±1294	23 500±102	87 389±3064
−P+M	3681±125	7883±431	25 944±236	78 222±2834
+P+M	3768±220	11 050±100	25 667±157	107 056±4878

Table 26.4 Effect of mycorrhizal inoculation and P application on onion, garlic, chickpea and horsebean plant nutrient uptake and root infection under field conditions

Treatment	Fe	Cu	Zn	Mn	P	Infection
	(mg/kg dry weight)				(%)	
Onion						
–P–M	52.8±5.0	7.1±0.1	13.6±1.2	39.6±0.6	0.24±0.01	7±3
+P–M	78.3±6.7	7.5±0.9	14.2±2.7	58.2±11.0	0.28±0.01	10±3
–P+M	53.0±4.5	7.2±0.9	17.6±3.2	56.9±16.1	0.28±0.04	42±25
+P+M	67.6±1.8	6.4±0.8	16.1±3.6	42.6±3.7	0.32±0.05	35±12
Garlic						
–P–M	60.6±9.9	7.7±0.6	13.8±0.7	25.6±0.6	0.25±0.01	13±8
+P–M	100.6±4.2	8.6±4.9	13.9±1.0	26.7±0.5	0.29±0.01	14±12
–P+M	65.9±17.5	11.5±0.1	16.8±2.3	27.0±0.0	0.32±0.03	41±7
+P+M	250.2±237.0	12.5±7.1	15.4±2.2	29.8±2.7	0.30±0.01	32±3
Chickpea						
–P–M	376.7±0.0	14.0±0.0	26.7±0.0	65.4±0.0	0.22±0.00	10±0
+P–M	232.5±24.9	14.9±0.8	26.9±0.6	109.6±27.2	0.24±0.01	8±2
–P+M	235.6±60.4	20.2±4.2	27.3±2.1	94.2±6.3	0.31±0.01	35±7
+P+M	255.6±13.4	21.6±7.3	27.7±2.1	93.1±9.8	0.33±0.01	42±7
Horsebean						
–P–M	590.2±77.14	17.7±0.8	17.0±4.6	114.6±32.9	0.17±0.02	27±0
+P–M	390.1±97.651	18.4±12.0	14.4±4.7	78.9±0.8	0.18±0.03	15±7
–P+M	488.3±190.84	24.0±9.9	21.3±3.9	88.4±17.0	0.22±0.03	38±12
+P+M	449.6±69.437	15.2±3.6	26.7±1.2	103.9±7.8	0.24±0.04	38±2

experiment were set up on Menzilat soil series (typical xerofluvent) which is located in the Research Farm of the University of Cukurova, Faculty of Agriculture, Adana/Turkey. In that experiment 0, 100 and 200 kg/ha P_2O_5 were applied as triple superphosphate. Mycorrhizal inoculum was applied (by hand) 50 mm under the seeds. After two years evaluation it was found that mycorrhizal inoculation under field conditions significantly increased wheat yield (Fig. 26.5). Also, increasing P application increased wheat yield. In the same experiment mycorrhizal inoculation also increased plant P, Zn and Cu content, compared with the control plant.

The results show that mycorrhizal inoculation increased wheat yield, but at the same time indigenous soil mycorrhizal spores significantly inoculated plant roots and consequently the plant got a benefit from indigenous mycorrhizae.

Plant yield increased with increasing P addition in non-inoculated plots. But in the inoculated plot increasing the P addition increased plant yield up to 50 kg/ha P_2O_5. In further addition, P did not increase plant yield (Fig. 26.5). Also, root inoculation reduced with increasing P addition.

Plant species and cultivars are also different in term of nutrient uptake and their colonization by mycorrhizal fungi. Baon et al. (1993) tested eight barley cultivars for P efficiency by comparing their efficiency with *G. etinicatum* inoculum. Responsiveness to mycorrhizae was negatively correlated with agronomic P efficiency and P utilization efficiency. Similarly, Hetrick et al. (1996) used ten wheat cultivars compared at three P regimes and found that mycorrhizal responsiveness declined with increasing P for the six "responsive" cultivars, but four "non-responsive" cultivars were unaffected.

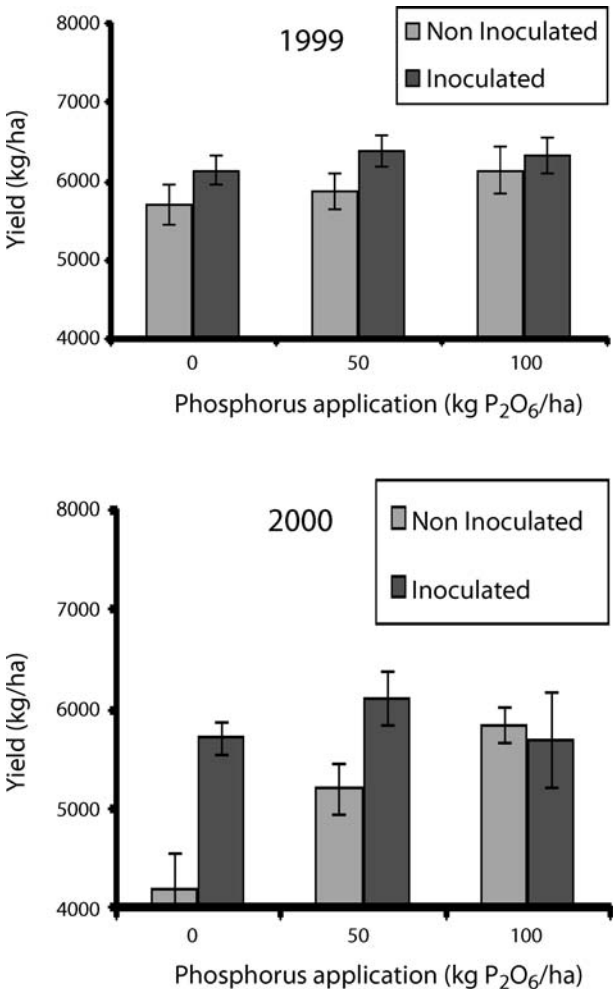

Fig. 26.5 The effect of mycorrhizal inoculation and P application on wheat yield under field condition

26.5 Soil and Crop Management System

Plant responses to mycorrhizal inoculation can be affected by several factors, such as mycorrhizal dependency of the host crop, the nutrient status of the soil and the inoculum potential of the mycorrhizal fungi. Also, soil and crop management practices such as tillage, crop rotation and fallowing may adversely affect populations of mycorrhizal fungi in the field. Soil disturbance significantly reduces the native inoculum potential and consequently reduces nutrient uptake and plant growth (Ortaş et al. 2002). Management practices can influence the types of vesicular–arbuscular mycorrhizal fungi found in agricultural soils. Culturing in soils from degraded ecosystems significantly influences the effectiveness of indigenous AMF isolated from disturbed and undisturbed soils (Enkhtuya et al. 2000). The development of AMF isolates is reduced in soils with more adverse chemical properties, irrespective of the isolate origin (Enkhtuya et al. 2000). Understanding the contributions of soil micro-organisms to soil stabilization at the molecular level will lead to ways to enhance inputs for sustainable agricultural systems.

Plant and soil management should be implemented for mycorrhiza-dependent higher plants, especially less soil distribution, less irrigation and less fertilizer application. In the past 50 years, it has been accepted that taking the maximum yield per unit of land has depredated the soil; and the indigenous mycorrhizal organisms have also been depredated.

The management of mycorrhizal populations in the field is certainly feasible and requires a clear understanding of the ecology of plant communities and different farming systems which affect the populations of mycorrhizal fungi and their diversity and the nutrient uptake and growth of crops. Mycorrhizal inoculation had a positive effect on maize plant P uptake, which was still exhibited even when a high level of P was applied. But high P fertilization reduced the degree of root colonization and also the quantity of external hyphae (Posta and Fuleky 1997). The major benefit of the mycorrhizal symbiosis for crops is improved P uptake; and the management of mycorrhizal fungi will be most critical when soil P is limiting. In temperate zones, P is sometimes applied in excess of crop demand. When the soil P is so high, then root infection percentages are reduced.

Micro-nutrients are very important in terms of human health. Since agriculture is the main source of macro- and micro-nutrients for human food, it is very important to produce a balance of feed plants for the food chain from soil to human. It has been also shown that mycorrhizal inoculation can increase micro-nutrients such as Zn and Cu (Kothari et al. 1990). Liu et al. (2000) reported that the total content of Zn and Cu in maize shoots was higher in mycorrhizal than in non-mycorrhizal plants grown in soils with low P addition. Similarly, Tarkalson et al. (1998) and Ryan and Angus (2003) reported that, under field conditions, the total crop Zn uptake and grain Zn concentration were positively correlated with colonization by AMF, due to enhanced Zn uptake after anthesis of the wheat plant.

26.6 Inoculation Techniques

Compared with pot experiments, less work has been done under field conditions. Field responses to mycorrhizal inoculation were often disappointing, especially in high-input agricultural systems. It has been concluded by many researchers that mycorrhizae have little practical importance in agriculture, since each agro-ecosystem has its own ecological conditions, such as nutrient status of the soil, mycorrhizal dependency, inoculum potential of the indigenous mycorrhizal fungi, crop rotation and fallow systems. Agriculturists should appreciate the distribution of mycorrhizae within their systems and understand the impact of their management decisions on mycorrhizal functioning (Ortaş et al. 2002). Inoculum potential can be adversely affected by management practices such as fertilizer application, pesticide use, crop rotation, fallowing, tillage and topsoil removal. Field experiments have shown that most agricultural plants are colonized by mycorrhizal fungi, which have a substantial impact, both positive and negative, on crop productivity (Johnson 1993). Under field conditions, native inoculum potential is generally low and sometimes ineffective (Ortaş 2003). It is very important to know the mycorrhizal inoculation potential before using mycorrhizal inoculum.

Since AM fungi cannot be grown on laboratory media, the production of a large quantity of inoculum is difficult, as is the inoculation of soil under field conditions. Also since most of the commercially important crops are mainly horticultural plants and are raised under nursery conditions before being transplanted to the main field, the inoculation of soil in the nursery would not only result in a saving of the cost of production of the inoculum but would also help in the better establishment of the transplanted horticultural seedling. Horticulture plants which are grown as seedlings give a high response to mycorrhizae. Mycorrhizal seedlings are more reliable then non-mycorrhiza-inoculated ones. It is sound to produce mycorrhiza-inoculated seedlings before transplanting to the field conditions. Our early results showed that mycorrhiza-infected seedlings are highly resistant to environmental stress factors. Under field conditions, the effect of mycorrhizal inoculation on mortality of seedling was tested. Ortaş et al. (2004) observed that non-mycorrhizal seedlings had a high mortality but mycorrhizal seedlings had less mortality (Table 26.5).

Inoculum strategies are very important. Ortaş et al. (2004) tested several techniques to develop suitable inoculum strategies. Very recently biotechnological

Table 26.5 Mycorrhizal and non-mycorrhizal dead and surviving seedlings after transplanting to field conditions (mean of three replicates; Ortaş, unpublished data)

Plant species	Number of seedlings transplanted to the plot	Number of dead seedlings	% dead seedlings	% surviving seedlings
−Mycorrhizae				
Tomato	48	1	2	98
Pepper	60	4	8	92
Eggplant	48	3	7	93
Bell pepper	60	4	8	92
Marrow	24	3	13	87
Cucumber	24	3	13	87
Melon	24	2	9	91
Watermelon	24	7	29	71
+Mycorrhizae				
Tomato	48	0	0	100
Pepper	60	1	2	98
Eggplant	48	0	0	100
Bell pepper	60	0	0	100
Marrow	24	0	0	100
Cucumber	24	1	4	96
Melon	24	0	0	100
Watermelon	24	2	8	92

techniques were applied before transplanting mycorrhiza-inoculated seedlings to the field conditions, which is a most feasible technique.

Very recently a new technique was tested for better seedling performance under field conditions. Mycorrhiza-inoculated and uninoculated pepper seedlings were transplanted to the field with and without seedlings treated with a liquid solution containing mycorrhizal inoculum. The results showed that mycorrhiza-inoculated seedling production is very important (Fig. 26.6). Also, before transplant to the field conditions, seedlings can be treated with a mycorrhizal liquid solution and are highly responsive to such inoculation. The technique is easy and practical. A liquid solution is prepared using a large quantity of spores (soil, roots, hyphae), mixed with water 1:1, v/v. Seedling roots are dipped into the solution before being transplanted to the nursery hole.

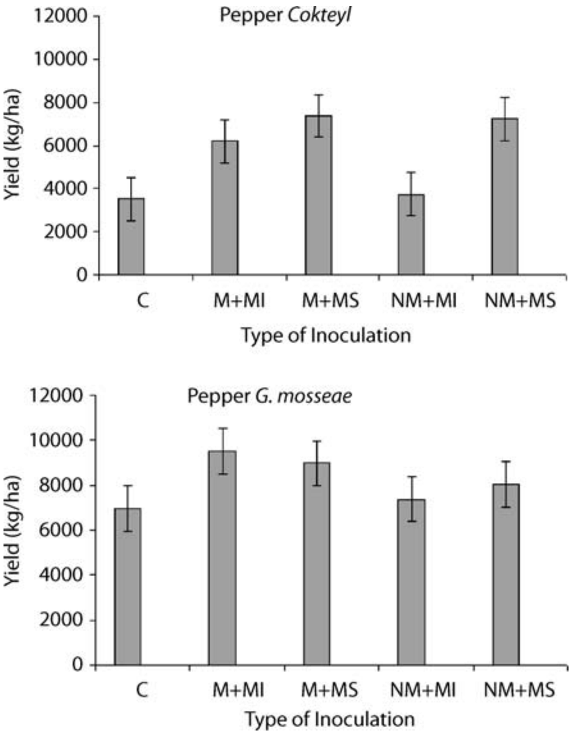

Fig. 26.6 Effect of different inoculation types on paper plant growth under field conditions (Ortaş, unpublished data)

26.7 Conclusion

A large number of studies have expanded our understanding of the potential contribution of mycorrhizae to nutrient uptake under field conditions. Since plant species can give different effects upon mycorrhizal inoculation, these can be related to other beneficial effects of mycorrhizal infection. Also, the response depends on several factors, such as genetic variation and environmental factors.

Recently it was reported that mycorrhizae have several benefits to plants other than nutrient uptake, such as resistance to water deficiency (Bowen and Rovira 1999; Drüge and Schönbeck 1992; Goicoechea et al. 1996). So it is very important to manage the indigenous mycorrhizae when soil nutrients, especially P, are limited under field conditions. For sustainable P management, soil and crop management can help to get maximum benefit from indigenous mycorrhizae (Ortaş 2003). Bowen and Rovira (1999) suggested that a good managed rhizosphere would increase soil and plant quality. Rizosphere management can increase the useful micro-organisms in the plant–soil system. For this reason, the management of mycorrhizae is very important for agricultural sustainability.

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