Disease management through biological control agents: An eco-friendly and cost effective approach for sustainable agriculture- A Review

Ranveer Kamal*, Yogendra Singh Gusain1, Vivek Kumar2 and A. K. Sharma

Department of Biological Sciences, College of Basic Sciences & Humanities, G. B. Pant University of Agriculture and Technology, Pantnagar-263 145, India.

Received: 04-08-2014
Accepted: 10-02-2015
DOI: 10.5958/0976-0741.2015.00004.5

ABSTRACT

Biological control is a mechanism in which the natural enemies to diminish the number of destructive organism, which could be in any form, small bacterium to large animals. This mechanism includes the use of predators, competitors, pathogens and compounds of biological origin. Plant pathogens are important factors that cause serious losses to agricultural products every year. Present review briefly focuses on the use of microorganisms as Biological Control Agents (BCAs) for reducing the plant diseases. These microorganisms can be act as both, less toxic and more flexible agent as compare to chemical pesticides. Biological controls lean to be highly specific and have different mode of action which includes, parasitism, predator, antibiosis, competition for site and nutrition, as well as by inducing the resistant in plants against pathogen, including Induced Systemic Resistance (ISR). However suitable management strategies are needed for the successful application of BCAs to sustainable agriculture.

Key words: Antibiosis, BCA's, Biological control, ISR, Sustainable agriculture.

Several diseases associated with field crops, particular soil borne is much widely spread throughout the whole cropping area. In rhizosphere there are vast communities of different microorganisms which are directly or indirectly influence the plant health and growth development. Out of them some are beneficial bacteria which are called as plant growth promoting rhizobacteria (PGPR) and some other are non-beneficial which harm plant through many ways by reducing plant vigor and growth in many ways. Diseases which are associated with soil borne pathogens and are difficult to predict or characterize particular disease. Sometimes a plant or a crop may be infected with more than one disease. There are some interspecies interactions held in soil environment as well as in rhizosphere which lead biological control of pathogens (Fig 1).

The soil borne plant pathogens may be called biological agents which are responsible for disease caused in many plants. These biological agents can be any of kind bacteria, virus, fungi and some nematodes etc. their target in only to feed themselves by harming plants in several means. The plants affected by pathogens can visibly recognize for example shoot blight, leaf blight, wilt, vascular wilt, crown gall, leaf spot, root decay, tissue discoloration etc.

Arbuscular mycorrhizal fungi can provide numerous benefits to their plant hosts, including improved nutrient uptake, drought resistance, and disease resistance. Two main groups of bacteria interact with AM fungi in the mycorrhizosphere: saprophytes and symbionts, both groups potentially consisting of detrimental, neutral and beneficial bacteria (Barea et al., 2002; Johansson et al., 2004).

Some PGPR may have properties that support both mycorrhizal establishment and function. In addition, Sanchez et al. (2004) showed that a fluorescent pseudomonad and an AM fungus (G. mosseae) had similar impacts on plant gene induction, supporting the hypothesis that some plant cell programs may be shared during root colonization by these beneficial microorganisms. Specific interactions between AM fungi and PGPR most likely occur, and certain groups of bacteria have been shown to be established to a much higher extent in the mycorrhizosphere compared with other groups. In addition, most plant roots are colonized by mycorrhizal fungi and their presence also generally stimulates plant growth. Constituting the PGPR such as Azospirillum, Agrobacteria, Pseudomonas, Bacillus etc. Their role was recognized more recently than for mycorrhizae or nodules, many rhizospheric microorganisms also contribute to plant

*Corresponding author e-mail: ranveerbiotech@gmail.com, 1College of Forestry, Uttarakhand University of Horticulture & Forestry, Bharsar, Ranichauri-249199, 2D.S.B Campus, Kumaun University, Nainital-263002, Uttarakhand, India.
Soil environment and common diseases: Soil borne plant pathogens, a common and important factor in reducing yield and quality of vegetable as well as crops. These pathogens are more challenging than other pathogens in soil ecology (Fig 3), because they can survive in soil environment for many years and can affect the crops more instantly by damaging them. Each vegetable and crops may be susceptible to many species resulting disease complex. The most familiar disease caused by soil borne pathogens are roots that affect beneath tissues including seed decay, root and crown roots, damping off of seedlings and vascular wilts initiated trough root infections.

Several pathogens live in soil portion in active and some are inactive form, when they found suitable host they all become active in such condition. They reside in soil may be for a long time or for short time depending upon their life cycle or habitat. Some bacteria and fungi survive in form of sclerotia which are inactive under certain environmental conditions.

Fungi which is considered most important pathogen in plants. The examples of soil borne fungi are *Fusarium*, *Rhizoctonia* and *Verticillium*, *Pythium* and *Phytophthora* (Koike et al., 2003).

Bacteria are also a disease causing biological agents. Bacteria caused fewer soil borne disease than fungal pathogens. For example *Erwinia*, *Rhizomonas* and *Streptomycetes* (Koike et al., 2003). Pathogens from the *Xanthomonas* and *Pseudomonas* groups usually persist for a short time in soil environment. There are few soil borne virus pathogens reported that caused disease in plants. The symptoms of virus disease are tissue discolorization and distortions of foliage and fruit, stunting of plant etc. (Koike et al., 2003).
Nematodes are soil borne plant parasites which spend most of their lives in the soil, either as external feeders on plant roots or as residents inside roots. Nematodes affect plants by reducing their growth. In soil, nematodes either live freely or represent eggs or durable cysts. Root knot nematodes (*Meloidogyne* species) cause a general reduction in vigor for many plant species and can cause severe distortions and swellings of roots.

**Natural control of plant disease:** One of the most important things in natural control is to understand about all possible factors causing disease in plants like environmental moisture and temperature. Soil borne pathogens are highly complex in ecosystems in which plants are exploited by existing predators, pathogens, parasites and decomposers.

Many of natural control is done worldwide by using agriculture chemicals to control some diseases. These may be useful tool for controlling pathogen attack to host plant but on other side it can be promoted more pathogen to bring in focus. There are some strategies or methods to control disease naturally including disease suppressive soil, crop rotation, plant nutrients and compost. Suppressiveness is linked to the types and numbers of soil organisms, fertility level, and nature of the soil itself (drainage and texture). The mechanisms by which disease organisms are suppressed in these soils include induced resistance, direct parasitism (one organism consuming another), nutrient competition, and direct inhibition through antibiotics secreted by beneficial organisms.

For management of disease in field plan a crop rotation, it is essential to know what crops are affected by what disease organisms. In most cases, crop rotation effectively controls those pathogens that survive in soil or on crop residue. Crop rotation will not help control diseases that are wind-blown or insect vectored from outside the area. Nor will it help control pathogens that can survive long periods in the soil without a host—*Fusarium*, for example. Nutrients in soil for instance pH, calcium level, nitrogen form, and the availability of nutrients can all play major roles in disease management. Adequate crop nutrition makes plants more tolerant of or resistant to disease. Also, the nutrient status of the soil and the use of particular fertilizers and amendments can have significant impacts on the pathogen’s environment.

Compost has been used effectively in the nursery industry, in high-value crops, and in potting soil mixtures for control of root rot diseases. Adding compost to soil may be viewed as one of a spectrum of techniques—including cover cropping, crop rotations, mulching, and manuring that add organic matter to the soil. The major difference between compost-amended soil and the other techniques is that organic matter in compost is already “digested.” Other techniques require the digestion to take place in the soil, which allows for both anaerobic and aerobic decomposition of organic matter.

**How to select beneficial microbes from soil environment**

There are several microbial community present in soil microfuna. The selection of these beneficial microbes from the soil may be a difficult task, In modern technologies the selection of desired or beneficial microbes i.e bacteria or fungi...
could be done under in vitro by various methods. The potential of any organisms may vary in field condition because of microbial competition for nutrient and space for their growth and survival. The use of these resources by one organism may reduce the amount available to the other. Competition for the same nutrient for the pathogen and antagonist may result an effective biocontrol agent.

What are Biological Control Agents (BCAs): The term ‘biological control’ and abbreviated term ‘biocontrol’ have been used in several areas of biology, especially in plant pathology and entomology. It describes the use of live predatory insects, microbial pathogens or entomopathogenic nematode which suppresses the other populations. The term Biological Control Agents (BCAs) applies to use of microbial antagonists which suppresses the growth of pathogens (host-specific). The bio-formulation of these antagonists may be used to control plant diseases, sometimes it is also called bio-pesticides or biofertilizers depending on the primary benefits to host plant.

A biocontrol agent, \textit{Streptomyces griseoviridis} Anderson et al. strain K61, originally isolated from light coloured Sphagnum peat Tahvonen (1982a), (1982b), has been reported to be antagonistic to a variety of plant pathogens including \textit{Alternaria brassicola}, \textit{Botrytis cinerea}, \textit{Fusarium avenaceum}, \textit{F. culmorum}, \textit{F. oxysporum}, \textit{Pythium debaryanum}, \textit{Phomopsis sclerotiodides}, \textit{Rhizoctonia solani} and \textit{Sclerotinia clavipes} (Tahvonen and Avikainen 1987). Weller (1988) reported that the microorganism that colonizes roots is ideal for use as a biocontrol agent against soil-borne diseases. \textit{Streptomyces griseoviridis} is a good example for colonization of plant rhizosphere by Actinomycetes. \textit{S. griseoviridis} is an antagonistic microorganism effective in biocontrol of plant diseases such as the Fusarium wilt of carnation, the damping-off of Brassica and the root rot disease of cucumber (Tahvonen and Lahdenpera 1988).

\textit{Streptomyces} from rhizosphere of Araucaria were shown to have the ability to inhibit the growth of \textit{Fusarium} and \textit{Armillaria} causing pine rot (Vasconcellos, 2009). The treatment with the Talc-based formulation of \textit{S. griseus} of seeds and seedlings of tomato showed a significant reduction in the disease severity caused by \textit{F. oxysporum} f. sp. \textit{lycopersici} (Anitha et al., 2009). Kanini et al. 2013 found inhibitory efficacy of indigenous \textit{Streptomyces} isolates against the soil-borne fungal plant pathogen \textit{Rhizoctonia solani}.

\textit{Streptomyces} species have also been implicated in the biological control of a number of other pathogens. \textit{S. ambofaciens} inhibited \textit{Pythium} damping-off in tomato plants and Fusarium wilt in cotton plants. \textit{S. hygroscopicus} var. geldanus was able to control \textit{Rhizoctonia} root rot in pea plants and the inhibition was due to the production of the antibiotic geldanamycin. \textit{Streptomyces lydicus} WYE108 inhibited \textit{Pythium ultimum} and \textit{R. solani} in vitro by the production of antifungal metabolites (Yuan and Crawford, 1995).

The VAM fungus \textit{Glomus mosseae} stimulated localized and induced systemic resistance to Phytophthora parasitica in tomato using mycorrhizal and non-mycorrhizal roots in a split root experimental system demonstrated by Condier et al., (1998). In this scheme, decreased pathogen development in mycorrhizal and non-mycorrhizal parts of mycorrhizal root systems was associated with the accumulation of phenolic compounds, and with typical plant cell defence responses. Mycorrhizal cortical cells were immune to \textit{P. parasitica} and showed callus development at sites of parasite infection. The systemic component of resistance was characterized by host cell wall thickenings of pectins and proteins in non-mycorrhizal root parts, as well as callus deposition at infection sites. None of these observations were apparent in non-mycorrhizal pathogen-infected root systems.

\textbf{Eco-friendly approach to overcome plant diseases:} In soil environment, a vast majority of micro-organisms exist, out of them some are beneficial and most of other are pathogens. Most practices or organic amendments can raise the diversity if micro-organisms, which may further led the suppression of disease. World agriculture is interested in reducing dependence on chemical inputs, so biological management of plant diseases can be expected to play an important role in Organic and Integrated Pest Management (IPM) systems when successful. With the growing interest in reducing chemical inputs, companies involved in the manufacturing and marketing of bca’s should experience continued growth (McSpadden Gardener and Fravel, 2002). Research has led to the development of a small but essential commercial sector that produces a number of biocontrol products. Most of the commercial bca’s production is handled by relatively small companies with total sales on the order of 10 to 20 million US dollars annually (Fravel, 2005). Currently, several biocontrol products although not being registered as such yet, circulate as plant strengtheners or growth promoters without any specific claim regarding disease control by the distributors.

While biological control of plant diseases developed mainly as an academic discipline over fifty years ago, now is being supported by both the public and private sector. A tremendous number of scientific papers are currently published in phytopathological journals or others specifically
devoted to the discipline of biological control. The advancements of sciences in computing, molecular biology, analytical chemistry, modernize re-search approaches and elucidate topics regarding structure and functions of bca’s along with plant and pathogens at certain levels. Thus, topics of biocontrol research and development related to the ecology of plant and bca’s, to the discovery of new effective strains along with the development of more efficient application procedures and practical integration into agricultural systems are essential parameters for moving from hope to reality in biological management of plant diseases.

**Strategies to control disease through BCA’s:** Biological control simply means that pathogens are antagonized by the presence, activities or products of other similar or different organisms that they encounter in the plant’s rhizosphere or phyllosphere. Direct antagonism by obligate parasites of a plant pathogen requires a high degree of selectivity for the pathogen, called hyperparasitism. There are several fungal parasites of plant pathogens, including those that attack sclerotia (e.g. *Coniothyrium minitans*), while others attack living hyphae (e.g. *Pythium oligandrum*). Single fungal pathogen (e.g. powdery mildews) could be parasitized by several hyper-parasites such as *Acremonium alternatum*, *Ampelomyces quisqualis*, *Cladosporium oxysporum*, and *Gliocladium virens* (Kiss, 2003). On the contrary, indirect antagonisms could be seen from activities that do not involve sensing a pathogen by the bca’s. These include antibiotics, enzymes, competition and induced resistance-mechanisms (Pal and McSpadden Gardener, 2006).

Studies of the interaction between mycorrhizal fungi and sedentary parasitic nematodes have provided evidence that resistance to soil pathogens can be related to factors other than improved plant nutrition. Investigations of the interactions between root knot nematode (*Meloidogyne hapla*) and VAM fungi on susceptible cultivars of tomato and white clover revealed that phosphorus nutrition was negatively correlated with nematode numbers in mycorrhizal roots (Cooper & Grandison, 1986). Furthermore, nematode numbers per gram of root were consistently less in mycorrhizal soils, and plants pre-infected with mycorrhizal fungi showed improved growth compared to un-inoculated controls. Mycorrhizal fungi and other soil microorganisms are known to confer resistance, tolerance, or other forms of bioprotection to host plants, the actual mechanisms involved are not clear.

**Systemic Acquired Resistance (SAR):** SAR is characterized by an early increase of endogenously synthesized SA and the enhanced production of pathogenesis-related (PR) proteins. Eleven different PR families are recognized in tomato and tobacco (van Loon and van Stein, 1999). The PR-1 family is the main group of PRs induced by pathogens or SA and is commonly used as a marker for SAR. PR-1, though, is the only family for which no function or relationship is known (van Loon and van Stein, 1999).

The second stage, the establishment phase, involves perception of the mobile signal (Cameron *et al*., 1999). The final stage of SAR requires the plant to be challenged with a second normally virulent pathogen and the plant responds to this pathogen as if it was a virulent (Cameron *et al*., 1999). In Arabidopsis the SAR pathway confers resistance to *Pseudomonas syringae* (P.v) maculicola ES 4326 and *Peronospora parasitica* (Ryals *et al*., 1996). SAR has been reported in rice with *Pseudomonas syringae* pv. syringae as the inducing pathogen. Although SAR has not been conclusively demonstrated in wheat, it has been reported that *Erysiphe graminis* infection appears to induce SAR as does treatment with BTH leading to induced resistance against *Septoria* spp., *P. recondita* and *E. graminis* (Gorlach *et al*., 1996).

Systemic Acquired Resistance (SAR) is induced by prior inoculation with a necrotizing pathogen or the application of chemical agents such as salicylic acid (SA), 2,6-dichloro isonicotinic acid (INA) and benzo (1,2,3) thiadiazole-7-carbothioic acid S-methyl ester (BTH) (Uknes *et al*., 1992). Once the SAR pathway has been activated resistance can be conferred to a number of pathogens. SAR has been extensively studied in the dicots, tobacco (*Nicotiana tabacum*) and *Arabidopsis thaliana*. SAR was first characterised in tobacco plants that expressed increased resistance systemically after infection by tobacco mosaic virus (Ross, 1961).

**Mycorrhiza-induced resistance (MIR):** AMF infection is known to stimulate biological activity in the rhizosphere, a phenomenon commonly referred to as the ‘mycorrhizosphere effect’ (Linderman, 1988). This effect includes the attraction and selection of specific bacterial strains, such as plant growth-promoting rhizobacteria (PGPR) that possess the capacity to enhance plant growth and suppress pests and diseases. Some of these mycorrhizosphere inhabiting bacteria can act as ‘mycorrhiza helper bacteria’ and promote the efficiency of mycorrhizal symbiosis (FreyKlett *et al*., 2007). Comparatively little is known about the mechanisms conferring non nutritional benefits by mycorrhiza such as suppression of soil-borne diseases and enhancing plant resistance to pests and diseases (Cameron, 2010). Plants routinely signal to conspecific organisms in the rhizosphere by releasing primary and secondary metabolites from their
roots. Some of these metabolites recruit beneficial microbes, including AMF. Furthermore,

AMF can suppress plant pests and diseases through induction of systemic resistance (Jung et al. 2012, Pozo et. al 2007, Pineda et al. 2010). The induced resistance shares characteristics with both pathogen-induced SAR and rhizobacterial ISR; MIR has been associated with SAR-like priming of salicylic acid (SA)-dependent genes, but more often coincides with priming of jasmonic acid (JA)-dependent defences and cell wall defences MIR confers protection against a wide range of attackers, including biotrophic pathogens, necrotrophic pathogens, nematodes, and herbivorous arthropods. It has been proposed that MIR is the result of active suppression of components in the SA-dependent defence pathway, causing systemic priming of JA-dependent defences (Pozo et. al 2007). However, the exact contribution of jasmonates in MIR remains unclear (Hause et al. 2007) and the long distance signals controlling MIR remain to be resolved.

Several MIR studies have quantified the level of resistance when the plant–AMF symbiosis and the mycorrhizosphere are fully established (Jung et al., 2012). It is therefore possible that MIR involves an ISR component elicited by bacteria in the mycorrhizosphere. Like AMF, rhizobacteria possess MAMPs, which can trigger MAMP-induced immune responses (Berendsen et al., 2012). Well-known examples of defence eliciting MAMPs from bacteria are rhamnolipids, the elongation factor Tu, flagellin, and cell-wall lipopolysaccharides (Boller et. al., 2009). The spatially confined structure of the mycorrhizosphere allows rhizobacterial strains to reach exceptionally high cell densities (Linderman, 1988). Under these conditions, bacterial gene expression can be controlled by small diffusible signal molecules from members of the population themselves. This autoinduction process, known as quorum sensing (QS), allows bacteria to adjust community gene expression in accordance with their environment (Waters et. al., 2005). Many rhizosphere-colonizing bacteria, including Pseudomonas and Burkholderia strains, employ QS to control gene expression (Lugtenberg et. al., 2009).

**Induced Systemic Resistance (ISR):** Induced Systemic Resistance (ISR) is phenotypically similar to SAR; however, the resistance is induced by non-pathogenic biotic agents. It is believed that ISR is distinct from the SAR pathway, but mediated by a JA/ET pathway and it has been reported that there is no up-regulation of PR proteins (Hammerschmidt, 1999; van Wees et. al., 2000; Pieterse, 2002). There are some conflicting reports on this matter. Park and Klopper (2000) investigated the effect of ten PGPR strains on the induction of the PR-1a gene promoter in regards to systemic resistance in tobacco against Pseudomonas syringae pv. tabaci. The results of this study indicated that PR-1a promoter activity and PGPR-mediated induced systemic resistance are linked events but this finding contradicts the model for PGPR mediated ISR proposed by Pieterse et. al. (1998). However, the architecture of the SAR and ISR pathways may vary among different plant species.

Conrath et. al. (2002) believe that the non-pathogenic bacteria prime the plant for accelerated and enhanced response when the plant is challenged by a second stress stimulus such as a pathogen. Verhagen et. al. (2004) were gone through the microarray technique to identify ISR-related genes in Arabidopsis. Over 8000 genes were surveyed and it was found, when using the ISR-inducing bacterium P. fluorescens WCS417r, there was a substantial change in the expression of 97 genes in the roots but no changes in expression could be detected in the leaves. However, after subsequent challenge with Pseudomonas syringae pv. tomato DC3000 there was a change in the expression of 81 genes in the leaves. This indicates the role of rhizobacteria in priming the plant for ISR.

In the past few years, research has been directed more toward the induced systemic resistance (ISR), a process by which PGPR stimulate the defense mechanisms of host plants without causing apparent harm to the host. More recently, Choudhary and Johri (2008) have reviewed ISR by Bacillus spp. in relation to crop plants and emphasized on the mechanisms and possible applications of ISR in the biological control of pathogenic microbes. Various strains of species B. amyloliquefaciens, B. subtilis, B. pasteurii, B. cereus, B. pumilus, B. mycoides, and B. sphaericus are known as potential elicitors of ISR and exhibit significant reduction in the incidence or severity of various diseases on diverse hosts (Choudhary and Johri 2008; Kloeper et. al., 2004). It is believed that plants have the ability to acquire enhanced level of resistance to pathogens after getting exposed to biotic stimulation provided by many PGPR’s and this is known as rhizobacteria mediated ISR (Choudhary et. al., 2007).

**Sustainable agriculture by BCAs:** Several beneficial biological agents are widely used in agriculture at commercial level. They are called by their special activity for instance, (1) Bio-fertilizers perform special task towards improving nutrient acquisition, (2) Bio-protectants, suppress several plant associated disease, (3) Bio-stimulants, phytohormone production. Many bacterial genera included in these kind of properties are Pseudomonas, Bacillus, Paenibacillus, Streptomyces, Agrobacterium, and Burkholderia and some fungi species are also used for the same purpose.
Various antagonistic fungi have been used to control several plant diseases with 90% of applications being formulated using different strains of Trichoderma for instance *T. harzianum, T. virens, T. viride* (Benitez et al., 2004). A wide range of biological control agents have been used to develop commercial mycofungicide products (Benitez et al., 2004, Kim and Hwang, 2004, Fravel, 2005).

They suppress plant disease through various mechanisms i.e. ISR, MIR, production of siderophores or antibiotics etc (Fig 2). Biofertilizers are also available for increasing crop uptake of nitrogen from nitrogen-fixing bacteria (*Azospirillum*), and iron uptake from siderophore-producing bacteria (*Pseudomonas*). Control of various soil borne and other disease *Streptomyces* is used as a promising tool in agriculture and allied sectors. They also produce a range of phytohormones that include indole-acetic acid, cytokinins, gibberellins and inhibitors of ethylene production. These studies have contributed to the development of new biofertilizer products that utilize natural antimicrobial compounds produced by diverse antagonists (Harman et al., 2004).

A well known example of specific suppression is provided by a strategy used to control one of the organisms that cause damping off—*Rhizoctonia solani*. Where present under cool temperatures and wet soil conditions, *Rhizoctonia* kills young seedlings. The beneficial fungus *Trichoderma* locates *Rhizoctonia* through a chemical released by the pathogen, then attacks it. Beneficial fungal strands (hyphae) entangle the pathogen and release enzymes that dehydrate *Rhizoctonia* cells, eventually killing them. Currently, Trichoderma cultures are sold as biological seed treatments for damping off disease in several crops. For commercial sources of Trichoderma and other beneficial organisms.

**Future prospects:** The global food production must keep pace with the continuous growing population of world, which increases the use of chemical pesticides as a consequence. However recent uses of biological control agents for reduction of plant diseases have opened a new window of opportunity for microbial products to replace the chemical pesticide markets. However the commercial application of the biological control agents is slow mainly due to variable performance of the agent under variable environmental condition in field. To improve the commercialization of the biocontrol technology we have to developed field oriented biocontrol microorganisms with higher degree of stability and survival. In this direction we have to accelerate more research on some less develop aspects of biocontrol including, effect of variable environmental factors on biocontrol agents, development of formulations in which bioagent can survive for longer, mass production of biocontrol microorganisms and the use of advanced technique of biotechnology and nanotechnology in improvement of biocontrol mechanisms and strategies.

**ACKNOWLEDGEMENT**

Authors are thankful to Dr. Ramesh N Pudake, Amity University, Noida and Dr. Chandra Mohan Mehta, Assistant Professor, LPU, Punjab for their kind help in preparing manuscript.

**REFERENCES**


Cooper K M and G S Grandison (1986), Interactions of VAM fungi and root knot nematode on cultivars of tomato and white
Cordier, C. et al. (1998) Cell defense responses associated with localized and systemic resistance to Phytophthora
induced in tomato by an arbuscular mycorrhizal fungus. Mol. Plant Microbe Interact. 11: 1017–1028
de Boer, W., Folman, L.B., Summerbell, R.C., Boddy, L., (2005), Living in a fungal world: impact of fungi on soil bacterial
plant pathology 55: 77-84
Johansson, J.F., Paul, L.R., Finlay RD, (2004), Microbial interactions in the mycorrhizosphere and their significance for
Toppo G, Marinelli F (2000) Rare genera of Actinomycetes as potential producers of new antibiotics. Antonie van
Leeuwenhoek 78: 399–405
Linderman, RG (1988) Mycorrhizal Interactions with the rhizosphere microflora the mycorrhizosphere effect.
Phytopathology 78: 366–371
McSpadden Gardener B., Fravel D., (2002). Biological control of plant pathogens: Research commercialization, and
application in the USA. Online. Plant Heath Progress doi: 10, 1094/PHP-2002-0510-01-RV
10.1094/PHI-A-2006-1117-02
role of beneficial soil-borne microbes. Trends in plant Sciences 15( 9): 507–514


