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# Curative and Eradicative Effects of Fungicides

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## 1. Introduction

Fungi and oomycetes are the causal agents of numerous fungal plant diseases, causing losses in agricultural production worldwide. Plant pathogenic fungi and oomycetes have co-evolved with their plant hosts, and have developed extremely efficient mechanisms to cause an infection, to grow, multiply and spread on living plants. Most of these plant pathogens have an exceptional potential to reproduce within the plant host. For example, *Pytophthora infestans* can produce 50 000 to 117 000 sporangia per linear centimeter of infected potato stem length (Johnson et al., 2000). Larger apothecia of *Sclerotinia trifoliorum* can release about 4.7 million ascospores during their active period (Raynal, 1990). In late vegetation stages, the number of *Fulvia fulva* conidia per square centimeter of infected tomato leaf can exceed 17 000 (Veloukas et al., 2007), while *Pseudoperonospora cubensis* can produce even 195 000 sporangia per square centimeter of cucumber leaf seven days after infection (Wang et al., 2009). Considering the prevalence, ubiquitous nature and the ability of fungi and oomycetes to cause epidemics in relatively short period of time, disease management strategies are needed to secure the productivity in today's agriculture. Chemical control measures are particularly common in management of fungal plant diseases, and most of these measures rely on the use of fungicides.

No matter of many differences in biology of different fungal and oomycetous plant pathogens, they share certain similarities. Most of the fungi produce various kinds of spores, which come in contact with plant tissue, germinate, and penetrate into the plant during the infection process. Some plant pathogenic fungi (e.g. *Rhizoctonia solani*, *Sclerotium rolsii*, or *Macrophomina phaseolina*) rarely produce spores and infect plants through penetration of mycelia into plant tissue. After infection, fungi and oomycetes continue to grow as mycelium in or on plant organs, where they produce their new vegetative or generative, propagation or dormant structures. Nearly all fungicides used in agriculture today show their best effect if applied before the infection occurs. When present on the surface of plant organs, fungicides destroy fungal spores or suppress germination tubes, hyphae, and other fungal structures. As a rule, control of fungal diseases with fungicides is aimed to prevent an infection and subsequent disease development, and in such way the use of fungicides in plant protection differ from the use of antibiotics or antimycotics in medicine and animal health.

However, in agricultural practice, there are many cases in which disease control measures are needed after the infection has occurred, after the pathogen is already sporulating or after

the symptoms have appeared. Until the late 60s and 70s of the 20th century, possibilities for therapeutic treatment of infected plants with fungicides were limited, as most of the fungicides developed and available for use in agriculture were protectant fungicides. Such fungicides remain on the surface of the plant, do not penetrate in it or translocate within it, and have little or no effect on the pathogen established in plant tissue. Systemic fungicides, introduced into the market in the 60s and 70s of the 20th century, are absorbed by the plant and translocated in it over the shorter or longer distance. In such way, fungitoxic active substance can come into the contact with the pathogen already established in the plant, which can result in pathogen's elimination.

Movement and translocation of fungicides within the plant differs between various fungicide active compounds, and delineation between systemic and non-systemic fungicides is often not clear. Most of the true systemic fungicides translocate through the xylem, and relatively small number of them has an ability to translocate basipetally in the phloem (Jacob & Neumann, 1987). Some of the fungicides found on the market today are only locally mobile, translocating only within the organ of application (Jacob & Neumann, 1987). Many modern fungicides classified as non-systemic show translaminar activity, i.e. they penetrate through the leaf and move from the upper to the lower surface of the leaf.

Discovery and development of systemic fungicides offered some new possibilities in disease management, important from practical point of view - to achieve a relatively efficient control after the infection has already occurred. Such therapeutic effect of fungicides is usually referred as "curative effect" or "curative activity". Theoretically, fungicidal activity on a fungal parasite within the plant can result in pathogen's eradication, i.e. the elimination of the pathogen from the host. Although complete eradication of plant pathogens within the host following fungicide application is relatively rarely achieved in practice, such effect of fungicides is referred as "eradication effect" or "eradication activity". In plant protection terminology, application of a fungicide after the infection has occurred is often called "curative treatment", while application after the symptoms have appeared is sometimes called "eradication treatment".

Curative and eradication effects or performance of fungicides in chemotherapy of plants is dependent on a number of factors, out of which the most important are uptake, translocation and distribution of the fungicide in the plant, sensitivity of the pathogen to the fungicide, dose or concentration used, the position of the pathogen in plant tissue, and the stage of the pathogen development in the plant. Significant differences were recorded for different fungicides, different plant diseases, and different plant species investigated. Generally, results obtained in practice and recorded so far in experimental work showed that therapeutic treatments of plants with fungicides are usually less efficient than chemical control on preventive, protective basis. No matter of that, systemic fungicides with curative and eradication effects contributed to some significant advantages in plant protection, and in efficient and economical control of certain fungal plant diseases.

## 2. Effect of systemic fungicides on pathogens established in plants

Curative activity of fungicides implies the effect of a fungicide on fungal mycelium located in the plant. To affect mycelium of fungi and oomycetes in plant tissue, fungicide must come into contact with the pathogen inside the plant. This might not always be the case, but if fungitoxic compound reaches vegetative or generative structures of a sensitive pathogen in a plant, certain effects on pathogen's physiology and morphology are inevitable to occur.

The amount of damage to the pathogen in the plant following fungicide application is usually measured by monitoring further symptom development or decrement in spore production. Nevertheless, several studies revealed morphological, physiological or biochemical alterations in structures of fungi and oomycetes inside the plant after postinfection fungicide treatment. Triazole fungicides tebuconazole and myclobutanil caused breakdown of subcuticular and intercellular mycelia of *Diplocarpon rosae* in infected rose leaves (Gachomo et al., 2009). In the same experiment, less systemic strobilurin fungicides pyraclostrobin and trifloxistrobin also caused collapse of *Diplocarpon rosae* inside rose leaves, but their effects were evident only on subcuticular mycelia of the fungus (Gachomo et al., 2009). Abnormal growth and changes in hyphal morphology was observed in mycelia of *Venturia inaequalis*, causal agent of apple scab, on plants treated with bitertanol, fenarimol, triforine and benomyl (O'Leary & Sutton, 1986; Kelley & Jones, 1981). Similar effects on *Venturia inaequalis* subcuticular hyphae in infected apple leaves following postinfection treatments with different triazole fungicides were recorded in another study (Thakur et al., 1992). Triadimefon lead to swelling and distortion of hyphae of *Hemileia vastatrix*, causal agent of coffee rust, when applied 24 or 48 hours after inoculation of coffee leaves with the fungus (Coutinho & Rijkenberg, 1995). Incomplete and multiperforate septa, as well as extensive wall thickening were observed in mycelia of *Uromyces fabae* and *Puccinia recondita* inside the infected leaves of broad bean and wheat after treatment with triadimefon (Pring, 1984). Similar changes were recorded in another wheat rust fungus, *Puccinia striiformis*, after application of tebuconazole three days after infection (Han et al., 2006). Vacuoles inside mycelial cytoplasm increased and cell walls thickened, following by collapse of cytoplasm in fungal cells (Han et al., 2006). Four days after the treatment, destruction of *Puccinia striiformis* intercellular mycelia and haustoria was evident (Han et al., 2006). Application of kresoxim-methyl and penconazole on grapevine leaves infected with powdery mildew, *Uncinula necator*, resulted in reduced mycelial density of the fungus and in partial collapse of hyphae (Leinhos et al., 1997). Accumulation of electron dense deposits adjacent to mitochondria, followed by mitochondrial degeneration were observed in hyphae of *Phytophthora infestans* in infected tomato leaves after treatment with oxadixyl (Jing & Grossmann, 1991). Cell walls of *Phytophthora infestans* hyphae became thickened, and degeneration of haustoria was recorded (Jing & Grossmann, 1991). Abnormal shrinking of cells, separation of membrane from the hyphal wall, breakdown of cell membrane and indistinct structure of cell organelles were noted in *Phytophthora capsici* mycelium inside the pepper seedlings after treatment with metalaxyl (Hwang et al., 1990). Five days after metalaxyl application on pea plants infected with downy mildew, *Peronospora pisi*, haustoria of the parasite were deformed, and vacuoles were visible in the cytoplasm of haustorial cells (Hickey & Coffey, 1980).

As it can be seen, most of the studies in which the effects of fungicides on fungal mycelium inside the infected plant were studied were conducted on biotrophic and hemibiotrophic plant pathogens. Many of biotrophic plant pathogenic fungi and oomycetes can not be cultivated *in vitro*, and the effects of fungicides on their development often can not be investigated on usual artificial nutrient media. Beside this, such pathogens are an interesting object of research for biologists and plant pathologists because of their very close contact with the host plant. Changes in their morphology and physiology can also reveal some new aspects of the host-pathogen interaction.

Suppression of pathogen's spore production on infected plant tissue can be viewed as an indirect consequence of fungicide activity on fungi and oomycetes established in the plant.

Numerous studies showed such effect of various systemic fungicides, and these studies can be regarded as especially valuable in disease management practice. For example, tebuconazole, cyproconazole, flusilazole and prochloraz reduced the number of *Septoria tritici* pycnidia on wheat leaves when applied after inoculation of plants with the fungus (Schöfl & Zinkernagel, 1997). Three sprays of propiconazole destroyed all teliosori of *Puccinia horiana* when this fungicide was applied after the symptoms of white rust occurred on chrysanthemum leaves (Dickens, 1990). When tebuconazole was applied three days after inoculation of wheat leaves with *Puccinia striiformis*, no uredia and urediniospores were formed (Han et al., 2006). Postinfection treatment with propiconazole and difenconazole inhibited sporulation of *Cercospora arachidicola* on peanut plants for 100 % and 90 %, respectively (Dahmen & Staub, 1992). Production of *Venturia inaequalis* conidia on apple leaves was almost completely inhibited when fenarimol, bitertanol and triforine were applied up to 120 hours after infection (Schwabe et al., 1984). Similar results for the same three fungicides and benzimidazole benomyl were recorded in another study (O'Leary & Sutton, 1986). Lesions of *Venturia inaequalis* sprayed twice in a week with bitertanol two days after their emergence contained much more immature and non-viable conidia (Kelley & Jones, 1981). Low germination of *Venturia inaequalis* conidia was also recorded after postsymptom application of bitertanol, fenarimol, triforine and benomyl (O'Leary & Sutton, 1986). Propiconazole, tebuconazole, myclobutanil, flusilazole, triforine and fenarimol reduced *Monilinia fructicola* conidial production from 58 % to 95 % when applied 72 hours after inoculation of sour cherry blossoms with the fungus (Wilcox, 1990). Application of kresoxim-methyl and penconazole on grapevine leaves infected with powdery mildew, *Uncinula necator*, resulted in inhibition of conidial formation on fungal mycelia (Leinhos et al., 1997). Difenconazole and azoxystrobin suppressed *Cercospora beticola* sporulation after treatment of sugar beet plants on which symptoms of *Cercospora* leaf spot emerged (Anesiadis et al., 2003). When propiconazole and azoxystrobin were applied to ryegrass plants infected with *Puccinia graminis*, they reduced urediniospore production by 73 % and 95 %, respectively (Pfender, 2006). After treatments of grapevine seedlings inoculated with *Guignardia bidwellii*, myclobutanil and azoxystrobin suppressed formation of pycnidia in lesions caused by the fungus (Hoffman & Wilcox, 2003). Application of myclobutanil resulted in 100 %, 91 % and 75 % reduction of *Guignardia bidwellii* pycnidium formation when applied six, eight or ten days after inoculation of plants with the fungus (Hoffman & Wilcox, 2003). Trifloxystrobin significantly reduced sporulation of *Fulvia fulva* on tomato leaves when applied on symptomatic plants (Veloukas et al., 2007). Kresoxim-methyl inhibited sporulation of *Venturia inaequalis* and *Uncinula necator* when applied two to four days after inoculation of apple and grapevine leaves (Ypema & Gold, 1999). Azoxystrobin, pyraclostrobin and kresoxim-methyl significantly reduced sporulation of *Sclerospora graminicola* on infected pearl millet plants (Sudisha et al., 2005), while trifloxystrobin and pyraclostrobin significantly reduced sporulation of *Cercospora beticola* on infected sugar beet plants (Karadimos et al., 2005). When applied up to five days after inoculation of grapevine seedlings with *Plasmopara viticola*, azoxystrobin reduced downy mildew sporulation by 96 %, and metalaxyl by 94 % (Wong & Wilcox, 2001). When treatment with these two fungicides was performed after the incubation period, on already sporulating downy mildew lesions, azoxystrobin and metalaxyl inhibited resporulation from the lesions by 85 % and 84 %, respectively (Wong & Wilcox, 2001). One day after fungicide treatment, metalaxyl suppressed sporulation of *Peronospora pisi* on pea plants infected with downy mildew (Hickey & Coffey,



1980). Dimetomorph reduced sporangial production when applied one day after inoculation of potato and cucumber plants with *Phytophthora infestans* and *Pseudoperonospora cubensis*, respectively (Cohen et al., 1995). The same fungicide inhibited *Pseudoperonospora cubensis* sporangial production on cucumber leaf disks treated three days after the inoculation (Wang et al., 2009). Postinfection treatment with dimetomorph, propamocarb and cymoxanil significantly reduced sporulation of *Phytophthora infestans* on potato plants (Johnson et al., 2000), while dimetomorph, mandipropamid, benthivallcarb and iprovalicarb suppressed sporulation of *Bremia lactucae* on infected lettuce leaf discs (Cohen et al., 2008).

Beside effects on development of reproductive structures of different fungi and oomycetes inside the plants, it is interesting to mention that postsymptom application of certain fungicides can sometimes lead to long-term effect on further development of the pathogen inside the plant tissue. Such long-term effect was recorded in *Venturia inaequalis* after treatment with ergosterol biosynthesis inhibitors bitertanol, fenarimol and triforine (O'Leary & Sutton, 1986). *Venturia inaequalis* produce conidia on apple leaves during the vegetation, while during the winter period it continues to develop in fallen dead leaves and produce pseudothecia, fruiting bodies with asci and ascospores. It was noted that the fungus exposed to the above mentioned fungicides during vegetation produced smaller pseudothecia in fallen apple leaves, with many undeveloped asci containing fewer ascospores (O'Leary & Sutton, 1986).

Antisporulant activity on fungi and oomycetes established in plants is not a property attributed only to systemic fungicides. Fungicides regarded as protectant can also show similar effects. Reproductive structures of the majority of parasitic fungi and oomycetes develop on the surface of plant organs, providing the pathogen to spread its spores in environment. In such way, protectant fungicides on the surface of plant tissue can come into contact with conidiophores, sporangiophores, ascocarps, acervuli, pycnidia, sori or other fungal structures, which can result in reduction of sporulation. How much fungicidal compound will reach reproductive structures of fungi and oomycetes, depends on the position of a certain fungal species in infected plant. For example, it can be expected that protectant fungicides will have an effect on mycelia of many powdery mildews (Erysiphales), plant parasites which develop their hyphae and conidia on the surface of plant organs.

### 3.1 Curative and eradication effects of fungicides in seed treatment and treatment of planting material

The first systemic fungicides introduced to the market were carboxin fungicides (Kulka & von Schmeling, 1987). After their discovery, carboxin fungicides were proven to be extremely effective in seed treatments against loose smuts of barley and wheat, caused by *Ustilago nuda* and *Ustilago tritici* (Maude, 1996; Kulka & von Schmeling, 1987). These *Ustilago* species infect wheat and barley flowers, and become established in embryo of developing kernels, without causing visible symptoms. As *Ustilago nuda* and *Ustilago tritici* mycelia are located deeply in infected seed, fungicides that do not penetrate in seed embryo could not be effective in controlling these diseases. Carboxin fungicides enabled an eradication of loose smut pathogens inside the seed, and this was the first example of fungicidal therapeutic activity used in fungal disease management practice worldwide. Soon after the introduction of carboxin, other systemic fungicides were developed for seed treatment, like guazatine, ethirimol, benzimidazoles thiabendazole, benomyl or carbendazim, triazole

fungicides, fenpropimorph, metalaxyl, fosetyl-Al or fludioxonil. Eradication of seed-borne pathogens with systemic fungicides has become much more effective compared to the majority of non-systemic seed fungicides. Although protectant fungicides are still used successfully, most of the fungicides used for seed treatment on the market today are systemic fungicides. The advantages of systemic fungicides in seed treatment are not demonstrated only in better eradication of seed-borne parasites. Systemic fungicides are uptaken and equable redistributed inside the seedlings, which leads to better distribution of fungitoxic compound in all young plant tissues. Their movement to cotyledons and first leaves offers protection of the aboveground parts of the plant for a certain period. Such period of protection can be relatively long, and it can contribute to more efficient management of various foliar diseases. Nevertheless, eradication of different fungal pathogens established in the seed can be also accomplished with protectant fungicides. For example, systemic benomyl and protectant iprodione and vinclozolin equally effectively eradicated seed-borne *Sclerotinia sclerotiorum* from the sunflower seed (Herd & Phillips, 1988). The main reason for this is the position of parasitic fungi and oomycetes inside the seed. Generally, there are not many economically important fungal pathogens which are usually established deeply in the seed. Many seed-borne fungi and oomycetes are present as spores or mycelium on the surface of the seed or inside the superficial tissues of seeds, and often the infection is located in pericarp (Maude, 1996). Relatively smaller number of seed-borne fungal parasites is usually located in deeper seed tissues, like endosperm or embryonic axes (Maude, 1996). Therefore, protectant fungicides can come into contact with fungal structures of fungi and oomycetes which develop close to the seed surface, like relatively many *Alternaria*, *Fusarium*, *Botrytis*, *Sclerotinia*, *Phoma* or *Pythium* species (Maude, 1996). Eradicative effect of non-systemic fungicides is dependent how effectively and to which extent will fungicidal compound reach the pathogen inside the seed.

Comparing it to eradication in chemical control of foliar, fruit, root or stem diseases, eradication of fungal pathogens is much easier and more successfully achieved in seed treatment. Chemotherapeutic effect in seed treatment is often total, with the pathogen completely destroyed inside the seed tissues. There are several reasons for this. First of all, seed has a small volume compared to adult plants. When fungicides are applied, they can effectively reach each part of the seed and come into contact with the target pathogens. Seed treatment machinery is technically very advanced today, and all surfaces of the seed can be uniformly covered with a fungicide. Due to small volume of the seedling, concentration of a fungicide inside the seedling remains high for a relatively long period, which decreases the possibility of the pathogen to survive. At the same time, the biomass of the pathogen inside the seed is small and in such way easier to exterminate. Not less important, it must be pointed out that chemical companies which produce certain fungicide for a seed treatment are testing, calculating and accurately establishing dose rate needed for a treatment to be effective.

Treatment of planting material is another common measure where eradication effects of fungicides can be used in disease management practice. Some important and potentially destructive plant pathogens can be present in tubers, bulbs, cuttings, seedlings or other types of planting material, very often as symptomless infection. Disease control in nurseries and phytosanitary control of mother plants' health status are the main preventive measure intended to secure that economically important fungi and oomycetes are not present in planting material. However, in many cases it is relatively hard to prevent and control the presence of certain fungal diseases in planting material, especially considering the fact that they may not cause any visible symptoms for some time. The efficacy of fungicides in

eradication of pathogens from planting material basically depends on the same factors as it is with seed treatment. Due to some important differences, the efficacy of such treatments is usually not as high as the treatment of seed. First, all types of planting material have much larger volume than the seed. Fungicide must redistribute in all parts of plant tissue in sufficient fungitoxic amounts. Fungal biomass in different types of planting material is much larger, and more fungicide is needed for complete eradication of the pathogen. The technology of fungicide application on planting material is not as advanced, precise and practical as it is with the seed treatment. Finally, there are much less fungicides on the market registered for the treatment of specific types of planting material. This can lead to problems in assessment of appropriate dose, concentration, or exposure time, as well as to the higher risk of possible phytotoxicity.

Several studies showed the lack of complete pathogen's eradication following the treatment of planting material with fungicides. Application of thiophanate-methyl to potato seed pieces infected with *Phytophthora infestans* significantly reduced the amount of tuber surface area colonized by the oomycete, but such reduction was not very high (Inglis et al., 1999). An incidence of *Phaeoconiella chlamydospora* and *Phaeoacremonium* species in grafted grapevine cuttings and uprooted nursery vines was reduced following drench in benomyl, although such reduction was not significant compared to plants drenched only in water (Fourie & Halleen, 2004). Prochloraz, propiconazole and difenconazole dip resulted in 11.5 %, 53.5 % and 57.2 % mortality of strawberry transplants caused by *Colletotrichum acutatum*, compared to 80 % mortality in untreated transplants (Freeman et al., 1997). The percentage of *Colletotrichum acutatum* recovery from strawberry runners dipped in prochloraz was less than 5 % after three days, but it increased to 60 % after 12 days (Freeman et al., 1997). Nevertheless, fungicide treatment can also be exceptionally effective in eradication of the pathogens from planting material. For example, 10 and 20 days after dip of chrysanthemum cuttings in myclobutanil, no pustules of *Puccinia horiana* appeared on treated plants, while more than 90 % of control plants showed symptoms (Bonde et al., 1995). Thirty days after the dip, *Puccinia horiana* was visible on only two out of the 720 treated plants, while 94 % of untreated plants were infected (Bonde et al., 1995).

### 3.2 Curative effects of fungicides in management of root and crown roots

Generally, root and crown rots are plant diseases which are difficult to control with chemical measures. Caused by different soil-borne pathogens, symptoms of such diseases can develop on the aboveground parts of the plant relatively long after the infection has occurred, often after considerable damage has already been done to plant's root or crown tissue. Symptoms of many root and crown rots are unspecific and it can be relatively hard to make an accurate diagnosis without laboratory analysis. Root and crown rots can develop unevenly over the production area - in some parts of the field a disease can be especially severe, while in other parts it may be absent. Soil-borne pathogens which are causal agents of root and crown diseases can sometimes attack plants during the whole year, and it is relatively complicated to develop a reliable forecast model which could predict infection risk periods. On the other hand, a small number of systemic fungicides have an ability to translocate downward through the plant in the phloem sap. In such way, foliar treatments with the most of systemic fungicides against root or crown diseases are not effective, as fungicidal compound does not reach the pathogen in roots or basal parts of a stem or a trunk. If fungicides are applied as soil treatment, plants can uptake a relatively small amount of a fungitoxic compound. This can cause difficulties in calculation of an appropriate dose and concentration of a product. While



lower doses can be ineffective, larger doses of a fungicide can cause phytotoxicity problems. High amount of the fungicide applied to a soil can be rapidly degraded, and repeated applications of the fungicide may be required, which can significantly influence the cost-benefit ratio and economic justifiability of soil treatments. A relatively small number of granular-formulated fungicides are labelled for soil treatment on the market today, and they may not be available in all countries. Comparing it to foliar treatments, agricultural mechanization for soil treatment or trunk application has not been intensively developed. Trunk paints, trunk injections, or root drench of separate plants is labour-intensive and not practical in many cases. These are some of the reasons why chemical control of root and crown diseases could be problematic, and why management of root and crown diseases is relied primarily on prophylactic non-chemical methods, like host resistance, crop rotation, or regulation of water regime in soils. During the last two decades, much work has been done on biological control of such diseases, and it is obvious that biological control of soil-borne pathogens will become increasingly important in practice.

Theoretically, preventive chemical control of root and crown rots could be efficient if fungicides are present in all susceptible root and stem plant tissue in effective fungitoxic amounts during the period when infection is possible. The other possibility for chemical control of soil-borne diseases would be eradication of pathogens in soil prior to cultivation. Fungicides are used in management of certain root and crown diseases, like those caused by *Phytophthora* or *Rhizoctonia*, but nearly all of these fungicide treatments are intended to be used on preventive basis. In case of such diseases, options for curative treatments of already infected plants are limited. When symptoms begin to develop on the aboveground parts of the plant, parasitic fungus or oomycete has often developed a relatively high amount of biomass, and high amounts of a fungicide are needed to be effective. Fungicide must be applied and redistributed in a plant to reach the zones where pathogen's mycelium is active. If a part of mycelium survives fungicide treatment, or revive after fungistatic activity of a fungicide has ceased, the disease can continue to advance.

Despite many difficulties and limitations in therapeutic treatments of plants affected with root or crown rots, producers are often looking for each solution which could stop the disease progress if such disease emerge in a field and start to threaten the production. After the discovery and development of systemic fungicides, some studies have been done in order to explore the possibilities for curative treatments and the possible eradication of root and crown rot pathogens after the disease has started to develop. The majority of such research has been done on root and crown rots caused by various *Phytophthora* species, especially after introduction of potent systemic compounds metalaxyl and fosetyl-Al to the market (Erwin & Ribeiro, 2005). Fosetyl-Al was shown to be efficient in control of cankers caused by *Phytophthora citricola* on avocado (El-Hamalawi et al., 1995). One week after fosetyl-Al application, expansion of cankers on infected plants was stopped, and six months after the treatment it was not possible to recover the oomycete from canker lesions (El-Hamalawi et al., 1995). Mean disease ratings of avocado trees, infected with *Phytophthora cinnamomi* and trunk-injected with fosetyl-Al, decreased dramatically, from 5.3 in the first year to zero in the fourth year of the experiment (Darvas et al., 1984). Apple trees in the initial stage of root and crown rot caused by *Phytophthora cactorum* and drenched with metalaxyl remained alive and productive, while control untreated trees died within a three-year period (Utkhede, 1987). Survival of azaleas, infected with *Phytophthora cinnamomi* and treated with three foliar sprays of fosetyl-Al and two drenches of metalaxyl, was monitored for three years after transplanting the plants in disease-free landscape beds (Benson, 1990).

A small number of treated plants developed symptoms of root rot after three years in beds, while mortality of control plants reached 39 % (Benson, 1990).

Curative effects of fungicides on root and crown rots other than those caused by *Phytophthora* species have not been studied intensively. Certain effectiveness of soil drench with benomyl and tridemorph on plants affected with *Rosellinia necatrix* root rot has been recorded (ten Hoopen & Krauss, 2006). An interesting study has been conducted on propiconazole treatment of almond plants affected with *Armillaria mellea* root rot, using medical intravenous bags hanged around the trunk (Adaskaveg et al., 1999). Five months after the treatment, all five treated trees were alive, while four out of five control trees died (Adaskaveg et al., 1999). In the second year, four out of five treated trees were alive, while four out of five control trees died, and disease severity was significantly lower on treated trees (Adaskaveg et al., 1999).

### 3.3 Curative effects of fungicides in management of vascular wilts, cankers and wood rots

Chemical control of fungal vascular wilts, cankers, and wood rots more or less share the same problems related with the use of fungicides in management of root and crown rots. In fact, certain fungi and oomycetes which can cause canker diseases can also cause root and crown rots, and delineation among such diseases is sometimes not sharply defined. This is especially evident among diseases caused by different *Phytophthora* species, some of which are able to attack roots, stems, branches, or fruits of various cultivated plants. *Sclerotinia sclerotiorum* on sunflower or soybean, or *Colletotrichum acutatum* on strawberry are the other examples of such diseases.

As it is with root rots, symptoms of vascular wilts and wood rots can become evident when development of the pathogen inside the plant is already in advanced stage. In cases of vascular wilts, fungus is growing through the xylem tissue, and can be present in different parts of the plant. Wood rots are caused by fungi which degrade lignin and cellulose inside the wood, and can also develop large amounts of mycelia before a tree starts to wither. It is often hard to determine the periods when infection is possible, as vascular wilt pathogens or wood-rotting fungi penetrate the plant from the soil through the roots, through the wounds on the aboveground parts of the plant, or can be carried by insect vectors. Cankers are more easily to detect on plants, but one of the significant problems in chemical management of such diseases can be the fact that these diseases frequently develop throughout the whole year, often even more intensive out of the vegetation period. Relatively large amount of pathogen's mycelia inside the diseased plants, invisible early stages of infection, location of the pathogen deep inside the plant tissues, lack of adequate machinery needed for special types of fungicide application, and a small number of fungicides labelled for use are the major constraints associated with chemotherapy of vascular wilts, wood rots and canker diseases. Beside this, it must be pointed out that protective or curative treatments in cases of such diseases are usually labour-intensive, and can often be economically unjustifiable. As it is with many root rots, it can be cheaper and more practical to eradicate the diseased plant than to eradicate the disease from the plant.

After the introduction of systemic fungicides to the market, their curative and eradication potential in treatments of certain vascular wilts, wood rots and cankers has started to be studied. For the above mentioned reasons, during the next twenty years such experiments were remitted, and the research on management of such diseases focused on other possibilities. Nevertheless, some results have been achieved in therapeutic treatments of

various cankers caused by *Phytophthora* species and vascular wilt diseases of landscape ornamental trees like oaks and elms. For example, cankers caused by *Phytophthora palmivora* on cocoa trees were significantly reduced following potassium phosphonate trunk injections (Guest et al., 1994). Metalaxyl and fosetyl-Al, applied in granular formulations, or fosetyl-Al applied as foliar spray, significantly reduced cankers on peach caused by *Phytophthora cactorum* when applied as curative treatments (Taylor & Washington, 1984). Both fungicides were also effective in reducing cankers following postinfection treatments as trunk paints (Taylor & Washington, 1984). Almost no active lesions were found on trees treated with granular formulations of metalaxyl and fosetyl-Al (Taylor & Washington, 1984), which indicates that these fungicides were capable of complete eradication of the oomycete from infected trees. Fosetyl-Al and mefenoxam, active isomer of metalaxyl, applied as topical treatments with paint brush or as a spray, reduced canker expansion on almond inoculated with *Phytophthora cactorum* or *Phytophthora citricola* by 36 - 88 % (Browne & Viveros, 2005). Active cankers treated with fosetyl-Al sprays expanded 71 - 77 % less, while those sprayed with mefenoxam expanded 54 - 79 % less than on control trees (Browne & Viveros, 2005). In other variant, fosetyl-Al reduced canker expansion by 86 - 88 %, while mefenoxam reduced canker development by 52 - 80 % (Browne & Viveros, 2005). Curative bark drench applications of phosphonate on beech saplings inoculated with *Phytophthora citricola* significantly limited canker expansion on infected trees (Weiland et al., 2009).

Several experiments have been done on chemical control of oak wilt, caused by *Ceratocystis fagacearum*, and Dutch elm disease, caused by *Ophiostoma ulmi*. Trunk injections with thiabendazole were somewhat effective as therapeutic treatment of elms affected with Dutch elm disease (Lanier, 1987). Trunk injections with benomyl to elm trees with various stages of decline led to remission of disease in many trees, but disease development was not affected if application was performed on trees which showed more than 5 % of crown damage prior to the treatment (Smalley et al., 1973). Generally, it is proven that thiabendazole and propiconazole can be effective in therapeutic treatments of trees affected with Dutch elm disease (Scheffer et al., 2008), but these fungicides need to be applied in relatively early stages of infection. These two fungicides are labelled for chemical control of Dutch elm disease in the USA, but are not recommended to be used on severely affected trees. On thiabendazole label, it is written that treatments may not be effective when tree shows more than 5 % of crown symptoms, while on propiconazole label it is stated that treatment may not be effective when applied to trees in advanced stages of disease development (Scheffer et al., 2008). The same triazole fungicide, propiconazole, has shown to be effective in curative treatments of oak wilt (Appel & Kurdyla, 1992). Following intravascular injection of infected oaks with propiconazole, level of crown loss 9 to 36 months after the injection ranged from none to 41 %, while it reached 61 - 100 % in untreated trees (Appel & Kurdyla, 1992). Injections in presymptomatic stage of the disease resulted in better control (Appel & Kurdyla, 1992).

It is recorded that curative treatments can be effective in control of Fusarium wilt on certain vegetables, caused by different forms of *Fusarium oxysporum*. Prochloraz and carbendazim were tested in control of Fusarium wilt of tomato in hydroponic system by adding fungicides in nutrient solution one week after plants were artificially inoculated with the fungus (Song et al., 2004). Two weeks after the treatment, prochloraz showed 50 % control, while carbendazim gave 34.4 % disease control (Song et al., 2004). Benomyl applied as soil drench reduced the quantity of mycelium in muskmelon plants infected with *Fusarium*

*oxysporum*, and it is reported that plants were generally cured when fungicide was applied before symptoms occurred (Maraite & Meyer, 1971).

Grapevine cultivation is somewhat different from fruit cultivation. In case of grapevine grown for vine production, breeding for resistance and development of disease-resistant cultivars is virtually not conducted. Some vineyard areas and locations are particularly valuable for winegrowing and appreciated in the vine market. In such perspective, labour-intensive curative treatments of certain grapevine diseases could be a measure regarded as acceptable for some producers. Eutypa canker, caused by *Eutypa lata*, and esca, complex disease caused by wood-rotting *Fomitiporia* species, *Phaeomoniella chlamydospora* and *Phaeoacremonium* species, cause considerable damage to grapevine production in many areas of the world, and it is not surprising that the possibility of their management with fungicides has been explored. Trunk injections of cyproconazole resulted in better productivity and lower mortality in vines affected with esca which were subjected to trunk removal and injection of fungicides for three consequent years (Calzarano et al., 2004). The number of vines showing symptoms of esca decreased after trunk injections with propiconazole, difenconazole and thiabendazole (Dula et al., 2007). Syringe treatments with cyproconazole, flusilazole, penconazole and tetraconazole of vines with early symptoms of esca significantly reduced foliar symptoms appearance of the disease (Di Marco et al., 2000). However, treatments of old infected vines were not effective, and neither were trunk paints or foliar applications of fungicides (Di Marco et al., 2000). Similarly, almost no effects were recorded following trunk injections of propiconazole and difenconazole in vines affected with *Eutypa lata* (Darrieutort & Lecomte, 2007).

### **3.4 Curative and eradivative effects of fungicides in management of foliar and fruit diseases**

Most of the fungicides are developed and registered for management of diseases which develop on aerial plant parts. Chemical control of various diseases affecting leaves, stems, branches, flowers or fruits on nearly all cultivated plants has become regular measure in agricultural production, and it is obvious that it will remain so in the future. Machinery for pesticide treatments is technically advanced, while the assortment of fungicides available on the market offers numerous possibilities for effective and economical disease control. These are the main reasons why curative and eradivative effects of fungicides have been most intensively studied in cases of foliar and fruit diseases.

As mentioned before, most of the fungicides are more efficient when applied prior to infection than after the infection has occurred, or after the symptoms have appeared. No matter of this, many fungicides are able to stop pathogen development inside the infected plant tissue. If applied shortly after infection, during the early stages of pathogenesis, fungicide treatment can sometimes completely eradicate the parasite from the plant, although such cases are actually rare. Generally, it can be stated that all the fungicides which are able to penetrate the plant can have curative or eradivative activity on certain plant diseases. True systemic fungicides, locally systemic fungicides, fungicides with translaminar activity, and in some cases even the fungicides regarded as protectants can reveal curative or eradivative effects in postinfection treatments.

One of the most important factors which implicate the curative effects of different fungicides is the period passed from the infection to the fungicide application. During the early stages of pathogenesis, fungal biomass inside the plant is relatively small, but mycelium of parasitic fungi and oomycetes is growing, proliferating and spreading with the time within



the plant tissue. While fungitoxic compound can be effective on small amounts of pathogen's mycelia located near the plant surface, larger amounts of mycelia deeper inside the plant tissue can be much less affected. In nearly all experiments and field trials on postinfection treatments, the efficacy of fungicides decreased as the period between the infection and fungicide application became longer. When trifloxystrobin was applied 24, 48 or 96 hours after inoculation of tomato with *Fulvia fulva* at concentration of 10 µg a.i./ml, its effectiveness was 89 %, 76 % and 60 %, respectively (Veloukas et al., 2007). Similar decrease of disease control level was also observed for other concentrations of trifloxystrobin applied (Veloukas et al., 2007). Fluazinam and boscalid applied two days after inoculation of peanut plants with *Sclerotinia minor* reduced disease incidence, but no reduction was recorded when these fungicides were applied four days after the inoculation (Smith et al., 2008). Applied one and three days after inoculation of cucumber plants with *Pseudoperonospora cubensis*, dimetomorph gave 67 and 32 % disease control, respectively, while the efficacy of azoxystrobin decreased from 96 % when applied one day after inoculation to 39 % when applied three days after inoculation (Wang et al., 2009). Mandipropamid and dimetomorph applied 24 hours after inoculation of potato and tomato leaflets with *Phytophthora infestans* significantly reduced sporulation of the oomycete, but no curative effects were observed when fungicides were applied 48 hours after the infection (Cohen & Gisi, 2007). When azoxystrobin, pyraclostrobin, mefenoxam and phosphonate were applied 13, 24, 36 or 48 hours after strawberry plants were inoculated with *Phytophthora cactorum*, disease incidence on azoxystrobin- and pyraclostrobin-treated plants was about 40 % when applied 13 hours after inoculation, comparing it to 70 % on control plants and zero on mefenoxam- or phosphonate-treated plants (Rebollar-Alviter et al., 2007). When azoxystrobin and pyraclostrobin were applied 24 hours after the inoculation, disease incidence on treated plants was the same as on control (Rebollar-Alviter et al., 2007). Mefenoxam and phosphonate provided significant disease control when applied even 48 h after the inoculation of plants (Rebollar-Alviter et al., 2007). Pyraclostrobin applied 3 or 8 hours after inoculation of strawberry plants with *Colletotrichum acutatum* provided excellent disease control, but was less effective when applied 24 or 48 hours after inoculation (Turechek et al., 2006). Trifloxystrobin, pyraclostrobin and difenconazole were efficient in control of *Cercospora beticola* when applied 24 hours after inoculation of plants, but their efficiency decreased if 96 hours has passed from the inoculation to the application time (Karadimos et al., 2005). When propiconazole, tebuconazole, myclobutanil, flusilazole, triforine, fenarimol, vinclozolin and iprodione were applied 24 hours after inoculation of sour cherry with *Monilinia fructicola*, they reduced or completely prevented blossom blight. When application was prolonged to 72 hours after inoculation, none of the fungicides provided significant disease control (Wilcox, 1990). One day after inoculation of tomato with *Alternaria solani*, difenconazole provided more than 90 % disease control, but the level of control fell to 60 % when the fungicide was applied two days after inoculation (Dahmen & Staub, 1992). Reduction of necrotic leaf area caused by *Septoria tritici* on wheat plants rapidly decreased the longer was the period between infection and application of tebuconazole, cyproconazole, flusilazole and prochloraz (Schöfl & Zinkernagel, 1997). Similar decrement in efficacy was recorded when pyrimethanil, azoxystrobin and fludioxonil were applied to lemon fruit 9, 12, 15, 18 and 21 hours after inoculation with *Penicillium digitatum* (Kanetis et al., 2007). These are only some of the examples which show the relation of curative effects of different fungicides and postinfection application time.

The effect of fungicides on pathogen established in the plant will typically be more pronounced when higher dose or concentration is used. Such effects can easily be measured *in vitro*, by monitoring mycelium growth in the presence of different fungicide concentrations on agar media, in broths, or on various detached leaf assays. Numerous *in vitro* studies of this kind have been conducted, often as preliminary screening to further glasshouse or field experiments on living plants. The impact of dose or concentration applied on efficacy of postinfection fungicide treatment can be clearly seen from several studies. Bitertanol applied at 150 µg a.i./ml was less effective in suppressing apple scab lesion development than the same fungicide applied at concentration of 300 µg a.i./ml (Kelley & Jones, 1981). When applied one day after inoculation of cucumber plants with *Pseudoperonospora cubensis*, dimetomorph in concentrations of 250, 500 and 1000 µg a.i./ml provided 33, 43 and 62 % of disease control, respectively (Cohen et al., 1995). An increase in suppression of sporulation and lesion development was recorded when higher concentrations of difenconazole, penconazole and propiconazole were used in postinfection treatment of *Venturia inaequalis* on apple and *Cercospora arachidicola* on peanut (Dahmen & Staub, 1992). When trifloxystrobin was applied one day after inoculation of tomato with *Fulvia fulva* at different concentrations, level of disease control was 70 % for 5 µg a.i./ml, 89 % for 10 µg a.i./ml, and 93 % for 20 µg a.i./ml (Veloukas et al., 2007). Level of postinfection *Puccinia horiana* control on chrysanthemum was different when myclobutanil was applied at different concentrations (Bonde et al., 1995).

Similarly like curative effects of fungicides are more pronounced with higher fungicide dose or concentration, higher inoculum level can lead to decrement in efficacy of postinfection fungicide treatment. In cases of higher diseases pressure, multiple infections occur, and disease development is faster. In such conditions, there are less possibilities for a fungicide to efficiently affect all the infection sites. Moreover, faster development of a pathogen within the plant leads to faster accumulation of more mycelia, incubation period is shorter, and sporulation is more rapid. Studies conducted in controlled conditions show such effects. Propiconazole, tebuconazole, myclobutanil, flusilazole, triforine, fenarimol, vinclozoline and iprodione were very effective in reducing blossom blight when applied 48 hours after inoculation of sour cherry with 5000 *Monilinia fructicola* conidia, but they were less effective when plants were inoculated with 50 000 conidia (Wilcox, 1990). Postinfection disease control with azoxystrobin was low when grapevine seedlings were inoculated with million *Guignardia bidwellii* conidia/ml, while it was relatively high when plants were inoculated with 20 000 conidia/ml (Hoffman & Wilcox, 2003). Effectiveness of curative treatments of tebuconazole, cyproconazole, epoxiconazole, flusilazole and prochloraz in control of *Septoria tritici* on wheat was different depending on the environmental factors which have conditioned disease development in different experiments (Schöfl & Zinkernagel, 1997).

It is not easy to evaluate the differences in curative effects among the fungicides from the same chemical groups, or to compare fungicides from different chemical groups. General conclusions regarding the therapeutic potential of a certain fungicide can be made based on its uptake and movement within the plant, mode of action, toxicity to a certain plant pathogen, results of laboratory experiments or field trials, and experience in practice, but the performance of each fungicide can vary depending on specific conditions in which it is applied. Many differences in performance of fungicides are recorded among different active compounds and in cases of different fungal plant diseases. For example, among strobilurin fungicides, azoxystrobin showed better effectiveness than trifloxystrobin or kresoxim-methyl in treatments of pearl millet plants infected with *Sclerospora graminicla* (Sudisha et al.,

2005). In foliar treatments, azoxystrobin gave 97 % of disease control, while trifloxystrobin and kresoxim-methyl gave 92 % and 69 %, respectively. When applied to roots of infected pearl millet plants, azoxystrobin gave 36 % of control, trifloxystrobin about 10 %, while kresoxim-methyl gave only about 4 % of disease control (Sudisha et al., 2005). On the other hand, trifloxystrobin was more efficient than azoxystrobin in reducing fruit rot of apple caused by *Alternaria alternata* when applied 24 or 48 hours after inoculation of fruits with the fungus (Reuveni & Sheglov, 2001). In experiments with strawberry plants inoculated with *Phytophthora cactorum*, azoxystrobin and pyraclostrobin showed mostly the same level of postinfection disease control (Rebollar-Alviter et al., 2007). In several trials, triazole fungicides showed higher effectiveness in postinfection treatments than strobilurin fungicides. Higher levels of disease control was achieved with difenconazole comparing it to azoxystrobin in curative treatments of sugar beet inoculated with *Cercospora beticola* (Anesiadis et al., 2003), and the same was recorded comparing curative effects of tebuconazole, myclobutanil, pyraclostrobin and trifloxystrobin on *Diplocarpon rosae* (Gachomo et al., 2009). When applied to grapevine seedlings inoculated with *Guignardia bidwellii*, myclobutanil provided complete control of lesion development up to six days after inoculation, while azoxystrobin provided only 61 % control of lesion formation (Hoffman & Wilcox, 2003). On the other hand, there are examples of other diseases where better results in postinfection treatments were obtained with strobilurin fungicides than with triazoles. Azoxystrobin significantly reduced severity of *Puccinia graminis* on ryegrass when applied up to 14 days after infection, while propiconazole was effective only up to seven days after infection (Pfender, 2006). The highest reduction of *Rhizoctonia solani* foliar blight on inoculated soybean plants was achieved with pyraclostrobin, followed by azoxystrobin, trifloxystrobin, difenconazole, bromuconazole, tebuconazole, benomyl, thiabendazole, fluazinam and carbendazim (Meyer et al., 2006). Propiconazole and triadimefon significantly reduced *Puccinia hemerocallidis* severity on daylilies when applied up to five days after inoculation, myclobutanil only up to three days after inoculation, while azoxystrobin significantly reduced disease severity when applied even up to seven days after inoculation of plants with the fungus (Mueller et al., 2004). Superior performance of azoxystrobin compared to myclobutanil, propiconazole and triadimefon was also recorded in postinfection treatments of sunflower plants inoculated with *Puccinia helianthi* (Mueller et al., 2004).

An influence of different pathogens on curative effects of fungicides can be showed in examples with the same fungicides applied as curative treatments on plants affected with different diseases. Benomyl was effective when applied up to 72 hours, while fenbuconazole and azoxystrobin were effective when applied up to 48 hours after inoculation of citrus seedlings with *Elsinoe fawcettii*, causal agent of citrus scab. None of the fungicides was effective in postinoculation treatments on melanose, another disease of citrus, caused by the fungus *Diaporthe citri* (Bushong & Timmer, 2000). Triadimefon significantly reduced lesions caused by *Puccinia pelagonii-zonalis* on geranium plants when applied up to seven days after inoculation of plants with the fungus (Mueller et al., 2004). The same fungicide significantly reduced lesions of another rust, *Puccinia hemerocallidis* on daylily, when applied up to five days after inoculation, while significant effect of this triazole fungicide on sunflower rust, *Puccinia helianthi*, was observed only up to one day after inoculation of plants with the fungus (Mueller et al., 2004). Applied one day after inoculation of tomato with *Alternaria solani*, difenconazole showed more than 90 % of disease control, while control level decreased to 60 % when the same fungicide was applied two days after inoculation of plants (Dahmen & Staub, 1992). In the same study, difenconazole completely prevented the

appearance of disease symptoms when applied up to three days after inoculation of apple with *Venturia inaequalis* or inoculation of peanut with *Cercospora arachidicola* (Dahmen & Staub, 1992).

As all the above mentioned studies show, an effect of a fungicide applied as curative treatment is dependent on many factors. In addition, it must be considered that the results of studies performed in controlled conditions can somewhat differ from the results which will be obtained in practical, field conditions. No matter of this, all of the scientific research on therapeutic treatments show what can be expected from the certain fungicide compound in cases of different foliar and fruit diseases.

#### 4. Conclusions

Development of systemic fungicides led to some significant advantages in disease management in modern agriculture. Systemic fungicides, uptaken by the plant, translocated and redistributed within the plant, are able to protect new growth of the plant for a certain period. The performance of such fungicides is generally less influenced by application method, which make their use more practical. Further advantage of fungicides which penetrate into the plant and translocate within it is their potential to affect the parasite already established in the plant, their theoretical potential to "cure the disease". Curative and eradicated effects of fungicides are commonly used in today's agriculture, with a range of clear benefits. The most important one is the flexibility in plant disease control. For a producer, it is usually hard to determine when the infection occurs. Even with the most accurate disease-warning or forecasting system, practical limitations may prevent the treatment to be conducted in optimal period. Being effective after the infection, curative treatments offered much more flexible control of numerous economically important plant diseases. Curative or eradicated activity of systemic fungicides can lead to reduced number of treatments, and can contribute to more economical and ecologically acceptable use of plant protection products. Second, if the symptoms are already present, most of the fungicides which are used for curative treatments show significant antispore activity. Reducing the spore production, fungicides reduce an inoculum needed for further disease spread. In such way, curative treatments can contribute to the delay of epidemic phase of the disease, which usually leads to considerable yield losses. Finally, systemic fungicides are often effective in eradication of certain seed-borne pathogens, or pathogens present in bulbs, tubers, stolons, or other types of planting material. Eradicated effects of fungicides contribute to the production and use of seed or planting material of higher quality. In such way, development of systemic fungicides offered some new possibilities in control of seed-borne diseases, in disease management in nurseries, in establishment of field crops, vegetables, ornamentals, orchards or vineyards, as well as in disease control strategies in various areas of cultivation.

Although all systemic fungicides can have a potential therapeutic effect, curative treatments are generally less effective than protective treatments. Considering the biology of plant pathogenic fungi and oomycetes, and some common facts in epidemiology of plant diseases, it is clear that complete eradication of the pathogen in practical conditions is rarely achieved, with some exceptions. Economic constraints regarding the costs are further limiting factors in plant chemotherapy. Therefore, it must be pointed out that no matter of their potential to affect disease development after an infection has occurred or when symptoms have appeared, systemic fungicides show their best effect if applied to prevent an



infection. In such way, strategies for the most efficient disease control with protectant and systemic fungicides mostly remain the same.

Research and development of new fungicides is constant, as well as is exploring for the new possibilities which different fungicidal compounds can offer. Numerous new active ingredients or combinations are introduced to the market, while other are being withdrawn for the ecotoxicological reasons. Different fungicides are being labelled for new uses, and other lose their permission. Various disease-warning systems are being continuously improved. Plant pathogenic fungi and oomycetes continue to change, evolve, and adapt to new agricultural practices, with populations changing, new pathotypes emerging, resistant forms developing and spreading to new areas. Many plant diseases are emerging or becoming more important, while other decline and become less significant. Agricultural practice is advancing, with development of new strategies in disease management. Production is becoming more and more market-oriented, and the number of people producing food and other agricultural products for their own needs is rapidly decreasing. These are the reasons why the possibilities of therapeutic treatments of plants with different fungicides are intensively studied for more than fifty years, and it will continue to be investigated in the future. Numerous studies are conducted on active compounds in chemical companies. Fungicides are subjects of studies in scientific research on universities, institutes, and other scientific institutions. A number of field trials is performed each year by plant pathologists, plant protection experts or agronomists. Such dynamics makes a more complete summary of current knowledge regarding curative and eradicated effects of fungicides almost impossible. Beside this, it must be said that almost all agricultural producers have their own experiences and considerable knowledge about the use of various fungicides in practice, and such experiences are seldom published. Based on their experience, they often know which fungicides are effective if a disease emerged or if there is a risk that an infection has already taken place. In such way, producers often indirectly witness the curative or eradicated effects in the field, without knowing much about fungicide biochemistry, mode of action or interaction with the plant and the pathogen. Research, experiments and experience will contribute to the further advance and benefits in use of curative and eradicated activity of modern fungicides.

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## **Fungicides**

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Plant and plant products are affected by a large number of plant pathogens among which fungal pathogens. These diseases play a major role in the current deficit of food supply worldwide. Various control strategies were developed to reduce the negative effects of diseases on food, fiber, and forest crops products. For the past fifty years fungicides have played a major role in the increased productivity of several crops in most parts of the world. Although fungicide treatments are a key component of disease management, the emergence of resistance, their introduction into the environment and their toxic effect on human, animal, non-target microorganisms and beneficial organisms has become an important factor in limiting the durability of fungicide effectiveness and usefulness. This book contains 25 chapters on various aspects of fungicide science from efficacy to resistance, toxicology and development of new fungicides that provides a comprehensive and authoritative account for the role of fungicides in modern agriculture.

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