

# **Impact of Plant Disease Biocontrol and Allelopathy on Biodiversity and Agricultural Sustainability**

Hung-Chang Huang<sup>1,3</sup> and Chang-Hung Chou<sup>2</sup>

<sup>1</sup> Agriculture and Agri-Food Canada, Research Centre, Lethbridge, Alberta, Canada T1J 4B1

<sup>2</sup> National Pingtung University of Science and Technology, Pingtung, 912, Taiwan

<sup>3</sup> Corresponding author, Fax: (403) 382-3156; E-mail: huangh@agr.gc.ca

Accepted for publication: February 25, 2005.

## **ABSTRACT**

Huang, H. C., and Chou, C. H. 2005. Impact of plant disease biocontrol and allelopathy on biodiversity and agricultural sustainability. *Plant Pathol. Bull.* 14:1-12.

Microorganisms such as fungi, bacteria, viruses, and nematodes are integral parts of agroecosystems. Some of them are harmful plant pathogens, whereas others are neutral or beneficial in their effects on plant growth. Control of disease-causing organisms is an essential component in every crop production system. Since World War II, numerous synthetic pesticides have been developed and used for control of crop pests. Many of the chemical pesticides killed not only the target species of pests but also other non-harmful or beneficial organisms. The 'one chemical kills all' approach for management of plant diseases is detrimental to the microbial biodiversity in agroecosystems, and is therefore no longer acceptable in modern agriculture which emphasizes the importance of using sustainable technologies for food production. Numerous reports suggest that control strategies such as biocontrol, allelopathy and organic soil amendment can be developed and used as viable alternatives to chemical control. However, most of these reports focus only on the control of target pathogens by biocontrol agent(s) or allelopathic substances without further investigations of their impacts on the agroecosystem and the environment. The potential of using biocontrol and allelopathy for the management of plant diseases must be determined not only by effective control of target pathogen(s) but also by their effectiveness in mitigation of negative impacts of agricultural production on biodiversity and agricultural sustainability.

**Key words :** Eco-friendly index, biodiversity, biocontrol, allelopathy, organic soil amendment, soilborne pathogens, risk assessment, sustainable agriculture

## **INTRODUCTION**

Animals, plants and microorganisms are important elements of every natural ecosystem. These living creatures interact continuously in a variety of complex relationships under fluctuating environmental conditions, in order to maintain or increase stability within the ecosystem. Some of the interactions may be beneficial to a particular microbial population; others may be detrimental to it. Prior to the agricultural era, people depended exclusively on the natural ecosystem for their food supply. With the establishment of agriculture, humans began to settle and cultivate crops for food, creating various artificial agroecosystems as a result of their agricultural practices.

An agroecosystem contains numerous species of plants,

animals and microorganisms, with some of them harmful plants and others not harmful or even beneficial to plants. However, because all agroecosystems focus on the production of food and fiber crops, any living creatures detrimental to such production are considered pests. Although plant pathogens represent a relatively small proportion of the taxonomic spectrum of microbial life, they have received a disproportionate amount of research attention because of their negative impact on crop production. Agricultural production must find ways to control diseases of crops in order to ensure their food supply and livelihood. Unfortunately, in the past years, many of the synthetic pesticides developed for control of crop diseases not only killed the intended target pathogen but also caused unintended damages to non-target species present in the same agroecosystem. Consequently, here

reliance on chemical pesticides has contributed to a steady decline in the biodiversity of agroecosystems.

Since the late 1980s, the predominant paradigm of crop protection has shifted from 'Chemism' to 'Environmentalism' <sup>(76)</sup>. In this new era of environmental conservatism, producers are constantly faced with the dilemma of finding methods that provide for effective control of unwanted plant pathogens while simultaneously minimizing negative impacts of crop production on the environment and non-target organisms. The approach of applying biocontrol agents or modifying the physical or chemical environment by soil amendments can lead to changes in population dynamics of microorganisms in a given ecosystem and such ecological instability can be used to improve the management of plant pathogens <sup>(27)</sup>. Unless we understand the components of the agroecosystem and their complex interactions in the physical and chemical environments, it is difficult to predict the best method of managing agricultural land without detrimental effects.

Control of plant diseases can be achieved either by direct application of biocontrol agents <sup>(3,4,5,26)</sup> or by indirect methods such as organic soil amendment <sup>(29,58)</sup> and crop rotation <sup>(37)</sup>. A variety of phytotoxic allelochemicals may be produced during the decomposition of many types of plant tissues in the soil under certain conditions <sup>(60)</sup>. Some of these allelopathic substances can be used as naturally occurring herbicides, fungicides or nematocides without deleterious effects on the environment <sup>(10)</sup>. Despite numerous reports on the potential of plant disease management strategies such as biocontrol and allelopathy, most of the studies were often focused only on the control of target pathogen(s) without further investigations on ecological impacts of these technologies. The objectives of this review were to propose the use of the term 'eco-friendly index' for assessing pros and cons of various disease management technologies, using biocontrol, allelopathy and soil amendment as examples, and to ensure that the technologies developed are not only effective and economical, but also ecologically sound and socially acceptable.

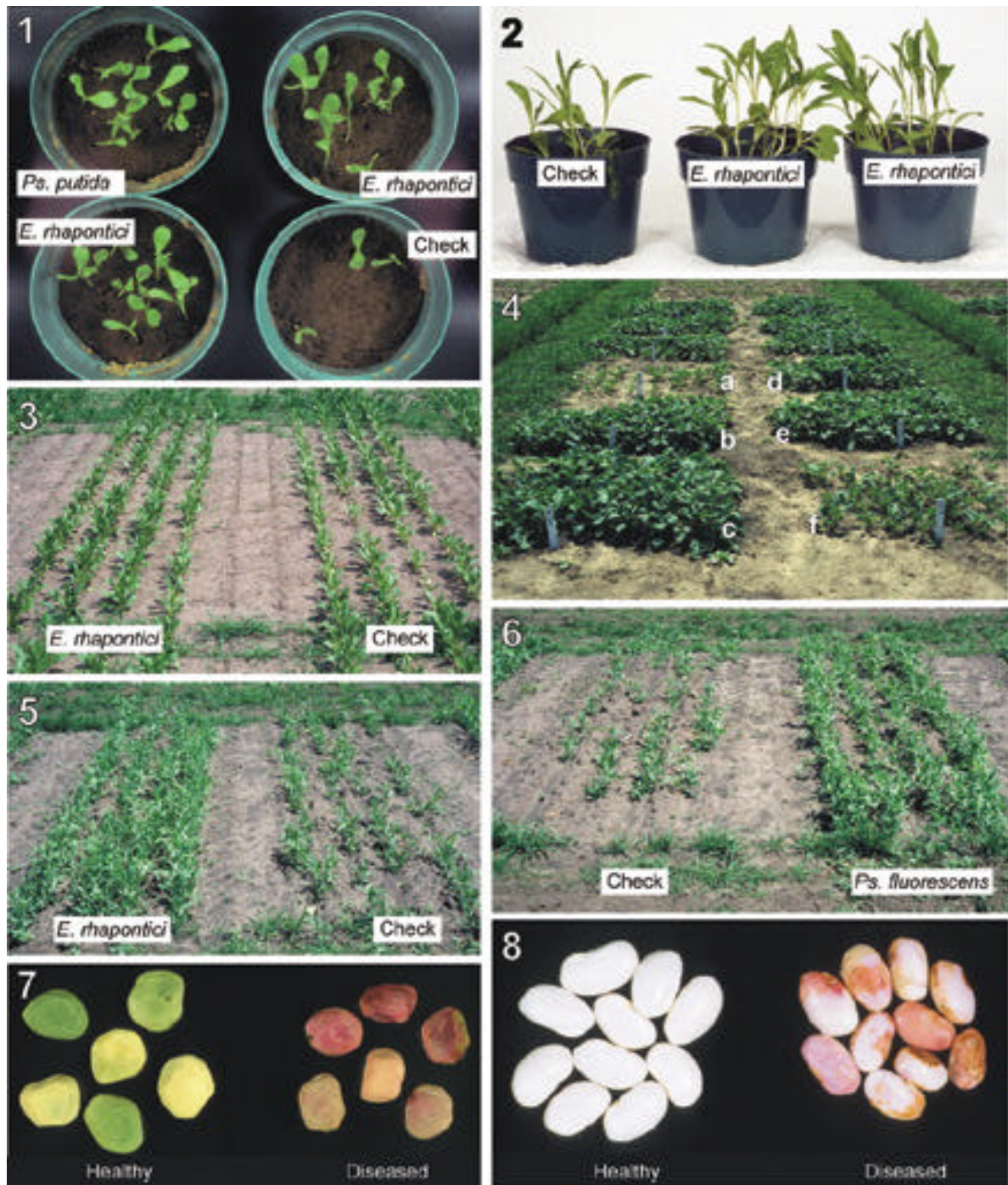
## BIOCONTROL OF PYTHIUM DAMPING-OFF AND BIODIVERSITY

*Pythium* spp. are important pathogens, causing damping-off, seed rot, root rot, crown rot and seedling blight of numerous field and greenhouse crops and turfgrass worldwide <sup>(50,61)</sup>. *Pythium* species isolated from crops in the Canadian prairies include *Pythium debaryanum* Heese, *P. hypogynum* Middleton, *P. irregulare* Buisman, *P. paroecandrum* Drechsler, *P. salpingophorum* Drechsler, *P. sylvaticum* Campbell and Hendrik, *P. torulosum* Trow, *P. ultimum* Trow, and *Pythium* sp. 'group G' <sup>(15,22,33,61,72)</sup>. In the province of Alberta, Canada, *Pythium* sp. "group G", a sterile form of *Pythium ultimum* Trow, is a predominant pathogen of sugar

beet (*Beta vulgaris* L.), field pea (*Pisum sativum* L.), safflower (*Carthamus tinctorius* L.) and canola (*Brassica napus* L. and *B. rapa* L.) in southern Alberta <sup>(33)</sup>, whereas *P. ultimum* and *P. irregulare* are the predominant species for damping-off of field pea in northern Alberta <sup>(40)</sup>.

*Pythium* damping-off is one of the major factors limiting production of certain field crops in western Canada <sup>(61)</sup>. Some survey reports revealed that incidence of *Pythium* damping-off may reach 99% in canola <sup>(21,74)</sup>, 83% in cicer milkvetch <sup>(22)</sup>, 30% in cucumber <sup>(9)</sup>, and 82% in safflower <sup>(23)</sup>. *Pythium* damping-off is also a potential problem of greenhouse crops in the provinces of Quebec and British Columbia because disease incidence may reach 95 to 100% in some greenhouse vegetables <sup>(61)</sup>. On turfgrass, *Pythium* spp. can cause a cool season dieback in Ontario and Quebec provinces <sup>(24)</sup>.

Several fungicides have been registered for control of *Pythium* damping-off of field crops. For example, Thiram 75 WP is registered for control of *Pythium* damping-off of sugar beet, mustard (*Brassica* spp.), grasses (Poaceae), bean, pea, soybean (*Glycine max* (L.) Merr.), corn, and safflower and Apron FL is registered for control of *Pythium* damping-off of alfalfa, clover (*Trifolium* L. spp.), bird'sfoot trefoil (*Lotus corniculatus* L.), canola, pea, bean and sugar beet <sup>(1)</sup>. However, increased health and environmental concerns on the use of fungicides have stimulated the search for more eco-friendly methods for the management of *Pythium* damping-off of field and greenhouse crops. Biocontrol is considered a viable alternative to chemical control, particularly in farming systems such as organic farming, which strictly prohibits the use of chemical pesticides. Several reports indicated that seed treatment with antagonistic strains of rhizobacteria were effective in the control of *Pythium* damping-off of field crops such as safflower <sup>(45)</sup>, sugar beet, field pea and canola <sup>(3)</sup> and greenhouse crops such as cucumber <sup>(52)</sup> and tomato <sup>(19)</sup> (Table 1). Liang *et al.* <sup>(45)</sup> reported that selected strains of *Erwinia carotovora* (Jones) Bergey, Harrison, Breed, Hammer and Huntoon, *Pantoea agglomerans* (Beijerinck) Gavini *et al.* (syn. *E. herbicola* (Lohnis) Dye), *Erwinia rhapontici* (Millard) Burkholder (Fig.1), *Pseudomonas putida* (Trevisan) Migula (Fig.1), and *P. fluorescens* Migula were effective seed treatment agents for control of damping-off of safflower caused by *Pythium* sp. 'group G'. In addition, *E. rhapontici* (Fig. 2) and *P. fluorescens* also stimulated seedling growth of safflower <sup>(45)</sup>. Bardin *et al.* <sup>(3)</sup> reported that *E. rhapontici* (Figs. 3-5), *P. fluorescens* (Figs. 4, 6), *P. agglomerans* (Fig. 4) and *Bacillus cereus* Frankland & Frankland were effective seed treatment agents for control of damping-off of safflower, canola, field pea, and sugar beet in fields naturally infested with *Pythium* spp. In greenhouse crops, some selected strains of *P. fluorescens* were effective agents for control of *Pythium* damping-off of cucumber <sup>(52)</sup> and tomatoes <sup>(19)</sup>. Other rhizosphere bacteria such as nitrogen-fixing bacteria, *Rhizobium leguminosarum* bv. *viceae* Frank, isolated from root nodules of pea and lentil were also effective agents for



Figs. 1-6. Biocontrol of *Pythium* damping-off of safflower (Figs. 1-3), canola (Fig. 4), and field pea (Figs. 5-6) by bacterial agents. Note reduction of disease incidence and promotion of seedling growth by seed treatment with *Erwinia rhapontici* (Figs. 1-3); *Pseudomonas putida* (Fig. 1); *Pseudomonas fluorescens* (Figs. 4b, 6) and *Pantoea agglomerans* (Fig. 4d), compared untreated controls (Figs. 1, 2, 3, 4a, 4f, 5, 6). Seed treatment with Thiram fungicide was also effective in reducing disease incidence and promoting plant growth (Fig. 4c). All tests were conducted in soil naturally infested with *Pythium* spp. in a controlled environment (Figs. 1, 2) or in the field (Figs. 4-6). Figs. 7-8. *Erwinia rhapontici* causes pink seed disease of field pea, cv. Marrowfat (Fig. 7) and navy bean (Fig. 8).

control of *Pythium* damping-off of field pea and sugar beet<sup>(5)</sup>.

Although some selected strains of rhizobacteria<sup>(3,19,45,52)</sup> and N-fixing bacteria<sup>(5)</sup> are effective agents for control of *Pythium* damping-off of crops, their non-target effects on other organisms may be drastically different; some are more

eco-friendly than the others (Table 1). For example, although the seven rhizobacteria are all effective agents for control of *Pythium* damping-off of crops<sup>(3,4,5,19,45,52)</sup>, they can be divided into the following groups according to the assessment of 'eco-friendly index'.

Table 1. 'Eco-friendly index' of rhizobacteria as biocontrol agents of *Pythium* damping-off of field crops.

Bacterial agent	Control of <i>Pythium</i> diseases	Environmental impact	Eco-friendly Index*	Reference
<i>Rhizobium leguminosarum</i> bv. <i>viciae</i>	Yes	-improve plant health -improve soil fertility	+++	[5,8]
<i>Pseudomonas fluorescens</i>	Yes	-improve plant health -a human pathogen	++	[3,4,25,45,55,71]
<i>Pseudomonas putida</i>	Yes	-improve plant health -a human pathogen	++	[3,45,49,69]
<i>Bacillus cereus</i>	Yes	-improve plant health -a foodborne human pathogen on fresh produce	++	[3,46] <a href="http://www.ccc.govt.nz">http://www.ccc.govt.nz</a>
<i>Pantoea agglomerans</i>	Yes	-improve plant health -a human pathogen	++	[3,16,17,43,45]
<i>Erwinia rhapontici</i>	Yes	-cause pink seed disease of pea, bean, lentil, chickpea and wheat -cause crown rot of rhubarb	+	[3,32,36,38,45,53,68]
<i>Erwinia carotovora</i>	Yes	-cause soft rot of carrot and other crops	+	[14,45]

\* Eco-friendly Index: -= Very Low; += Moderately Low; ++ = Moderately High; +++ = Very High

### Group 1. Very high 'eco-friendly index'

The 'eco-friendly index' of *Rhizobium leguminosarum* bv. *viciae* is very high (Table 1) because the bacteria not only effectively controlled damping-off of pea and sugar beet<sup>(5)</sup> but also improved soil fertility through its symbiotic relationships with legume crops belonging to the genera of *Pisum*, *Lens*, *Vicia* and *Lathyrus*<sup>(8)</sup>. Thus, the environmental risk is very low for using *R. leguminosarum* bv. *viciae* as a biocontrol agent for damping-off of crops<sup>(5)</sup>.

### Group 2. Moderately high 'eco-friendly index'

The 'eco-friendly index' of *Pseudomonas fluorescens*, *P. putida*, *Pantoea agglomerans* and *Bacillus cereus* is moderately high (Table 1). This group of bacteria exists in agroecosystems. They are effective biocontrol agents for *Pythium* damping-off of oilseed (Figs. 1-4) and pulse (Fig. 5) crops<sup>(3,4,45)</sup> and they have no known harmful effects on non-target species of plants or microorganisms in the same agroecosystem. However, *P. fluorescens*<sup>(25,55,71)</sup>, *P. putida*<sup>(49,69)</sup> and *Pantoea agglomerans*<sup>(16,17,43)</sup> were reported as human pathogens and *B. cereus* (<http://www.ccc.govt.nz>) was linked to outbreaks of foodborne illness associated with fresh fruits and vegetables<sup>(46)</sup>. Thus, although these rhizobacteria have few negative effects on agriculture food production and agroecosystems, the reported cases of human illness by this group of bacteria suggest some potential health risks and social concerns.

### Group 3. Moderately low 'eco-friendly index'

The 'eco-friendly index' for *Erwinia rhapontici* and *E. carotovora* is moderately low (Table 1). Despite effective control of *Pythium* damping-off of crops<sup>(3,19,45,52,61)</sup>, these

bacteria cause disease on a wide range of crops. For example, *E. rhapontici* causes pink seed disease of pea (Fig. 7)<sup>(31,32)</sup>, bean (Fig. 8)<sup>(36)</sup>, lentil, chickpea<sup>(39)</sup>, durum wheat (*Triticum durum* Desf.)<sup>(53)</sup> and common wheat (*Triticum aestivum* L.)<sup>(68)</sup> as well as crown rot of other plants<sup>(38)</sup> (Table 1). *E. carotovora* causes soft rot diseases of numerous vegetable crops<sup>(14)</sup>. Since most of the host plants of *E. rhapontici* and *E. carotovora* are major agricultural crops, diseases caused by these pathogens are of significance in creating potential negative impacts on food production and agroecosystems.

### Group 4. Very low 'eco-friendly index'

This group includes chemical pesticides that are highly toxic to target and non-target organisms and are highly persistent in the environment. For examples, the 'eco-friendly index' of the organic mercury fungicide, the DDT insecticide, and the atrazine herbicide (Table 2) is very low because of their possibly harmful side effects on the entire ecosystem. In Sweden, high mortalities of birds occurred as a result of eating seeds treated with mercury fungicides<sup>(42)</sup>. In addition, the heavy use of chemical fungicides might increase the risk of development of new fungicide-tolerant strains of plant pathogens, which would be more difficult to control.

The above examples clearly indicate the differences among disease control strategies in their effects on the target biota and the entire ecosystem. Therefore, developing a biocontrol technology for plant disease management must include studies of its ecological impacts to ensure that the technology is not only effective but also ecologically sound and environmentally safe. Only those biocontrol agents with high 'eco-friendly index' would be suitable for use in the commercial development of biocontrol products.

Table 2. 'Eco-friendly index' of soil amendment and cropping systems for management of plant diseases.

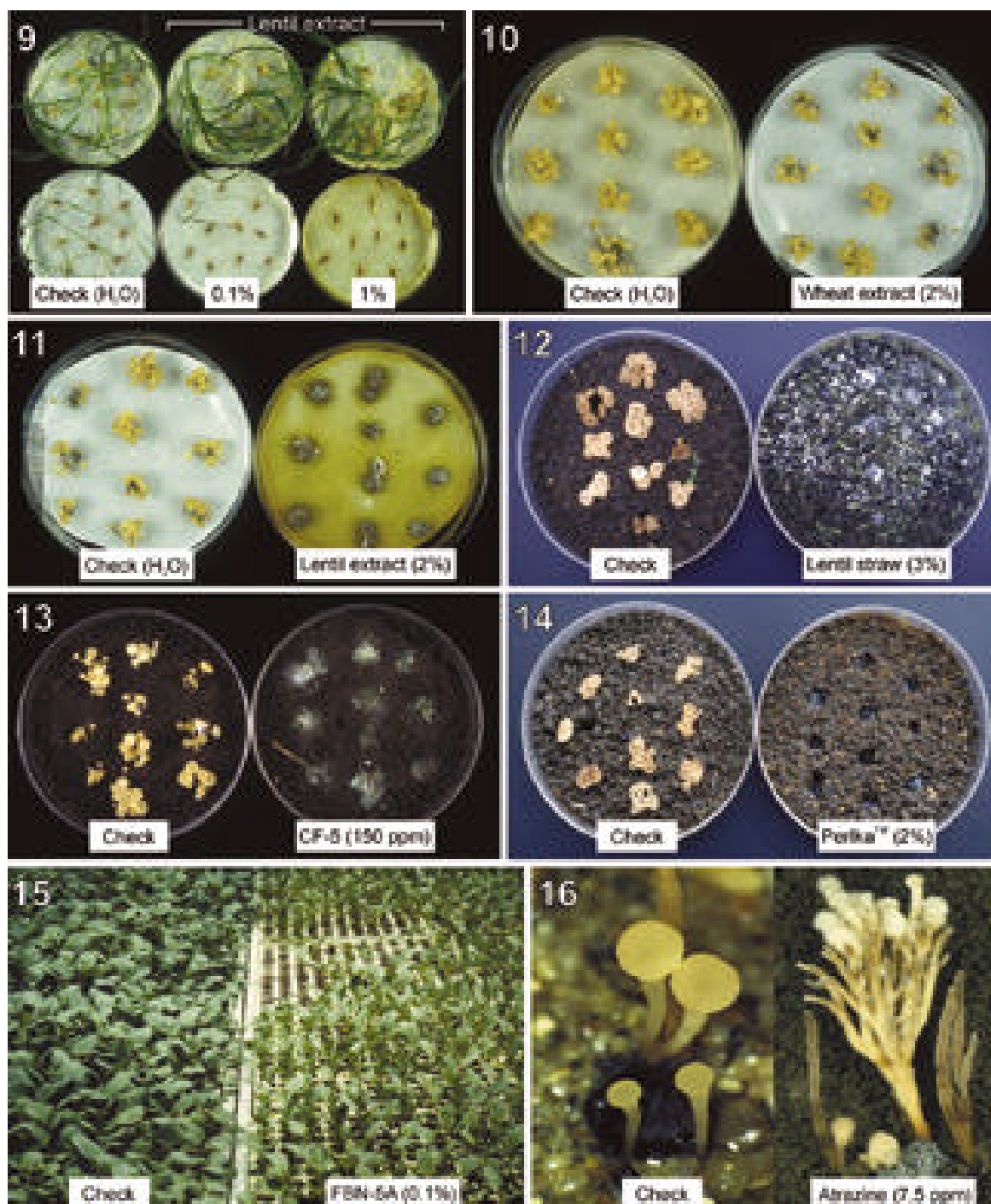
Treatment	Control of disease or weed	Environmental impact	Eco-friendly Index*	Reference
Composts (manures, leaf and yard wastes etc)	Pythium damping-off of turfgrass	-improve plant health -reduce soil compaction -reduce nitrate -reduce pesticide movement -increase soil organic matter	+++	[56,57,58]
Lentil straw (2.5 t/ha)	White mold of bean	-improve plant health -extracts toxic to weeds	+++	[35,54]
Canola straw (2.5 t/ha)	White mold of bean	-improve plant health -extracts toxic to weeds	+++	[35,54]
CF-5 (150 ppm)	<i>Sclerotinia sclerotiorum</i>	-improve plant health -promote <i>Trichoderma</i> spp. (biocontrol agents) -made of mainly agricultural wastes	+++	[29,34]
FBN-5A (0.1%)	Rhizoctonia damping-off	-improve plant health -made of mainly agricultural wastes	+++	[29,70]
Perlka™ (2%)	<i>Sclerotinia sclerotiorum</i>	-improve soil fertility -toxic to other organisms	+	[28]
Atrazine	weeds	-improve crop production -toxic to non-target plants and organisms	+	[1,30]
Bean in monocropping	None	-increase damping-off -reduce seed yield	-	[37]
Bean or legume in crop rotation	Pythium damping-off	-reduce disease -increase yield -improve soil fertility and quality	+++	[6,37]

\*Eco-friendly Index: -= Very low; += Moderately Low; ++ = Moderately High; +++ = Very High

## ALLELOPATHY, SOIL AMENDMENT AND BIODIVERSITY

Allelopathy is a direct or indirect biochemical inhibition of one plant or microorganism on another through the production of toxic compounds or allelochemicals released into the environment<sup>(65)</sup>. Because of the rapid degradation properties of allelochemicals, most of these naturally occurring compounds have no lasting harmful residual effects to the environment<sup>(12)</sup>. Some reports suggest that allelochemicals from plant tissues or microorganisms may be toxic to weeds, microorganisms and crops and thereby impact on plant and/or microbial biodiversity<sup>(12, 13, 60)</sup>. Patrick<sup>(60)</sup> reported that certain allelochemicals from decomposing plant tissues have potential for control of soilborne plant pathogens such as *Pythium* spp., *Fusarium* spp., and *Thielaviopsis basicola* (Berk. & Br.) Ferr. Moyer and Huang<sup>(54)</sup> found that aqueous extracts of lentil (Fig. 9), oat, canola and barley straws at 1% concentration were toxic to seed germination of some weed species such as stinkweed, flixweed, and downy brome (Fig. 9) but were non-toxic to seed germination of wheat (Fig. 9). The aqueous extracts from these crops at 2% concentration also effectively controlled the production of apothecia from sclerotia of *Sclerotinia sclerotiorum* (Lib.) de

Bary (Fig. 11), an important soilborne pathogen with wide range of hosts, except for the aqueous extract of wheat straw which was ineffective in control of the pathogen (Fig. 10) (H. C. Huang, R. S. Erickson and J. R. Moyer, unpublished data). Soil amended with 3% of straws of lentil (Fig. 12), canola or sweet clover not only suppressed production of apothecia of *S. sclerotiorum* but also enhanced the growth of soil microflora<sup>(35)</sup>. Further studies showed that soil amendment with straws of canola or sweet clover at 2.5 t/ha (equivalent to 3% in the indoor experiments) reduced incidence of white mold of bean caused by *S. sclerotiorum* (H. C. Huang, R. Erickson and J. R. Moyer, unpublished data). Other reports on turfgrass diseases revealed that composts prepared from animal manures, municipal biosolids, industrial sludges, leaf and yard wastes, grass clippings, food residuals and mixed solid wastes applied either as a topdressing, a winter cover, a root zone amendment, or as an aqueous extract were effective in reducing soil compaction, reducing nitrate and pesticide movement, increasing levels of soil organic matter, and reducing incidence and severity of certain turfgrass diseases<sup>(56,57)</sup>. High frequencies of microbes with biological control potential commonly recovered from composts<sup>(58)</sup>. For example, high frequencies of bacteria, suppressive to Pythium blight of creeping bentgrass (*Agrostis palustris* Huds.) caused



Figs. 9-11. Effects of allelopathic chemicals on seed germination of wheat (Fig. 9, top row) and downy brome (Fig. 9, bottom row) and on apothecial production of sclerotia of *S. sclerotiorum* (Figs. 10-11). Note 1% aqueous extract of lentil straws prevented seed germination of downy brome (Fig. 9, bottom right) but no effect on seed germination of wheat (Fig. 9, top right). Note also inhibition of production of apothecia from sclerotia of *S. sclerotiorum* by the treatment of 2% aqueous extract of lentil straws (Fig. 11) but no inhibition of apothecial production by the treatments of 2% aqueous extract of wheat straws (Fig. 10) or aqueous controls (Figs. 10, 11).

Figs. 12-16. Effects of soil amendments on target and non-target organisms. Note soil amended with 3% lentil straws suppressive to the production of apothecia from sclerotia of *S. sclerotiorum* and stimulatory to the growth of soil microorganisms (Fig. 12); soil amended with CF-5 liquid at 150 ppm controlled the production of apothecia of *S. sclerotiorum* and stimulated growth and sporulation of *Trichoderma* spp. (Fig. 13); soil amended with Perlka™ at 2% controlled production of apothecia of *S. sclerotiorum* as well as other soil microorganisms (Fig. 14). Soil amended with FBN-5A at 0.1% reduced incidence of *Rhizoctonia* damping-off of cabbage and promoted seedling growth (Fig. 15), whereas soil amended with herbicide, atrazine at 7.5 ppm, caused multiple branching of stipes which failed to form apothecia and produce ascospores of *S. sclerotiorum* (Fig. 16).

*Pythium aphanidermatum*, recovered from soil amended with yard waste compost, brewery sludge compost and chicken manure compost were 100.0, 86.4 and 68.4%, respectively, compared to 40.6% in non-amended turfgrass soil<sup>(58)</sup>. These findings suggest that certain types of organic matters such as legume crop straws and other organic composts may have negative effects on plant pathogens but positive effects on beneficial microorganisms and crops.

Ideally, soil amendment with organic matter would be carried out so as to maximize the harmful effects on target pathogens, to maintain or improve soil fertility, and to minimize any detrimental effects on the agroecosystem<sup>(29)</sup>. Today, there is considerable interest in using formulated compounds for the control of soilborne plant pathogens<sup>(73)</sup>. For example, CF-5 liquid is a fermented compound made mainly of waste mushroom manure<sup>(29)</sup> and is used commercially for control of *Rhizoctonia* damping-off of kale and garden peas in Taiwan<sup>(29)</sup>. Another study showed that amendment of soil with CF-5 compound at 100 to 400 ppm not only suppressed *S. sclerotiorum* but also enhanced the colonization of sclerotia by the mycoparasites, *Trichoderma* spp. (Fig. 13)<sup>(34)</sup>. Shiau *et al*<sup>(70)</sup> reported that soil amendment with 0.1 % (v/v) of FBN-5A, another formulated compound made of mainly mushroom compost, was effective in reducing incidence of damping-off of cabbage caused by *Rhizoctonia solani* Kuhn (Fig. 15). These examples suggest the potential of developing formulated products that are harmful to plant pathogens but beneficial to biocontrol agents and plants.

Besides organic matter, application of chemical fertilizers or pesticides may also affect microbial biodiversity in agroecosystems. For instance, Perlka<sup>TM</sup>, a granulated calcium cyanamide product (SKW Trostberg Aktiengesellschaft, Germany), is used as a nitrogen fertilizer and a chemical for control of plant pathogens such as *S. sclerotiorum*<sup>(28,44,51)</sup>. Amendment of soil with 1 or 2% Perlka<sup>TM</sup> for 3 weeks stimulated the growth of soil bacteria but completely suppressed the formation of apothecia from sclerotia of *S. sclerotiorum* as well as the growth of other soil fungi such as *Fusarium* spp. (Fig. 14)<sup>(28)</sup>. Some herbicides applied to the soil not only killed weeds but also killed non-target species of organisms. For example, sclerotia of *S. sclerotiorum* in soil amended with atrazine (Fig. 16) or simazine at commercial rates formed multiple branches of stipes<sup>(30,47,64)</sup> and failed to produce apothecia and ascospores<sup>(30,64)</sup>. Moreover, the breakdown of atrazine in the soil is slow and may cause injury to sensitive crops such as cereals, canola, and sugar beet for one or more years after application<sup>(1)</sup>. Thus, developing organic or inorganic soil amendment as control strategies for plant diseases should also include the assessment of 'eco-friendly index' to minimize their negative impacts on the agroecosystem (Table 2).

The 'eco-friendly index' is also useful in measuring the impact of allelopathic effects of different cropping systems on

agricultural sustainability. Numerous reports reveal that continuous mono-cropping can cause soil sickness and thereby, create imbalance of soil microbial populations such as plant pathogens and non-pathogens or accumulation of toxins released from decomposing plant residues<sup>(7,59,62)</sup>. In many parts of the world, crop rotation is a common practice in managing a specific agroecosystem<sup>(18,63)</sup>. For instance, results of a long-term crop rotation experiment in Hokkaido, Japan, showed that kidney bean under six-year rotation in a sequence of potato, sugar beet, oat, kidney bean, winter wheat and red clover had low incidence of *Pythium* damping-off and high seed yield, compared to the kidney bean under continuous monocropping<sup>(37)</sup>. Meanwhile, a study in Canada also indicated that legume-based crop rotation improved soil fertility and quality<sup>(6)</sup>. Another study in Cardenas, Tabasco, Mexico revealed that the biomass of corn intercropped with barley and timothy was higher than the biomass of corn produced in monoculture in four densities<sup>(2)</sup>. The beneficial effects of crop rotation (or polyculture) on crop production are often attributed to the influence of allelopathic interactions due to balance of microbial diversity in the agroecosystem. Some natural or modified allelochemicals have been used as pesticides<sup>(11,48,66,75)</sup>. For example, 'Agrostemin', is a natural product isolated from the root of the cockle of *Agrostemma githago* L., a common weed in fields of wheat and other cereals<sup>(20,41)</sup> and is widely used as a herbicide in crop production in eastern European countries, particularly the former Yugoslavia. Neem plants (*Melazedarach* L.), a sacred tree in India, produce allelochemicals which can be used as herbicide, fungicide or nematocide<sup>(1)</sup>. Thus, the beneficial or detrimental effects of allelochemicals from a specific plant or microorganism on target and non-target species of organisms must be considered in order to determine the value of such allelopathic substances in crop production systems.

## CONCLUSION

Microorganisms are an integral part of natural ecosystems. In all agricultural practices, producers focus mainly on the production of crops and control of crop-associated pathogens, whereas the importance of other microorganisms in the agroecosystem is largely ignored. Producers realize that a diversity of pathogens is generally harmful to crop production and unless such disease-causing organisms are properly managed, heavy losses in crop yield and quality may occur as a result of disease outbreaks. In the past few decades, synthetic pesticides were used heavily to control crop pests. Such drastic pest control measures have led to reduced biodiversity as many chemical pesticides are highly toxic to target pest species and non-target species of organisms and vertebrates in the ecosystem. Thus, heavy reliance on chemical pesticides for crop production is no longer a viable option for agriculture in the 21st century.

public demands for food safety continue to increase, the demand for use of effective, economical and eco-friendly pest management methods with minimal negative impacts on microbial biodiversity in agroecosystems will also increase. The biologically based technologies of disease management such as biocontrol, allelopathy and organic soil amendment may provide a more sustainable and healthier ecosystem, if such technologies are properly assessed for their impacts on the integrity of the ecosystem. Unless we understand the components of the ecosystem, and how organisms interact with each other and the environment, it will be difficult to predict how best to utilize agricultural land without causing harm. To achieve genuinely sustainable management of crop diseases in agricultural production, the development of a new disease control strategy should also include studies on ecology, ecotoxicology, allelopathy, biodiversity and sustainability of populations of plants, animals, and microorganisms in the agroecosystem. The promotion of responsible management of agroecosystems in agricultural practice demands careful studies of this kind, with extensive research inputs and attention to detail.

## ACKNOWLEDGEMENTS

The authors would like to thank R. S. Erickson of Agriculture and Agri-Food Canada, Research Centre, Lethbridge, Alberta, Canada, for critical review of the manuscript. Figure 9 is courtesy of Dr. J. R. Moyer, Agriculture and Agri-Food Canada, Research Centre, Lethbridge, Alberta, Canada, and Figure 14 is courtesy of Dr. J. W. Huang, Department of Plant Pathology, National Chung-Hsing University, Taichung, Taiwan. This is LRC contribution No. 387-05008.

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**Hung-Chang Huang**

Dr. Huang is a principal research scientist at the Agriculture and Agri-Food Canada, Research Centre, Lethbridge, Alberta, Canada. He received a B. Sc. in plant pathology from the Chung-Hsing University, Taichung, Taiwan, in 1963 and M. Sc. and Ph. D. in plant pathology from the University of Toronto, Canada, in 1969 and 1972, respectively. His research interests include fungal and bacterial diseases of pulse (field bean, field pea, lentil), oilseed (canola, sunflower, safflower), forage (alfalfa) and sugar beet crops, especially in the areas of biological control, disease resistance, insect transmission of fungal diseases, microbial ecology, epidemiology, biology of fungal sclerotia, and pollen-fungus relationships. He received the Canadian Phytopathological Society Award for Outstanding Research, the Taiwan Phytopathological Society Award for Outstanding Contribution to Plant Pathology and the Japanese Government Research Award for Foreign Specialists.



**Chang-Hung Chou**

Prof. Chou was born in Taiwan in September 5, 1931. He received his B. Sc., M. Sc. in National Taiwan University and accomplished his Ph D in the field of Plant Ecology at the University of California at Santa Barbara in 1971. Prof. Chou has been vice president of National Sun Yat-sen University, director of Institute of Botany Academia Sinica, research fellow of Institute of Botany, Councilor of Academia Sinica and Vice President of the International Union of Biological Sciences. He received many distinguished research awards from the National Science Council, Ministry of Education, Taiwan. He was elected Fellow of Third World Academy of Science, Member (Academician) Academia Sinica, and Award of Highest Honor of Soka University. He is now the National Chair Professor and President of National Pingtung University of Sciences and Technology.

## 摘要

黃鴻章<sup>1,3</sup>、周昌弘<sup>2</sup>. 2005. 植物病害生物防治與生物相生相剋作用對生物多樣性與農業永續性的影響. 植病會刊 14:1-12. (<sup>1</sup>加拿大農部 Lethbridge 研究中心; <sup>2</sup>國立屏東科技大學; <sup>3</sup>聯絡作者, 電子郵件: huangh@agr.gc.ca; 傳真: +1-403-382-3156)

在農業生態環境裡的所有微生物如真菌、細菌、病毒和線蟲等, 有些是對植物有害, 而其他大部分都對植物生長無害或有益的。植物病害防治是每一作物生產過程不可或缺的手段。自從第二次世界大戰以後, 很多新的化學合成農藥相繼開發成功並普遍應用於防治植物病、蟲、雜草等。其後陸續發現有些化學合成農藥不但能夠殺死病原菌、害蟲或雜草, 而且還會連帶傷害到其他無害或有益的微生物。這種「一藥治百病」的病害防治方法對農業生態與生物多樣性會造成不良的影響, 且與現今注重農業永續經營的理念不符。因此過去很多具有強殺傷力的化學農藥, 現在都已禁止使用。近年來很多研究報告指出用生物防治, 生物相生相剋作用以及土壤有機添加物等方法或許可以替代化學農藥以防治植物毒害。但是這些研究報告, 很多只是注重於用生物防治菌或生物相生相剋物質來防治病害, 而沒有進一步去探討該生防菌或化學物質對農業生態的影響。發展一種良好的生物防治菌或生物相生相剋物質, 不但要注重該生防菌或化學物質對病害防治效果, 而且也要研究這些防治策略對生物多樣性與農業永續性的影響。

關鍵詞: 生態良性指數、生物多樣性、生物防治、生物相生相剋作用、土壤有機添加物、土傳病原菌、風險評估、永續農業