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Plant Disease Management in the Era of Energy Conservation

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ABSTRACT

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In the 21st century, the term of "agricultural sustainability" has become a norm for modern agriculture as we are facing several long-term crises such as energy shortage, global warming and environmental pollutions. As environmental and ecological issues continue to impact on agriculture, all technologies developed for crop production must be economically feasible, ecologically sound, environmentally safe and socially acceptable. Numerous non-chemical methods for control of crop diseases such as pathogen-free seeds, disease resistance, crop rotation, plant extracts, organic amendments and biological control are considered less harmful than synthetic chemical pesticides and, therefore, offer great potential for application in conventional agriculture, organic farming and/or soil-less culture. No single method can provide satisfactory control of crop diseases. Integration of all effective and eco-friendly measures in accordance with the dynamics of the agroecosystem management would be the best strategy for efficient control of diseases in crops. In this era of energy conservation and environmental protection, research on energy saving and environmentally sound methods for sustainable management of crop diseases is a priority and a challenge.

Key words: disease management, sustainable agriculture, non-chemical control

INTRODUCTION

During the second half of the 20th century, we have witnessed an unprecedented growth in human population, agricultural production and technology. The population pressure increases demands for basic human needs such as food and clothing; it is one of the driving forces for the evolution of modern agriculture. The most striking feature in this period was the practice of intensive agriculture to increase crop production. As a result, high crop yield in that period was achieved through heavy use of synthetic pesticides, chemical fertilizers and new cultivars grown in monoculture with or without a short crop rotation. The success of control of plant diseases by synthetic chemicals had created a general perception that chemical control could provide a permanent solution to disease problems in modern agriculture. Zadoks (76) defines the period between 1940s and 1980s as 'chemism' to reflect high dependency on agrochemicals for crop production. In this period, the agricultural economy was highly dependent on the development and application of chemical pesticides and fertilizers.

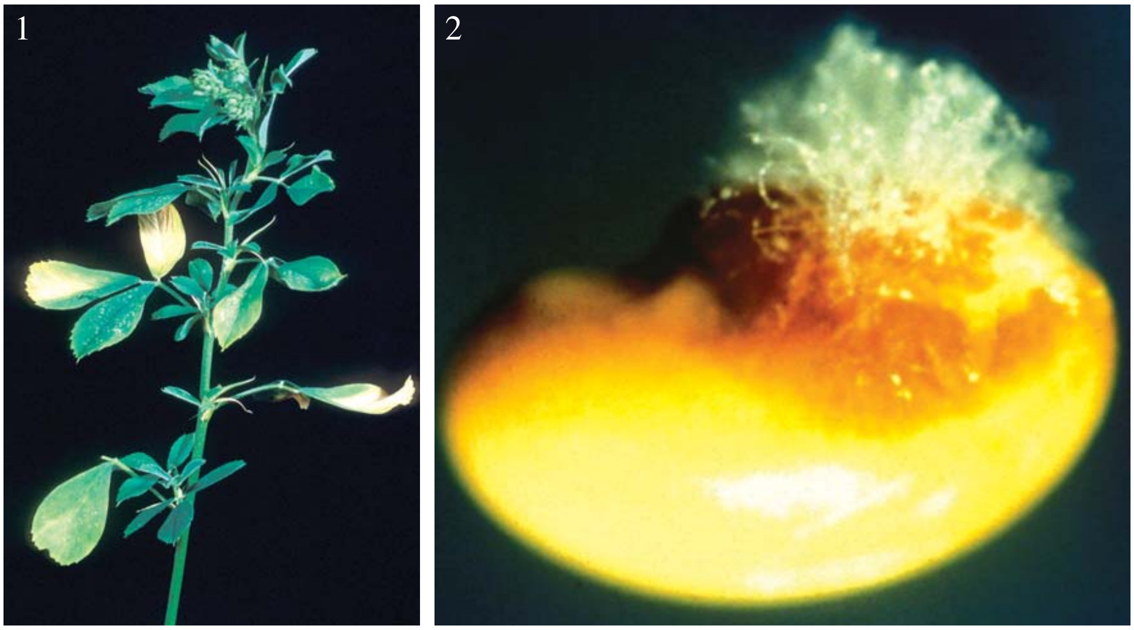
By late 1980s, numerous environmental problems associated with chemical pesticides emerged. Questions were raised on whether an agricultural production system heavily dependent upon expensive, ecologically-unsound chemical pesticides could be sustained in the long run. Since then, the philosophy of plant protection has shifted from the use of chemical pesticides to methods that are more energy saving and environmentally friendly. Zadoks(76) defined this period as 'environmentalism' and attributed the year of 1990 as the beginning of this new era. Under the environmental era, all practical solutions to plant disease control must be based on safety of environment, conservation of natural resources, and maintenance of biodiversity(36). Environmentalism addresses the renewability and persistence of these resources, and considers long-term impacts of agricultural production systems on present and future generations(71). The energy crises in the past 50 years have drawn further concerns on the use of non-renewable resources such as fossil fuel for farm machinery in crop production and pest management. The objective of this review was to discuss research and development of some of the energy saving and ecologically sound methods for sustainable management of plant diseases in this era of energy conservation and environmental protection.

METHODS FOR SUSTAINABLE DISEASE MANGEMENT IN CROPS

Following disease control methods are considered more environmentally friendly than the chemical control. They are of potential for plant disease management in sustainable agriculture.

Pathogen-free seeds, bulbs or seedlings

Use of pathogen-free seeds, bulbs or seedlings is a pre-requisite for sustainable control of crop diseases because numerous plant pathogens are transmitted to the field or to other countries via infected- or contaminated-seeds, bulbs or seedlings. For example, Verticillium wilt of alfalfa (caused by *Verticillium albo-atrum* Rheinke and Berthold) (Fig. 1) has long been recognized as an important disease in Europe since its first discovery in Sweden in 1918 (30). The disease is transmitted by infected seeds (Fig. 2) or infected crop debris. Thus, commercial trades of alfalfa seeds or alfalfa hay may serve as important venues for spread of this pathogen regionally, nationally and internationally (29). The outbreak of this disease in the USA in 1976 (26), Canada in 1977 (66) and Hokkaido, Japan in 1981(64) was attributed to the importation of pathogen-contaminated seeds from other countries. Quarantine measures such as seed indexing and seed certification have been implemented in some countries to prevent importation of infected alfalfa seeds from diseased regions or countries. Bacterial wilt of common bean, caused by *Curtobacterium flaccumfaciens*



Figs. 1-2. Verticillium wilt of alfalfa showing a diseased stem with brown V-shaped lesion on leaflets (Fig. 1) and a diseased seed with mycelia (Fig. 2).

pv. *flaccumfaciens* (Hedges) Collins & Jones, is another example of disease transmission mainly through infected seeds (Fig. 3). Use pathogen-free seeds is also a sound strategy to minimize the danger of spread of this disease in the field or to other countries.

Developing efficient methods such as molecular techniques or selective media for rapid detection of seedborne pathogens should be a research priority for seedborne diseases. Such methods are particularly useful in seed certification and plant quarantine. Moreover, different seedborne pathogens may occur on the same host crop, developing a multiplex PCR(5) to detect several pathogens would be more efficient and economically feasible than a PCR to detect a single pathogen.

Field sanitation

Field sanitation is another important method to reduce primary source of inoculum and prevent transmission of plant pathogen within or between fields. It is always a good practice to collect and destroy diseased materials such as roots, stems, leaves and fruits. Also, cleaning farm implements would reduce danger of transmission of plant pathogens from diseased fields to non-diseased fields.

Crop rotation

Crop rotation is an effective measure for management of crop diseases, if the crops are grown in a right sequence. For example, a long-term crop rotation study (1959-2000) in Hokkaidao, Japan, revealed that kedney bean (*Phaseolus vulgaris* L.) cv. Taishokingtoki in 6-year rotation (in the order of potato- sugar beet-oat- kidney bean- winter wheat- red clover) increased seed yield and reduced soilborne diseases, compared to kidney bean in monoculture (45) (Fig. 4). Other studies in Canada showed that a rotation of legume crops with cereals is superior to the cereal monoculture because the legume-based rotation

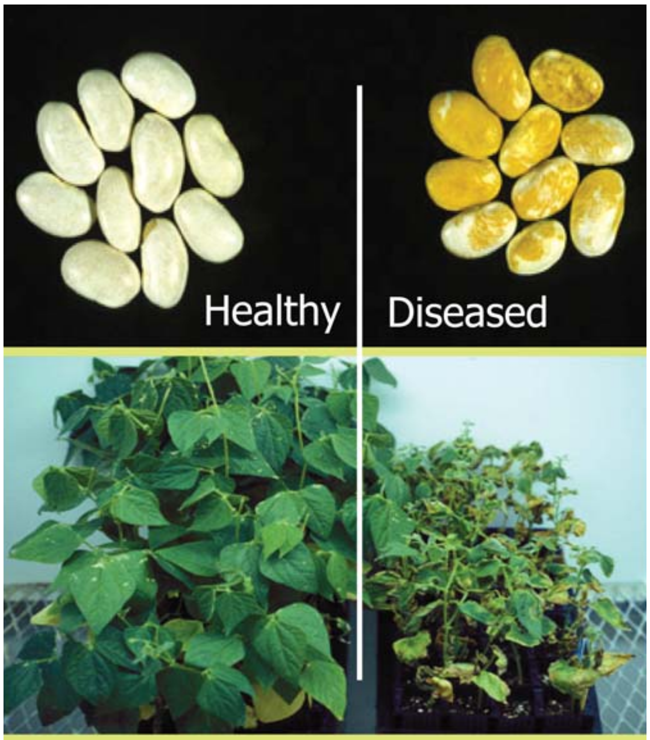


Fig. 3. Bacterial wilt of bean (cv. GN1140). Note healthy seedlings derived from healthy seeds (left) and wilt, stunted seedlings derived from infected seeds (right).

Fig. 4. Kidney bean, cultivar Taishokintoki, in monoculture (left plot) and 6-year rotation (right plot). Note stunting, yellowing plants in monoculture (left plot) and tall healthy plants in 6-year rotation (right plot). (The experiment was conducted from 1959 to 2000 at the Kitami Agricultural Experiment Station, Hokkaido, Japan. The two photos were taken on July 17, 1994).

system improves yield of cereal crops (15, 75), improves fertility and quality of soils (8, 27) and increases soil microbial populations including fungi, bacteria and actinomycetes (9). Thus, types of crops and cropping sequence are important factors affecting effectiveness of crop rotation as a disease control strategy.

The major obstacles to successful disease management through crop rotation are wide host range and long-term survival of some pathogens (14). For example, the number of sclerotia of *Sclerotinia sclerotiorum* (Lib.) de Bary in a canola field remained unchanged after planting barley (non-host crop) in this field for three consecutive years (72). Morrall and Dueck (56) reported that a 3-4 year rotation was ineffective in reducing Sclerotinia stem rot of canola. Although rotation alone may not always reduce disease levels, it is still a good practice for most of diseases as growing non-host crops would prevent further build-up of pathogen inoculum in the field.

Natural toxic compounds from plants

There is a broad range of natural, plant extracts that can be used as alternatives to chemical pesticides, allowing sustainable protection of crops against economically important diseases (65). For examples, extracts from *Allium* and *Capsicum* plants (73) or essential oils from certain species of plants (73) were used in sustainable management of gray mold of crops caused by *Botrytis cinerea* Pers.:Fr. Inorganic and/or organic matter from plant residues were used in soil amendment to alter soil physical and chemical properties and thereby, affect population dynamics of soil microflora(44). For example, glucosinolates from Brassicaceae are well known for their toxic effects on plant pathogens (18, 62). Amendment of soil or growth media with cabbage (*Brassica oleracea* L. var. *capitata*) residues as green manure (25) or seed treatment with Brassica seed meal (18) is effective in controlling damping-off diseases caused by *Rhizoctonia solani* Kühn AG-4. Recent research has also focused on the development of formulated products for control of soilborne pathogens and improvement of soil fertility at the same time. Such formulated products were developed and commercialized in Taiwan(44) and other countries.

Biological control

Fig. 5. Application of *Coniothyrium minitans* in a field naturally infested with *Sclerotinia sclerotiorum* reduced incidence of sclerotinia wilt of sunflower (right plot), compared to untreated control (left plot). Field experiment at Agricuture Canada Research Station, Morden, Manitoba, Canada, 1978.

Numerous studies indicate that biological control may be of potential for management of plant diseases. For example, the mycoparasite *Coniothyrium minitans* Campbell was reported as an effective agent for control of diseases caused by *S. sclerotiorum*, including Sclerotinia wilt of sunflower (11, 34, 53) (Fig. 5), white mold of bean (38, 41), pea (Fig. 6) and lettuce drop (13). Application of *C. minitans* to soil not only reduced disease incidence and increased crop yield(34), but also reduced sclerotial survival (34, 39, 54) and induced soil suppression to *S. sclerotiorum* (35, 47, 53). In 1997, *C. minitans* was released as a commercial product Contans® by Prophyta in Germany (52) and Koni ® by Bioved Ltd. in Hungary (www.bioved.hu) for control of Sclerotinia diseases in crops. Environmental condition might be one of the most determinant factors affecting efficacy of biocontrol agents. In western Canada, *C. minitans* was the most effective agent for control of white mold of bean, compared to other mycoparasites such as *Trichothecium roseum* (Pers.:Fr.) Link (46), *Talaromyces flavus* (Klocker) Stolk and Sampson (53, 54) and *Trichoderma virens* (Miller, Giddens & Foster) Arx.(38) because it survived well under prairie conditions (40) and effectively controlled sclerotia (34, 54) and apothecia (12, 40, 41) of *S. sclerotiorum.*

Numerous attempts have been made in the past five decades to use antagonistic bacilli, Streptomyces, and fluorescent pseudomonads as biocontrol agents for management of plant diseases. Some agents were developed into commercial products for control of fungal and/or bacterial diseases of crops. For instance, the commercial products, Quantum™ and Kodiak™ (Gustafson, Texas, USA), Epic (MicroBio, England), and Bactophyt (Novosibirsk, Russia) are based on formulation of *Bacillus subtilis* Cohn and used for control of seedling diseases of numerous crops, including cotton, peanut and vegetables (51). Although fluorescent pseudomonads were identified as biocontrol agents for commercial development in numerous reports, very few pseudomonads-based products showed high values and high commercial returns. For example, the sale of the product Dagger G™ (Ecogen, Pennsylvania, USA), formulated by *Pseudomonas fluorescens* Migula strain EG1053, was discontinued, likely due to short shelf-life of this product (51).

A good biocontrol technology is not only economically feasible but also environmentally safe, ecologically sound, and socially acceptable. Other than efficacy and shelf-life, research should also focus on risk assessment of biocontrol agents. For example, *Erwinia rhapontici* (Millard) Burkholder is an effective agent for control of damping-off of canola, safflower, dry pea and sugar beet caused by *Pythium* spp. (6, 50) but it is also a pathogen causing pink seed disease of pea (48), bean (43) lentil(42), chickpea (42) and wheat (55). *Trichothecium roseum* is a mycoparasite of *S. sclerotiorum* (46) but it produces a mycotoxin, Trichothecin (49), which is harmful to animals.

Biofumigation as Alternative to Methyl Bromide

Methyl bromide has been used since 1930s as an effective soil fumigant for control of nematodes, fungi, insects and weeds in more than 100 crops worldwide (63). This chemical has been classified as a Class 1 stratospheric ozone depletor (74) and has been scheduled to phase-out by 2005 in developed countries and by 2015 in developing countries (74). Composts can provide a food base for biocontrol agents of soil-borne pathogens (31) and thereby, improve the consistency of disease control (22). De Ceuster and Hoitink (23) reported that composts and biocontrol agents can be used as substitutes for methyl bromide in

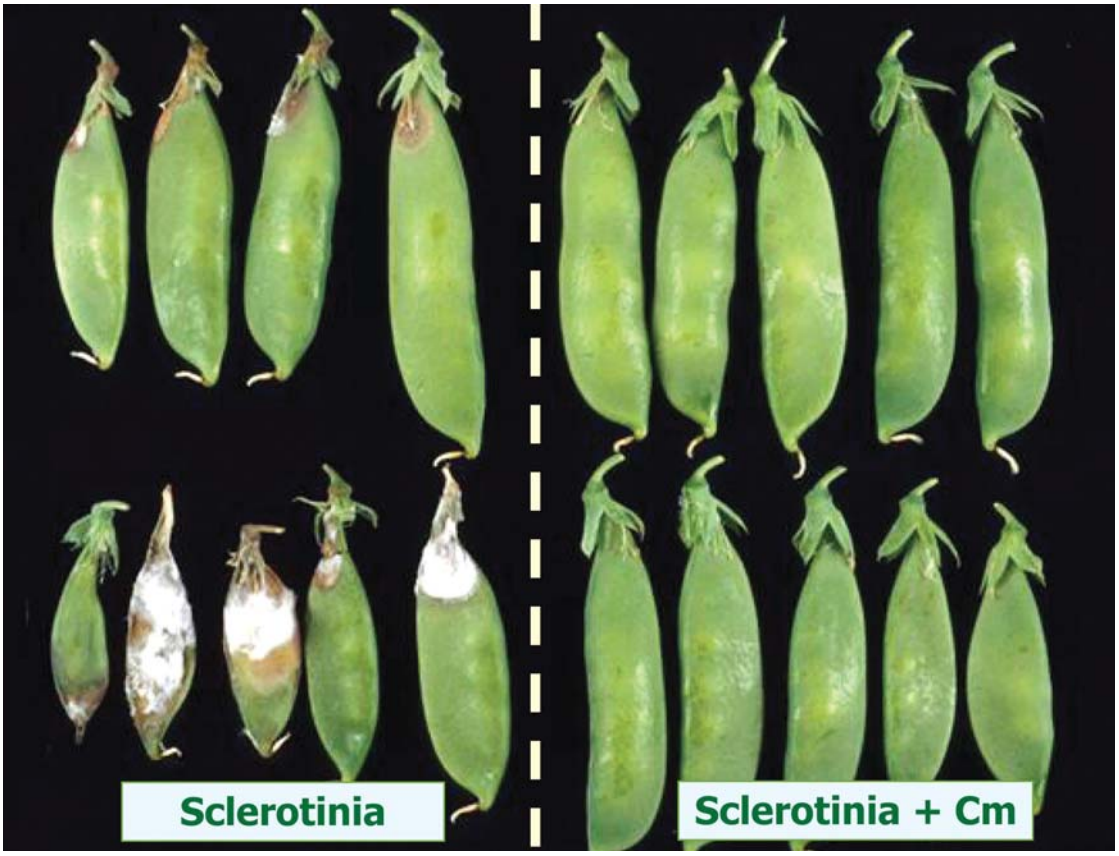


Fig. 6. Control of Sclerotinia pod rot of peas by *Coniothyrium minitans* (*Cm*). Note diseased pea pods from plants sprayed with pathogen alone (left) and healthy pods from plants sprayed with pathogen and *Cm* (right).

biological control of plant diseases. In Taiwan, Huang *et al.*(33) developed a granulate biofumigant named PBGG, using *Pseudomonas boreopolis* Gray and Thornton, *Brassica* seed pomace, glycerin and sodium alginate. Application of 1.0% (w/w) of PBGG to the soil infested with *Rhizoctonia solani* AG-4 significantly reduced the percentage of colonization of cabbage seeds by the pathogen and stimulated proliferations of actinomycetes, including *Streptomyces padanus* and *S. xantholiticus* which were effective biocontrol agents of *R. solani* (19). Thus, the granulated product PBGG (33) can be a useful alternative to methyl bromide in the management of soilborne pathogens.

Breeding for disease resistance in crops

Breeding for disease resistance is the most efficient way to manage diseases in crops. For example, Verticillium wilt of alfalfa, caused by *Verticillium albo-atrum*, is a devastating disease that can cause millions of dollars in losses to alfalfa producers in Europe and North America. Through the breeding efforts, three alfalfa cultivars Barrier (28), AC Blue J(3) (Fig. 7) and AC Longview(1) were developed in Canada. These cultivars showed high level of resistance to Verticillium wilt, high yielding ability and high adaptation to the growing conditions in western Canada (2, 37). The economic benefits of growing these disease-resistant cultivars in western Canada were estimated at $26.6 million (Canadian dollars) per year (67).

Breeding for disease resistance remains a difficult task for many diseases in many crops, due to lack of source of resistance in cultivated plants. Moreover, genetics of resistance may be complicated in some crops. Take Verticillium wilt of alfalfa, for example, alfalfa is an autotetraploid species having four loci for each gene. In addition, the resistance of alfalfa to *V. albo-atrum* is conditioned by a multigenic system with predominantly additive genes (58, 59). Thus, breeding alfalfa for resistance to Verticillium wilt is a slow process because of the polyploidy of the host (alfalfa) and polygenic nature of genes for resistance to the pathogen (*V. albo-atrum*)(2). Genetic engineering of crops to enhance resistance to plant pathogens may become a valuable component of a disease management program in the future (60).

Induced disease resistance

Induced host resistance to plant pathogens, elicited by microbial invasions or chemical treatments, may offer potential for management of crop diseases (17, 32). It results from fortification of cell walls, accumulation of phytoalexins, biosynthesis of pathogenesis-related (PR) proteins or other mechanisms(32). For example, the intercellular fluid from salicylic acid (SA)-treated tobacco was effective in the inhibition of hyphal growth of *Botrytis*

Fig. 7. Comparison of 12 alfalfa cultivars for resistance to verticillium wilt in a field naturally infested with *V. albo-atrum*. Note loss of alfalfa stand in susceptible cultivars due to encroachment of dandelion (yellow plots) and only light dandelion infestation in the plots of wilt-resistant cultivars (green plots), including AC Blue J (arrow).

cinerea in vitro and this might be due to presence of extracellular antifungal PR-proteins (57). Some of PR-proteins identified during the infection process of *B. cinerea* were chitinase and β-1,3-glucanase (7). The SA-induced resistance to *B. cinerea* in tobacco was also found in lily infected by *Botrytis eliptica* (16).

INTEGRATION OF CONTROL METHODS

For most crops, there is no single method for satisfactory control of a disease. Integration approach is the best strategy for effective management of diseases of greenhouse and field crops. For example, gray mold of strawberry (caused by *Botrytis cinerea*) in organic farming in greenhouse can be effectively managed by aeration, plastic mulch, sanitation, biocontrol using *Trichoderma* spp.(4), spray of *Ullocladium atrum* Preuss (10) and spray of non-chemical fungicides (20, 21). For control of gray mold of grapes in the field, the main components of an IPM program may include management techniques such as maintaining a canopy configuration of 45 nodes/vine (68), removal of leaves and thinning of clusters 2-3 times during the season (61), shoot tipping at bloom(69), shoot positioning and topping to improve air flow through the canopy (70), rational application of N fertilizer (61), and integration of biocontrol agents such as *Trichoderma harzianum* T39 (24).

Strategy for sustainable management of crop diseases include judicious use of nature toxic substance from plants, soil management such as biofumigation and organic soil amendment, crop management such as the use of pathogen-free seeds or other planting materials, disease resistant cultivars, and biological control agents, and cultural practices such as field sanitation and crop rotation. Future success hinges on further integration of these control strategies in various crop production systems such as conventional agriculture, organic farming and soilless cultures. Such integrated disease management approach requires a thorough understanding of the ecology of each cropping system, including the crop, the pathogen and the antagonists, as well as the surrounding environments.

CONCLUSION

No single method is capable of controlling crop diseases satisfactorily. A combination of effective control measures may enhance protection of crops from diseases as well as reduce production inputs for crops. Integration of these effective measures in accordance with the dynamics of the agroecosystem management is the key to succeed the control of crop diseases and achieve sustainable production of crops. As energy conservation and environmental protection remain the major issues for human beings in the 21st century, research on development of energy saving and environmentally friendly methods for sustainable disease management in agriculture is a challenge and a priority.

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摘　要

黃鴻章[1]、吳明哲[1,2]. 2009. 節能下的病害管理策略. 植病會刊 18: 1-12. ([1]講座教授與研究員兼組長、農委會農業試驗所生物技術組；[2]聯絡作者，電子郵件：wu@tari.gov.tw；傳眞：+886-4-2330-2806)

現今廿一世紀，人類面臨著能源短缺、地球暖化和環境破壞等問題。這些問題使我們體驗到過去半個世紀以來，農業生產由於過度使用合成化學農藥和化學肥料而造成環境破壞與生態失衡等不良後果，因此乃提倡『農業永續經營』的理念。在此理念下，所有作物病害的防治策略都必需符合經濟效益、注重生態平衡與環境安全、以及注重社會大眾的需求，以達到每一植物保護策略都能節約人力、物力和保護環境的目的。因此現今作物病害防治策略是研發有效且對環境安全性高的病害防治方法，以取代化學農藥做爲作物傳統栽培、有機栽培和介質栽培等的病害管理手段，期能達到農業永續經營的目的。這些非化學防治方法包括使用健康種子、種球或種苗，田間衛生，抗病育種，輪作栽培，天然植物萃取液，以及生物防治等。這些方法的應用雖然因作物和病害種類而異，通常是以數種有效方法在作物栽培過程中加以綜合應用效果最佳。如果再配合適當地調控農業生態環境，更會發揮這些防治方法的效果而達到病害有效管理和農業永續經營之目的。於現今的能源危機和環保壓力下，研究更安全有效的病害防治方法尤其是當務之急。

關鍵詞：病害管理、永續農業、非農藥防治