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Review

Soil amendments, plant extracts and plant products for integrated disease management in agricultural crops: A review

Deepak

Nusun Genetic Research Limited, 235-239, supermall-I, Infocity, Gandhinagar-Gujarat, 382007, India.
E-mail: deepak_bijarniya@rediffmail.com.

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Various cultural practices, including the use of cover and rotational crops, composts, tillage systems, and others have been promoted as management options for enhancing soil quality and health. All cultural practices are known to directly or indirectly affect populations of soilborne pathogens and the severity of their resultant root diseases. Number of products formulated with plant products and extracts are harmful to plant pathogens and maintain soil fertility. The mechanisms by which container media, organic amendments, and plant extracts affect plant pathogens can be simple or complex depending on the product and the pathogen. In some cases, control is achieved by direct killing of the pathogen propagules. In other cases, disease suppression is the result of a combination of multiple factors, including direct poisoning of the pathogen and indirect effects by enhancing microbial activity and improving vigor of plants. Thus, there is a great need to assure that the introduced soil management practices to improve soil quality will also result and maintain a healthy soil. The latter include the abundance and diversity of total soil microbes, high population of beneficial organisms and low population and/or activities of crop pests.

Key words: Plant extracts, sustainable agriculture, plant disease, soil amendments.

INTRODUCTION

Organic soil amendments stimulate the activities of microorganisms that are antagonistic to plant-parasitic nematodes. The mode of action of organic amendments leading to plant disease control and stimulation of microorganisms is complex and dependent on the nature of the amendments (Akhtar and Malik, 2000). The Food and Agriculture Organization (FAO) of the United Nations defines sustainable agriculture as a practice that involves the successful management of resources for agriculture to satisfy human needs, while maintaining or enhancing the quality of the environment and conserving natural resources (FAO, 1989). A common philospy among sustainable agriculture practitioners is that a ‘healthy’ soil is a key component of sustainability; that is a healthy crop plants that have optimum vigor and are less susceptible to pest and diseases (Wagner, 1999). A sustainable system of crop production is one that may be used continuously for many years and is based on the potential of a particular region (Wood, 1996). The system does not unduly deplete the resources as it makes best use of energy and materials ensure good and reliable yields, and benefits the health and wealth of the local population at competitive production costs (Wood, 1996). There is a potential for the use of plant residues for inducing soil suppressiveness and further contributing to the control of diseases caused by soilborne pathogens (Klein et al., 2011). Disease incidence and severity of crown and root rot in cucumber plants inoculated with *Fusarium oxysporum* f. sp. *radicis-cucumerinum* macroconidia were reduced by 20 to 80% when seedlings were planted in the tested soils 2 to 34 months after soil amendment. Residues of *Diplotaxis tenuifolia* (wild rocket [WR]), *Artemisia dracunculus* (tarragon), *Salvia officinalis* (sage), and *Brassica oleracea* var. *italica* (broccoli) were most effective for inducing soil suppressiveness. Sustainable agriculture is a trend for future agricultural development and has been promoted vigorously in some countries. This trend was the consequence of applying intensive cropping system with improved high-yielding crop varieties and the heavy application of chemical fertilizers and pesticides in the past decades. Intensive monocropping has created an agricultural environment that is conducive to the outbreak and spread of crop diseases (Zadoks, 1993). The environmental era recognizes the importance of preserving and maintaining the balance of natural resources in the management of crop pests.

Sustainable pest management is one of the key factors in the success of long-term crop production. In order to avoid continuing reliance on chemical pesticides, plant pathologists have focused their efforts in developing sustainable measures for the management of crop diseases. Such research efforts have resulted in the development of new disease control technologies for use as alternative to chemical pesticides in the past few decades. This article discusses the practicality of developing formulated products with agricultural wastes for the management of crop diseases, using several successful examples in Taiwan.

PLANT DISEASE MANAGEMENT AND SUSTAINABLE AGRICULTURE

The incidence and severity of root diseases is an indirect assessment of soil health for specific commodity/soil use. In addition, understanding and selecting the appropriate cultural practices that limit or prevent damage of root diseases is essential for the long-term and sustainable management of soil quality and health. Case-study examples are presented to illustrate the impact of cover crops and their green manures on the density and damage of root-knot and lesion nematodes to vegetables; and also tillage, soil amendments, crop rotation, and cover crops on bean yield and root rot severity (Abawi and Widmer, 2000). Control of plant diseases will remain a high priority as growers adopt new measures for sustainable crop production (Conway, 1996). Growers should develop the skill to solve the problems of new and old diseases which emerged as a result of replacing chemical controls with cultural controls. Cook (1986) noted that high crop yields can be achieved in sustainable agriculture if plants were protected from diseases and pests. Therefore, major improvements in the technology of pest control are needed by assessing the immediate and potential risk of crops to diseases, and by developing short- and long-term control strategies in sustainable agriculture (Wood, 1996).

In India, farmers are encouraged to adopt environmentally sound measures for the management of crop diseases. Currently, the most common non-chemical control methods for soilborne diseases include the use of pathogen-free seeds or seedlings, disease resistant varieties, induced resistance, soil amendment and soil disinfectants, and other cultural practices such as crop rotation, net house cultivation, and soil mulches (Lin, 1999). Conway (1996) suggested that techniques such as crop rotation, tillage systems, adjustment of planting dates, and organic soil amendments are practical methods for the control of soilborne diseases and that these are important components in sustainable agriculture.

Management of soilborne diseases by organic amendments

A common philosophy among sustainable agriculture practitioners is that a "healthy" soil is the key to sustainability, since it will produce healthy plants with strong vigor and improved resistance to diseases. Crops grown under poor soil conditions often require greater inputs in terms of usage of water, nutrients and pesticides for reducing pest and weed problems and maintaining high yields. In every sustainable system, the soil is considered a fragile and living medium that must be protected and nurtured to ensure its long-term productivity. Some of the methods applied to maintain soil productivity include the use of green manure and cover crops, organic amendment, reduced tillage, reduced soil compaction, and soil solarization.

Amendment with compost

Composts made of agricultural and industrial wastes have been widely used as amendments in soil (Sun and Huang, 1985a, b; Voland and Epstein, 1994) or in other growing media (Chung and Hoitink, 1990; Hoitink, 1980; Nelson and Hoitink, 1982, 1983; Shiau et al., 1997, 1999) for horticultural crops. Potting substrates containing compost may suppress soilborne diseases of floriculture or vegetable crops (Hoitink et al., 1991; Huang et al., 1996). The use of synthetic media for container crops has become increasingly important to the greenhouse industry worldwide (Hoitink, 1980; Hoitink and Fahy, 1996; Huang, 1997; Trankner, 1992). Materials such as perlite, sand, vermiculite, expended Styrofoam, peat, pine bark, and hardwood bark are commonly used as synthetic growth substrates. Although container media are generally pathogen-free, contamination of these media by damping-off pathogens, such as *R. solani*, *Pythium* spp., and *Fusarium oxysporum* Schl. often occurs in the greenhouse production of vegetable and ornamental plant at the seedling stage (Huang, 1997). Early studies of nursery crops showed that *Phytophthora* root rot of rhododendron was less severe in plants grown in media amended with composted tree barks than in those amended with peat moss (Hoitink, and Fahy, 1986; Hoitink et al., 1991). Consequently, composted tree barks have been widely used to replace peat as media for container crops in the US because of their suppressive effects on plant pathogens (Draft et al., 1979; Hoitink, 1980; Kuter et al., 1983).

Both SFMC and SGMC were used as growth media for greenhouse production of cabbage seedlings (Huang, 1997). However, SFMC and SGMC were ineffective in suppressing damping-off of cabbage caused by R. solani AG-4. The formulated medium SSC-06, which consisted of 3L SFMC, 1 L carbonized rice hull, 0.2% (w/v) blood meal, 0.5% (w/v) shrimp and crab shell meal, and 0.3% (w/v) lime, resulted in reduction of *Rhizoctonia* damping-off of cabbage and improvement of seedling growth (Huang and Huang, 2000). The inhibitory effect of the SSC-06 medium on *R. solani* is associated with the activity of *Trichoderma harzianum* (Huang and Huang, 2000). The low incidence of damping-off of cabbage in SSC-06 medium inoculated with *T. harzianum* suggests that the growth substrate is conducive to the proliferation of the biocontrol agent (Huang and Huang, 2000). The FBN-5A is another formulated compound developed using spent forest mushroom compost, animal wastes, and ally alcohol (Shiau et al., 1997). Amendment of the growth media BVB No. 4 with FBM-5A was effective in the control of *Rhizoctonia* damping-off of cabbage (Shiau et al., 1997, 1999). The mechanism of control of *R. solani* by FBM-5A is similar to that observed in SSC-06 medium.

In field experiments conducted during 2001 and 2002, the lowest severity and incidence of common scab of potato were observed in soil treated with lopsided oat than with other treatments ($P < 0.05$ and $P < 0.001$, respectively). These findings suggest that lopsided oat used as fallow green manure can reduce the severity of common scab and increase potato yield (Sakuma et al., 2011).

Organic soil amendment

Soil management practices involving tillage, rotation, and burning will impact the amount and quality of organic matter that is returned to the soil. These practices influence pathogen viability and distribution, nutrient availability, and the release of biologically active substances from both crop residues and soil microorganisms as illustrated by the model system of *Cochliobolus sativus* on the development of common root rot in cereals. The application of organic amendments, manures and composts that are rich in nitrogen, may reduce soil-borne diseases by releasing allelochemicals generated during product storage or by subsequent microbial decomposition. The modes of action for disease suppression are elucidated for a number of diseases including verticillium wilt and common scab of potato. Developing disease suppressive soils by introducing organic amendments and crop residue management takes time, but the benefits accumulate across successive years improving soil health and structure (Bailey and Lazarovits, 2003). Organic amendments and chemical fertilizers are especially useful when the soil has poor fertility and productivity (Browning, 1983). In addition to soil fertility, soil amendment with inorganic and/or organic matter may also alter soil physical and chemical properties and thereby affect soil microflora (Huang, 1991, Huang and Huang, 1993). In the 1920s, Sanford first reported the use of green manure for the control of potato scab caused by *Streptomyces scabies* (Thaxt.) Waks et Henrici (Sanford, 1926). This report created some interest in using organic materials such as crop wastes, compost, green manure, and soybean powder in controlling soilborne plant diseases (Fryer, 1986; Kao, 1989; Palti, 1981; Sun, 1989). An effective organic amendment should reduce the population of plant pathogens, increase the activity of beneficial microorganisms, and improve the growth of crop plants (Cook and Baker, 1983; Huang and Huang, 1993; Papavizas, 1975; Papavizas and Lumsden, 1980). Since 1979, some attempts to use formulated organic compounds as soil amendments for the control of soilborne diseases have been made with considerable success (Huang et al., 2003a; Sun and Huang, 1983).The development of formulated amendments were based not only on their effects on soilborne plant pathogens and beneficial microorganisms, but also on nutritional requirements of plants (Huang and Huang, 1993). Seven formulated products for soil amendments, including S-H mixture (Sun and Huang, 1983), SF-21 mixture (Huang and Kuhlman, 1991a), LT mixture (Lin and Tsay, 1990), AR-3 mixture (Tu et al., 1992), CH-1 mixture (Chen et al., 1991), GS mixture (Chen and Huang, 1992), and CF-5 liquid (Huang et al., 1997), have been developed in the control of soilborne plant pathogens. Among these, S-H mixture, LT mixture, and CF-5 liquid have been commercialized for use in crop production in Taiwan. The ingredients of these compounds are mainly fertilizers and organic wastes (Huang and Huang, 1993, Huang and Kuhlman, 1991b). Studies in the US showed that SF-21 mixture was effective in the control of damping-off of slash pine caused by *R. solani, Pythium aphanidermatum* and *Fusarium moniliforme var. subglutinas*, and promoted growth of pine seedlings (Huang and Kuhlman, 1991a). In Taiwan, S-H mixture is widely used in the control of Fusarium wilt of watermelon, radish and pea, club root of crucifers, cucumber damping-off, and bacterial wilt of tomato (Huang, 1991). Another amendment, the LT mixture, has been reported to control tomato root knot nematodes (Lin and Tsay, 1990). Another soil amendment, AR-3-2 mixture, developed by the Agriculture Research Institute (ARI) of Taiwan ROC was effective in controlling southern blight of many crops caused by *Sclerotium rolfsii* under field conditions (Hsieh et al., 1999, Tu et al., 1992). The development and application of molecular methods for the characterization and monitoring of soil microbial properties will enable a more rapid and detailed assessment of the biological nature of soil suppressiveness. Although suppressive soils have provided a wealth of microbial resources that have subsequently been applied for the biological control of soilborne plant pathogens, the full functional capabilities of the phenomena have not been realized in production agricultural ecosystems. Cultural practices, such as the application of soil amendments, have the capacity to enhance disease suppression, though the biological modes of action may vary from that initially resident to the soil. Plants have a distinct impact on characteristics and activity of resident soil microbial communities, and therefore play an important role in determining the development of the disease-suppressive state (Mazzola, 2004).

Management of plant diseases by plant extracts

Extracts of higher plants such as neem tree, pyrethrum, and some herbs, contain toxic substances and so have potential for use in development of natural pest control products (Dev and Koul, 1997, Saxena and Kidiavai, 1997). For instance, essential oils from clove, cinnamon, and origanum inhibited the growth of *Clostridium botulinum* (Ismaiel and Pierson, 1990). Eugenol from clove was effective in controlling damping-off of cabbage caused by *R. solani* AG-4 (Lin, 2000) and anthracnose of cruciferous vegetables caused by *Colletotrichum higginsianum* (Lin, 2001). A commercial product based on the formulation of plant extracts and essential oils from pepper, mustard, cassia, and clove extracts was effective in reducing the population density of *F. oxysporum f. sp. chrysanthemi*, the causal agent of Fusarium wilt of chrysanthemum (Bowers and Locke, 2000). The effects of plant extracts on the management of plant diseases are discussed.

Control of plant pathogens by plant extract

Seeds of some plant species are known to possess antifungal properties. Seed meal extracts of *Brassica napus* were inhibitory to the growth of *Aphanomyces euteiches* (Smolinska et al., 1997) but slightly stimulatory to the growth of *Propionibacterium* (Rutkowski et al., 1972). Buffered seed homogenates of *B. hirta* were also effective in reducing the growth of *Nematospora* spp. (Holley and Jones, 1985). Seed meal extracts of radish *(Raphanus sativum)*, cvs. Akamaru Kinmon Hatsuka Daikon (AK-H), Hsia Heng No. 2 (HH-2), and Wan Sheng Ta Mei Hua (WS-T), applied at a concentration of 0.2% (w/v) completely inhibited conidial germination of *Acremonium lactucae*, the causal agent of lettuce brown spot (Muto, 2001). Greenhouse trials revealed that spraying lettuce plants with 0.5% (w/v) water-soluble extract from radish seed meal cv. WS-T three days prior to inoculation or two days after inoculation of *A. lactucae* provided consistent control of lettuce brown spot.

Numerous reports showed that oils from some plant species are harmful to fungal pathogens. Application of emulsified oils from corn, olive, or soybean was effective in reducing lesion development of powdery mildew of hop (*Humulu lupulus* L.) caused by *Sphaerotheca macularis* (Martin and Salmon, 1931). Northover and Schneider (1993) concluded that foliar applications of oils from sunflower, olive, canola, corn, soybean, and grapeseed were effective in the control of apple disease caused by *Podosphaera leucotricha* when applied one day before or one day after inoculation of the pathogen. Wilson et al. (1997) tested 49 essential oils from various plants and found that the oils from palmarosa (*Cymbopogon martini*), red thyme (*Thymus zygis*), cinnamon leaf (*Cinnamomum zeylanicum*), and clove buds (*Eugenia caryophyllata*) were effective in the control of *Botrytis cinerea*. Singh et al. (1980) observed inhibitory effects of essential oils from *C. martinii*, *C. oliveri*, and *Trachysperumm ammi* on *Helminthosporium oryzae*, as well as inhibitory effects of the essential oils from rhizomes and leaves of *Zingiber chrysanthum* on plant pathogens such as *Alternaria* sp. and *Fusarium* sp. Application of the oil from *Cinnamomum camphora* at 4000 ppm (Mishra et al., 1991) or the oil from *Cymbopogon citrates* at 1000 ppm (Mishra and Dubey, 1994) effectively controlled *Aspergillus flavus*, the causal agent of stored food rot. Meanwhile, the oil from *C. citrates* was more effective than the synthetic fungicides, agrosan, thiride and bavistin, in the control of *A. flavus* (Mishra and Dubey, 1994). Oils from *Eucalyptus globules* and *Ocimum canum* at 2000 ppm were effective in reducing mycelial growth and sclerotial production of *Sclerotium rolfsii* (Singh and Dwivedi, 1987). The essential oil lemongrass was known to control a wide range of microorganisms including fungi such as *R. solani* (Devi et al., 1982), *A. flavus, A. fumigatus, Macrophomina phaseolina* and *Penicillum chrysogenum* (Adegoke and Odesola, 1996), and bacteria such as *Escherichia coli*, *Pseudomonas aeruginosa, P. fluorescens, Bacillus subtilis* and *Staphylococcus aureus* (Adegoke and Odesola, 1996). Other essential oils from seeds of *Cuminum cyminum* L. and dry flower buds of *Syzigium aromaticum* L. at 1000 ppm were fungitoxic to *Colletotrichum falcatum* Went., *Curvularia pallescens* (Tsuada and Ueyama) Sivan, and *Periconia atropurpurea* (Berk. & Curt.) Litvinov (Rao et al., 1992). The oil from *Nepeta hindostana* was effective in the inhibition of *Pythium aphanidermatum*, *P. debaryanum*, and *R. solani* (Kishore and Dwivedi, 1992). Extracts of Brassica kaber roots expressed antifungal activity toward *Cladosporium cucumerinum* and *Glomus etunicatum* (Schreiner and Koide, 1993). Extracts from neem (*Azadirachta indica*) suppressed in vitro aflatoxin synthesis of *A. flavus* and *A. parasiticus* (Bhatnagar and McCormick, 1988). Extracts from other plants such as garlic and onion bulbs also contain fungicidal substances. Garlic extracts were effective in protecting peaches from brown rot caused by *Monilinia fructicola* (Ark and Thompson, 1959). Several studies showed that volatile substance from bark tissues of *Pinus echinata* Mill (Krupa et al., 1973), the root of *Acacia pulchella* R. (Whitefield et al., 1981), and the bulbs of garlic and onion (Chauhan and Singh, 1989) were toxic components showing inhibition effects on mycelial growth and spore germination of *Phytophthora cinnamomi* Rands. Bulb extracts of *Allium sativum* were more effective than leaf extracts in controlling the growth of *Macrophomina phaseolina* (Dubey and Dwivedi, 1991) and *Botrytis cinerea* (Wilson et al., 1997).

Disease control product made from plant extracts

Empirical knowledge of plants useful for combating plant pests has accumulated over the millennia in different cultures in the world (Dev and Koul, 1997). In the 17th century, insecticidal properties of tobacco (*Nicotiana tabacum* L.) were known to American Indians and European farmers, who used tobacco extracts for the control of plant pests. Jacobson (1975) noted that root extracts of cabbage in water possessed insecticidal property when tested against the vinegar fly, *Drosophila melanogaster*. In addition, glucosinolates in Brassica vegetables such as broccoli, Brussels sprouts, cabbage, and cauliflower showed antimicrobial activities (Chung et al., 2002). Thus, leaves of tobacco and cruciferous plants may be important sources of materials for developing natural products for plant protection because of their insecticidal and/or germicidal properties (Huang et al., 2003b).

CH100 is a liquid formulation containing extracts of tobacco and cabbage, which has been registered for use as a commercial product for the control of plant diseases by the Yuen Foong Yu (YFY) Biotech. Inc. in Taiwan ROC (Huang, 1992, 1994). The ingredients of CH100 are 44 kg of freshly ground cabbage leaves, 10 kg of dry tobacco debris, 5 kg of $CaCl_2$, 1 kg of beef extract, 30 kg of S-H mixture (Sun and Huang, 1985a), and 200 L of Hoagland's solution. These materials are mixed and placed in a plastic tank. After fermentation in the tank for 45 days, the mixture is filtered through double-layer sterile sponge (10 cm thick) and the filtrate is collected to make the final product by adding 95% ethanol at the rate of 95.5:0.5 (v/v) (Huang, 1992, 1994). This formulation is now sold commercially by YFY Biotech. Inc., Kaohsiung, Taiwan ROC under the name Plant Health Guard.

APPLICATION AND EFFECTIVENESS OF CH100 IN THE LABORATORY, GREENHOUSE AND FIELD

CH100 was effective in the control of a wide range of plant pathogens and insect pests (Huang, 1992). Water agar containing 1% (v/v) of CH100 was effective in significantly reducing mycelial growth of *Didymella melonis, Pestalotiopsis psidii* and *Rhizopus stolonifer*, and in inhibiting urediniospore germination and appressorium formation of *Puccinia allii* and *Uromyces vignae* (Huang, 1994). CH100 in water agar plate was also effective in inhibiting proliferation of the bacterial pathogens, *Pseudomonas solanacearum, Erwinia carotovora* subsp. *carotovora,* and *Xanthomonas campestris* subsp. *campestris* (Huang, 1992). Results of field studies showed that application of CH100 significantly reduced severity of leek rust caused by P. allii and promoted growth of leek plants (Huang et al., 1992). Moreover, a combined application of CH100 at 300-fold dilution and triforine, N, N'-[1,4-piperazinediyl-bis-(2,2,2-trichloroethylidene)]-bis-(formamide), at 1000-fold dilution was more effective in the control of leek rust, compared to the use of CH100 and triforine alone (Huang, 1992). These studies suggest a synergistic effect between CH100 and triforine in the control of leek rust. When the rust is severe in the field, it may require three sprays of CH100 to achieve the control of the disease. Application of CH100 on leek plants also resulted in a significant increase in phyllosphere microflora on leek leaves, especially the group of yeast-like microorganisms. The predominant phyllosphere microorganisms isolated from CH100-treated leek leaves were *Rhodotorula* spp., *Cephalosporium* spp., *Fusarium proliferatum, Penicillium* spp., and *Trichoderma* spp. After 5 days of treatment, the population of the above species remained 3 to 10 times higher than those of the leaves of untreated control.

In addition to leek rust, field trials in various locations in Taiwan showed that CH100 was effective in controlling diseases of other crops, including powdery mildew of cucumber caused by *Erysiphe cichoracearum*, soft rot of potato caused by *Erwinia carotovora* subsp. *carotovora*, black spot of Japanese apricot caused by *Venturia carpophilum* Fisher, and scab of guava caused by *Pestalotiopsis psidii* Pat. (Huang, 1992). Meanwhile, CH100 also stimulated the seedling growth of pepper, cabbage, tomato, cucumber, and watermelon under greenhouse and/or field conditions (Huang et al., 1992; Huang, 1994).

CONCLUSIONS

Changes in agricultural practices with time have led to a decline in soil structure and with it, an increase in soil-borne plant diseases. Agricultural practices such as incorporating organic amendments and managing the type and quantity of crop residue have a direct impact on plant health and crop productivity. Therefore it can be concluded that the soil management practices involving tillage, rotation, and burning will impact the amount and quality of organic matter that is returned to the soil. These practices influence pathogen viability and distribution, nutrient availability, and the release of biologically active substances from both crop residues and soil microorganisms as illustrated by the model system of *Cochliobolus sativus* on the development of common root rot in cereals. The application of organic amendments, manures and composts that are rich in nitrogen, may reduce soil-borne diseases by releasing allelochemicals generated during product storage or by subsequent microbial decomposition. The modes of action for disease suppression are elucidated for a number of diseases including verticillium wilt and common scab of potato. Developing disease suppressive soils by introducing organic amendments and crop residue management takes time, but the benefits accumulate across successive years improving soil health and structure. Soil amendment with inorganic and/or organic matter may alter soil physical and chemical conditions and it may have important consequences on the growth of plants and the occurrence of soilborne diseases. Whether an amendment works favorably or unfavorably in the establishment of a biological control system depends upon its influences on soil conditions, fertilization, and microbial interactions. It is important to obtain more basic information on changes of physical and chemical properties as well as microbial activities at different stages of decomposition of the added materials in the soil. An effective amendment creates a soil environment that is not only effective against the intended pathogen but also enhances the activity of beneficial microorganisms, improves soil fertility, and promotes the growth of plants. Most of the formulated soil amendments are made of chemical fertilizers and organic wastes and they are intended to maximize the harmful effects on target pathogens and maintain soil fertility with minimal negative impacts on the agroecosystem. Using formulated amendments for the management of soilborne plant pathogens can have agronomic benefits beyond suppression of specific diseases. Our growing understanding of the requirements for biocontrol through soil amendment justifies optimism about the prospects for effective control of soilborne plant pathogens by this method, especially in container crops grown in synthetic media and field crops grown under intensive cultivation systems.

Extracts of numerous plant species contain anti-microbial compounds that can be used as alternatives to synthetic fungicides, including fumigants and contact pesticides (Cutler and Hill, 1994). The prospect of using plant extracts for the development of natural fungicides is appealing, because most of the plant extracts and plant essential oils are readily available, environmentally safe, less risky for developing resistance in pests, less hazardous to non target organisms and pest resurgence, has less adverse effect on plant growth, less harmful to seed viability and quality, and above all, less expensive (Prakash and Rao, 1997). Although numerous fungitoxic compounds have been reported in essential oils and plant extracts, there are few successful examples in terms of developing these natural compounds for the control of plant diseases. The success of CH100 liquid for the control of leek rust and diseases of other crops indicates that it is possible to develop a natural plant disease control product using plant extracts. However, future development, application, and success of biological control of plant diseases with plant extracts will require further research efforts on formulation of plant extracts with the ability to control plant diseases, stimulate the growth of beneficial microorganisms, and increase crop yields. In order to achieve successful pest management in organic farming, the development of ecologically sound, appropriate disease-control systems for each crop is necessary. The strategies should include: a) understanding the local pest types and the ecologies of the crops to be cultivated; b) encouraging the soil-ecosystem's diversity via application of beneficial microbes and reasonable organic fertilizers to create a healthy soil environment to support stronger plant growth; c) deciding on an appropriate integrated pest management program suitable for organic practices, including various diseases, insect and weed control measures, under the advisory and suggestion of the certifying agencies or research institutes; and d) practicing pest management following strict control procedure and under the guidance of pest management experts. Finally, the development of more advanced techniques for use in organic farming is necessary, and the extension and promotion of organic farming practices to meet the goal of sustainable agricultural development are of vital importance.

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