MANAGEMENT OF CROP DISEASES WITH AGRICULTURAL WASTES

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ABSTRACT

Agricultural wastes such as rice straw, rice hull, peanut husk, corn cob, bagasse, rape seed pomace, castor seed pomace, tree bark, mushroom growth medium waste, and shrimp shell powder are widely used in land reclamation and in the production of horticultural crops. These agricultural wastes benefit crop production by improving soil fertility, increasing soil organic matter and, in many instances, reducing the incidence of plant diseases. During the past 25 years, several excellent container media, organic amendments and plant extract products, e.g. SSC-06, S-H, SF-21, LT, AR-3, CH-1, GS, FBN-5A, CF-5 and CH100, have been formulated by using agricultural wastes and fertilizers for the management of crop diseases in Taiwan. Most of the formulated products were designed to maximize the harmful effect on target pathogens and maintain soil fertility with minimal negative impact on the agroecosystem. 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.

Key words: agricultural wastes, organic farming, plant extract, soil amendment, sustainable agriculture

INTRODUCTION

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). During the past 15 years, sustainable agriculture has progressed from focusing primarily on low-input organic farming approach with major emphasis on small fruit or vegetable production farms, often described as Low Input Sustainable Agriculture, to the current situation where sustainability is an important part of mainstream plant production units (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).

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. The increasing public awareness on environmental pollution associated with pesticide toxicity and residues has resulted in the shift in pest control from the chemical era to the environmental era in late 1980s (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

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 Taiwan, 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. In this section, the impacts of organic amendment on management of soilborne diseases are discussed.

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, Nelson and Hoitink 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).

In Taiwan, raw spent forest mushroom growth medium and raw spent golden mushroom growth medium were used as basic substrates for making spent forest mushroom compost (SFMC) and spent golden mushroom compost (SGMC), respectively. 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, 1L 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 allylalcohol (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.

Organic soil amendment

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).

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 effect of plant extracts on the management of plant diseases are discussed below.

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 17^{th} 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* (Table 1) 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

Table 1. Effect of frequency of CH100 spray on germination of urediniospore and formation of appressoria of *Puccinia allii*

Spraying Frequency[1]	Spore germination (%)	Formation of appressoria (%)	Appressoria on stomata (%)
0	42	16	11
1	33	11	8
2	26	4	2
3	14	2	1
r^2*	0.92	0.90	0.89
P*	<0.0001	<0.0001	<0.0001

*r stands for correlation coefficient and P stands for its probability.
[1]Ten-week-old plants of Chinese leek were sprayed with CH100 at the rate of 10ml/L once per week. One week after three applications, 10 plants per replicate were sprayed with urediniospores of *P. allii* and covered with polyethylene bags for 24 hours at 16°C. Percentages of spore germination, formation of appressoria, and appressoria on stomata were determined using a light microscope. There were four replicates per treatment.

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 3-10 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

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 antimicrobial 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 nontarget 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.

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