IMPROVING PLANT PROTECTION FOR THE DEVELOPMENT OF ORGANIC AGRICULTURE IN TAIWAN

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ABSTRACT

Pest management is a key factor in organic agriculture, especially to an economy such as Taiwan, which has limited land and natural resources. Many non-chemical technologies and measures suitable for plant pest management in organic crop production have been developed and improved by researchers and scientists in Taiwan during the past two decades. Presently, the most common non-chemical control methods of diseases and insect pests include: use of healthy seedlings, resistant varieties, and root stocks; resistant induction; natural enemies; sex pheromones; beneficial and antagonistic microorganisms; soil amendment and disinfections; non-chemical pest-killing materials and vegetable oil; cultural practices such as crop rotation, net house cultivation, bagging and mulches; and physical measures such as heat and low temperature treatments. Integrated pest management (IPM), featuring pest identification, monitoring and management including timing application of biopesticides, is recommended to farmers to prevent pest problems. Pest management information in organic agriculture can be accessed through the ARI website.

Key words: plant protection, organic agriculture, organic certification, integrated pest management (IPM), non-chemical/biological control

INTRODUCTION

Taiwan is located in tropical and subtropical areas with climatic conditions of high temperature and humidity which are favorable to the occurrence and dissemination of many disease pathogens and insect pests. Taiwan is also frequently hit by natural disasters such as typhoons and heavy rainfall due to its geographic location. In spite of these unfavorable conditions, Taiwan has maintained high agricultural productivity for many years. This is achieved through the use of intensive cropping systems with improved high-yielding crop varieties, appropriate application of chemical fertilizers and pesticides, and use of new cultivation techniques and machinery (Lin 1996).

Diseases and insect pests are the major limiting factors in the production of good quality and high quantity agricultural products. Although synthetic-chemical pesticides can be used to control some pests economically, rapidly and effectively, most chemical pesticides cause serious negative impacts to the environment, such as: a) toxicity and residual effects to human being, target plants, foods, and other living things; b) induction of pathogen resistance resulting to ineffectiveness of pesticides; c) harmful effects to nontarget beneficial microbes; and d) unbalanced ecosystem due to pollution of soil, water, and environment. Especially, human health and environmental safety are the two most important issues in the long-term application of pesticides. Therefore, the reduction in the amount of pesticides used in sustainable agricultural production has been a major research subject in Taiwan for the last 20 years (Lin 1995).

In order to maintain the balance of ecosystem based on the conservation of
natural resources and minimization of harmful effects to the environment, measures other than chemical control for pest management (Ann 2001, Huang 2001, Lin 1995) have been studied for a long time. Meanwhile, research programs in search of alternative control measures to pesticides for organic farming have been conducted for at least 20 years in Taiwan (Lin 1998, Sun and Hsieh 1992). After great efforts, the government, research institutions, and universities in Taiwan have cooperatively developed many useful technologies which have been introduced to organic agricultural production systems (Ann 2001, Huang 2001, Lin 1995). These measures could partially replace and minimize the risk of using synthetic chemical pesticides to meet the requirement of organic farming (Lin 1995, Sun and Hsieh 1992). This report describes some newly developed and improved methods now commonly used in the fields for pest management in organic practices in Taiwan.

ORGANIC CERTIFICATION IN TAIWAN

Organic practice is a kind of agricultural production system which makes use of safe and natural materials, and must follow organic regulation in each cropping step, in order to produce certifiable agricultural products. There are certifying agencies that evaluate each application and certifies the qualified organic farms whose practices fit the requirement of organic standard. The Council of Agriculture (COA), Executive Yuan, designed “The Organic Agricultural Product Certification Regulation” as a guideline for organic certification by authorized certifying agencies. Today, three private organizations (NGO) have been authorized by COA as qualified certifying agencies for organic farming in Taiwan. These are the Mokichi Okada Association (MOA), Tse-Xin Organic Agriculture Foundation (TOAF), and Taiwan Organic Production Association (TOPA). In addition, the Chinese Organic Agriculture Association (COAA) and the Taiwan Formosa Organic Association (TFOA), both applying as certifying agencies, are currently being evaluated by COA. Only certified organic farms are permitted to label their agricultural products with the organic trademark. All certified farms are being reevaluated annually. Meanwhile, the authorized certifying agencies have the responsibility and obligation to train and give advisory to the growers of all certified organic farms.

NON-CHEMICAL MEASURES FOR DISEASE MANAGEMENT

Pathogen-free planting materials

All healthy plants are originally grown from pathogen-free seeds. Meanwhile, numerous systemic diseases are transmitted to progeny via asexually propagated materials infected by viruses, phytoplasmas, fastidious bacteria, and some vascular-inhabited fungi and bacteria. The use of pathogen-free planting materials has been proven to be the only effective and reliable measure in preventing the epidemic of these systemic diseases (Chang 1997).

In Taiwan, the production systems of pathogen-free seedlings/seeds in citrus (Su 2001), banana (Huang 1997), passion fruit (Chang 2001), potato (Lu et al. 1992), sweet potato, red sugarcane, green bamboo, asparagus bean (Chang 1997), garlic green (Deng and Wang 2003), lily, gladiolus, strawberry, tuberose, etc., have already been established. Moreover, the certification systems process of special pathogen-free seedlings of oncidium and anthurium are currently underway (Chang et al. 2004). By developing virus-free nuclear seedlings of passion fruit and asparagus bean seeds, both crops can be produced in good quality and high quantity by the farmers (Chang 1997, 2001). Mass production of Fusarium-free and Fusarium-resistant banana plantlets through tissue culture for commercial cultivation in Taiwan has also been highly successful (Huang 1997, 2001).

Resistant/tolerant varieties/root stocks

The use of resistant varieties is the most effective and economical way to control plant diseases and protect the environment at the same time (Agrios 1987). Resistant and tolerant varieties of various crops have been bred and released to the farmers in Taiwan in the past four decades.

Conventional crop breeding. Breeding varieties resistant to pathogens has been
achieved in many agronomic and horticultural crops in Taiwan. Registered disease resistant varieties of crops for commercial production include rice, sugarcane, corn, sorghum, peanut, soybean, tomato, cucumber, water melon, Chinese cabbage, amaranth, potato, and many others (Tu and Chang 1992, unpublished data).

**Induced mutation.** Taiwan's successful method of screening resistant clones through tissue culture mutation against Panama disease in banana had earned high international reputation (Hwang 1991). Several cultivars, including the Taiwan Banana No. 1 and Formosana resistant to Fusarium wilt caused by race 4 of *Fusarium oxysporum f. sp. cubense*, have been officially released to farmers (Hwang 1997, 2001).

**Resistant root stock.** Through grafting, sponge gourd resistant to *Fusarium oxysporium* is used as rootstock for the control of fusarium wilt in Taiwan, with remarkable results (Lin et al. 1998). The technique has already been widely used by the farmers.

**Biological control**

Biological control of crop diseases is one of the most important practices in sustainable agricultural production (Baker and Cook 1974). Application of antagonistic microorganisms and beneficial microbes to reduce disease incidence in the fields are the two newly developed technologies in Taiwan.

**Antagonistic microorganisms.** The mechanisms of biocontrol of pathogens with antagonistic microorganisms include: a) competition for nutrients and space; b) inhibition by antibiotics, enzymes and/or toxic substances; c) superparasitism; d) induction of host resistance; and e) other effects on non-target microbes. Biocontrol shows promise in reducing the use of fungicides and, at the same time, maintaining the balance of the ecosystem. Experimental results show several successful examples of using microbiological agents to control plant diseases in the field in Taiwan. These include: a) the use of *Bacillus cereus* to control root knot nematode and disease complexes caused by nematode and *Rhizoctonia solani* in tomato (Wu 1992); b) the use of *Bacillus subtilis* to reduce stem rot in chrysanthemum cuttings; c) the use of *Trichoderma* species to suppress root rot in carnation, cucumber, and muskmelon caused by *Pythium* and *Rhizoctonia* species (Lo 1996); and d) the application of *T. koningii* to control root rot disease in adzuki bean (Liu 1991). The techniques and procedure of producing formulated *Trichoderma* products via both liquid and solid fermentation have been developed by ARI, and the technology has been transferred to Houng-fu Co. for commercial production of biopesticides.

Other than biopesticides, soil amendments containing antagonistic microorganisms are frequently used for the control of soilborne diseases such as nematode diseases. The famous example, LT mixture, has been reported to control citrus nematodes and grape root knot nematodes (Tsay 1997). LT mixture contains antagonistic-*Bacillus* sp. and a mixed organic component including shrimp and crab shell (40%), castor bean pomace (40%), seaweed powder (10%), soybean powder (5%), and molasses (5%). The soil amendment was proven effective in: a) increasing the activity of soil biocontrol microorganisms; b) protecting citrus root systems; and c) killing nematodes directly.

**Beneficial microbes.** The mechanisms of biocontrol of pathogens with beneficial microbes include: a) promotion of plant growth (improved plant vigor); and b) protection against pathogen (competition with pathogen). Beneficial microbes include arbuscular mycorrhizal fungi (AMF), and plant-growth-promoting bacteria in root environment. To overcome the difficulties of the cultivation of symbiotic arbuscular mycorrhizal fungi, research is now mainly focused on developing the mass production of inoculum. Recently, the technology on pot culture and aeroponic system for arbuscular mycorrhizal production has been adopted for commercial production. Plant seedlings of melon and anthurium applied with mycorrhizal fungi grew stronger, were more resistant to diseases, and produced good quality and high quantity fruit and flowers.

**Application of non-chemical pathogen killing materials**

**Inorganic salts.** Many environment-safe inorganic salts, such as KHCO₃ and CaCO₃, which could kill the pathogen directly or
increase host resistance, were recommended to be used in organic practices. Recently, ARI found that potassium bicarbonate was very effective in the control of powdery mildew in many crops.

**Vegetable oil.** Edible plant oils such as sunflower oil via emulsification have been proven to be effective to control powdery mildew of many crops as well as aerial plant diseases (Ko et al. 2003).

**Medicinal herb extract.** The development of biopesticides from medicinal herbs is a major research program conducted in ARI recently. The alcohol- and aqua-extract of several herbs were found to be effective in controlling many plant diseases, such as cabbage anthracnose and powdery mildew (unpublished).

**Cultural practices**

Better cultural practices are simple and effective ways to reduce disease incidence (Agrios 1987). The following methods have been recommended to the farmers for crop management in Taiwan (Wu et al. 1998): a) appropriate application of fertilizers to maintain the crops' vigor to resist disease infection (Lin 1996); b) water management, i.e. regular watering and maintaining appropriate moisture to avoid creation of a suitable environment for the development of waterborne diseases such as Phytophthora diseases; c) soil liming to control club root disease in cabbage; d) rotation of upland crops with paddy rice to control soilborne diseases of many crops; e) change of planting date to escape disease infection; f) intercropping with other crops to reduce disease prevalence due to slower dissemination speed; g) use of high-stem crops, such as sorghum and corn, to form barriers for the protection of short crops from virus transmitted by insect vectors; h) use of net house (pore size, 28 mesh) to protect papaya trees from papaya ringspot virus (Wu et al. 1998); i) use of other protection facilities such as vinyl house and tunnel covered with plastic sheets to protect plants from waterborne pathogens; j) bagging of fruits to prevent disease infection and maintain high quality (Ann 1998, Wu et al. 1998); and k) other practices such as soil mulching (Ann 1998), grassing, and stand cultivation to reduce the severity of soilborne diseases.

**Physical control**

**Soil steam and solarization.** Disinfection of soil with steam at temperature 60-80°C is effective in reducing Fusarium and Rhizoctonia wilt in lily monoculture fields for the production of high-quality flowers in Taiwan (Lee and Leu 1988). A reduction of soilborne diseases in monoculture crops could be achieved by exposing soil to sunlight in the dry summer season which consequently killing soil pathogens by solar energy. Southern blight of peanut caused by *Sclerotium rolfsii* was reduced after solarization of soil covered with anti-UV transparent sheets for two weeks (Lin and Huang 1995).

**Hot water treatment.** Hot water, such as dipping mango fruit in 49°C for 5 minutes, was proven to be effective in reducing mango fruit anthracnose. The techniques and equipment, developed by ARI recently, have been transferred to a private company for commercial mango treatment (Young and Lin 1997).

**Integrated pest management**

Integrated pest management (IPM) is a fundamental component of conventional agriculture as well as organic farming. IPM attempts to understand and manage a pest with reference to its interaction with other organisms and the environment. With the help of agricultural experts from the government and the farmers’ associations, IPM strategies such as the use of resistant crop varieties (Chen 1996, Chen and Yu 1998, Tu and Chang 1992), pest identification, population monitoring, pest management options, etc. have been recommended to farmers in controlling their farm pests. Useful resources in agricultural production, especially those on management of diseases and insect pests, have been widely disseminated through the website of ARI in Taiwan (http://www.tari.gov.tw/).

**NON-CHEMICAL MEASURES FOR INSECT PEST MANAGEMENT**

**Biological control**

**Application of Trichogramma wasps to control Asiatic corn borer.** The Asiatic corn borer, *Ostrinia furnacalis*, is the most
important insect pest of corn in Taiwan. Yield loss can be as high as 30% of the total production. Application of *Trichogramma* egg parasitoids in Taiwan has been very successful since the mid-1980s. The *Trichogramma* wasps are also important egg parasitoids of many other major insect pests. Other than the aboriginal species, the exotic wasp *Trichogramma embryophagum* was introduced to fortify the biological control of Asiatic corn borer in Taiwan (Chen and Lo 1991, Hou 1997, Lo 1997).

In combination with the egg parasitoid, *Bacillus thuringiensis* (*Bt*) baits have also been used in the field to enhance the control effect. The *Bt* baits coated with attractant to Asiatic corn borer not only prolong the duration of pathogenicity under sunlight, but also stimulate the feeding of the borers and therefore greatly improve the control effect (Lo 1997).

**Biological control of coconut leaf beetle by *Tetrastichus* wasp.** Coconut leaf beetle (*Brontispa longissima*) was once an important insect pest of coconut in southern Taiwan (Chiu and Chen 1985). The beetles seriously damaged the leaf buds, resulting in failed development of new leaves and death of the palms. *Tetrastichus brontispae*, a pupal parasitoid of the coconut leaf beetle, was introduced from Guam in 1983. After its release, this parasitic wasp successfully established in Taiwan. Approximately 90% of the beetles were parasitized, and the population of pest beetles were reduced dramatically (Chiu and Chen 1985, Lo 1997). The damaged coconut trees were all recovered and saved. Therefore, coconut beetle had never been a problem in Taiwan.

**Use of predators to control spider mites and bulb mites.** Forty-seven species of native predators have been recorded as natural enemies of spider mites. *Amblyseius womersley* was identified as the most important one. This species, along with three exotic species, *A. californicus*, *A. fallacis* and *Phytoseiulus persimilis*, have been effectively used for the biological control of spider mites on pear, mulberry, tea, strawberry, and papaya in Taiwan (Lo et al. 1986, Lee and Lo 1989, Ho 1990, Chen and Lo 1991, Hao et al. 1996). Predators of bulb mites include the Cecidomyid fly and predaceous mites (Hodson 1928, Garman 1937). Among them, *Hypoaspis aculeifer* was the most abundant species commonly found in the field. *H. aculeifer*, with the ability to suppress the population growth of bulb mites, was proven to be an effective natural enemy (Zedan 1988, Ragusa and Zedan 1988, Lesna et al. 1995, 1996, 2000).

**Release of green lacewing for the control of small insects.** The green lacewing, *Mallada basalis*, is an effective predator of small insects and mites. Entomologists in Taiwan developed a machine to produce encapsulated artificial diets for the green lacewing. The low-cost and labor-saving rearing system enables the production of large quantities of green lacewings within a short period of time (Lee 1995). The cost of production was calculated as NT$1.22 (US$1 = NT$32) per adult (Lee 2003). Green lacewings have been applied to papaya, strawberry, Indian jujube, and tea for the control of spider mites, aphids, scale insects, and whiteflies (Hou 1997). The control effect is usually better in a confined environment.

**Development of microbial pesticides.** In addition to the bacteria, *Bacillus thuringiensis*, some entomopathogenic viruses and fungi are used as microbial pesticides. These include *Metarhizium anisopliae*, *Beauveria bassiana*, *Nomuraea riles*, and *Verticillium lecan*. The local microorganisms were surveyed and cultured to select strains with high infectious rate. Of these, *M. anisopliae* has been effectively used to control some insect pests of vegetables and rice (Hou 1997).

**Conservation of natural enemies**

Natural enemies of insect pests occurs in all crop production systems. Conservation of the existing natural enemies is the essential concept in the practice of organic pest management. Population of insect pests is kept at low level when natural enemies are conserved. Clearly understanding the components of the insect fauna is the basic requirement. Some cultural practices such as leaving habitat plants for natural enemies, and adjusting the time to plow in rice paddies have been proven to significantly increase the number of predaceous spiders and, hence, reduce the population of brown plant hoppers.
Botanical extracts

Natural components extracted from plants are used frequently for controlling crop pests (Isman 2000, Pascual-Villalobos and Robledo 1999). Many compounds have toxic, repelling, anti-feeding, anti-ovipositing, or growth regulating biological activities to insects (Jacobson 1990, Swain 1977). Some botanical extracts are produced commercially as insecticide. These include: Chrysanthemum spp., neem tree (Azadirachta indica or Melia azadarach), Derris elliptica, tobacco (Nicotiana longifolia), etc. Recently in ARI, a molluscicide and a fungicide were developed with the use of extracts from Sapindus mukorossi seeds, effectively controlling golden apple snail (Ampullarium canaliculatus) and powdery mildew on muskmelon and tomato.

Insect sex pheromone

More than 17 insect sex pheromones serving as attractants to control different insect pests have been developed in Taiwan (Hwang 1997). In a nationwide program, sex pheromones were applied to monitor the density of major insect pests around the island, which is important in determining the proper strategy of economic insect pest control. Field application of these pheromones has been proven effective in controlling insect pests on many crops such as legumes, sweet potato, vegetable, tea, and many ornamental plants, with control acreage exceeding 20,000 hectares (Cheng et al. 1996, Hung and Hwang 1993).

Yellow sticky cards

Yellow sticky cards can be used as an efficient tool to monitor the populations of leaf miners, aphids, thrips, and whiteflies as these insect pests are attracted to the yellow color. This control method, when used at the proper time, can suppress specific insect pests. Yellow sticky cards have been used as a practical control measure for Liriomyza flies as well as for whiteflies in vinyl houses producing vegetables. In gerbera production under protected facilities, 23% of L. trifolii was trapped when the cards were placed at a 2-m spacing within each row (Wu et al. 1998).

Fruit fly attractants

Various attractants, such as food and oviposition attractants, can be used to control fruit flies (Bactrocera dorsalis) to reduce the use of chemical pesticides. Scientists in Taiwan have improved the McPhail trap introduced from England to adapt to local agricultural environment. The modified McPhail trap is fruit-like in shape and consists of a yellow plastic reservoir containing protein hydrolysis solution as an odor attractant for female oriental fruit flies as well as melon flies (Wu et al. 1998).

Fruit bagging

Fruit bagging has been used to improve fruit quality in many orchards. The bags also act as barrier to protect the fruit against attack by insect pests. Individual fruits are bagged when they were young and remain bagged until harvest. No additional pesticide sprays are needed once the bags are placed on the fruit. Bagging has been a traditional practice adopted by farmers for controlling insects, especially melon flies and fruit flies. Bagging is also a good method to prevent fruits and squash from becoming contaminated with pesticides from neighboring farms. In addition, bagging is useful in the prevention of bird and wind damage (Wu et al. 1998).

Disposable PET bottles

The use of disposable PET bottles to control flat snails on grapevines is a pest management innovation in organic agriculture. The control rate can be as high as 95-100%. The traps are made by cutting off both ends of PET bottles and splitting one side of the cut bottle longitudinally to encompass the stem of the grapevine. The bottle is stapled firmly around the stem at a height of about one meter above the ground. Since the bottleneck is tightly fixed around the grape stem, snails are unable to pass through the neck to reach the upper part of the plant. Damage caused by the snails is therefore avoided.
Hot water treatment

Bulb mite, *Rhizoglyphus robini*, is one of the most serious pests of bulbous crops. After bulb harvest, bulb mites reproduce rapidly during storage period and damage the bulbs or cause complete rotting. Soaking the gladiolus or lily bulbs in hot water for 2 hours at 40°C or 0.5-1 hour at 45°C before storage can completely kill bulb mites. This treatment is more effective than the chemical treatment.

CONCLUSION

Twenty years ago, it was very difficult for farmers in Taiwan to produce good quality and high yield organic agricultural products with limited control measures other than synthetic chemical pesticides. However, many advanced techniques which have been proven effective and efficient in increasing host resistance and reducing pest activity, and which fit the organic farming standard, have been developed under the effort and collaboration of the government, research institutes, and universities in the past two decades.

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.

REFERENCES


