Micronesica Supplement 7: 101–112, 2003

Improving Plant Protection for the Development of Sustainable Agriculture in Taiwan

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Abstract—Pest management is a key factor in sustainable agriculture, particularly for an economy with limited land and natural resources. In view of the general recognition and acceptance of the importance of sustainable agriculture by the public, technologies of plant protection have been improved and measures disseminated to farmers in Taiwan during the past two decades. Presently, the most common non-chemical control methods of diseases and insect pests include uses of healthy seedlings, resistant varieties, cross protection, natural enemies, antagonistic microorganisms, non-pesticide pest-killing materials, sex pheromones, nutrient solution, high-molecular polymers, soil amendment and disinfections, and cultural practices such as crop rotation, net house cultivation, bagging and mulches. Integrated pest management (IPM), featuring pest identification, monitoring and management including timing application of insecticide, is recommended to farmers to prevent pest problems. The mark of Good Agricultural Products (GAP), issued to farmers under governmental guidance and inspection, has already gained the confidence of consumers in providing clean and high-quality products. A biochemical method for the rapid bioassay of pesticide residue in vegetables and fruits has been developed and applied in both fields and wholesale markets for screening products and educating farmers. This technique has also been introduced to other Asian countries. In addition, the TARI web site, offering pest management information in sustainable agriculture is accessible through the internet.

Introduction

The island of Taiwan is located in tropical and subtropical zones featuring climatic conditions of high temperature and humidity which are favorable for the occurrence and dissemination of disease pathogens and insect pests. Taiwan is also confronted with frequent natural disasters such as typhoons and heavy rainfall due to its geographical locality. In spite of the unfavorable conditions, Taiwan has maintained high agricultural productivity for several decades due mainly to the development of intensive cropping systems with improved high-yielding crop varieties and the heavy application of chemical fertilizers, fungicides, and pesticides.

A sound and balanced environment based on the preservation and proper utilization of natural resources has been in the public awareness in Taiwan for a long time. The methodology of reasonable fertilization and measures other than chemical control for pest management have been developed and introduced to agricultural production systems (Lin 1995). In short, the government of Taiwan has been marking great effort to develop sustainable agriculture since 1986 (Lin 1998, Sun & Hsieh 1992).

Pest management is a key factor to the success of sustainable crop production. In Taiwan, collaboration among government, research institutions, and private sectors has resulted in many techniques applicable to reasonable pest management to meet the requirements of sustainable agriculture. This paper provides a general description of measures for the non-chemical control and integrated management of disease and insect pests. In addition, the successful implementation of the Good Agricultural Production (GAP) and the rapid bioassay method for screening vegetables and fruits of insecticide residues at the field and wholesale market level are also introduced. By combining the various technical and administrative measures, we foresee a very successful future of sustainable agricultural production in Taiwan.

Regulatory Control System for Safety Use of Pesticides

Application of pesticides is critical to the sustainability of agriculture. Excess and improper use of pesticides tends to result in toxicity and residue problems that are harmful to crop growth, human health, non-target microbial activity, and environmental safety. Pesticides are used, but only those with low toxicity which are not carcinogenic, and well to decompose within a short time period are acceptable. Many pesticides with high toxicity, long-term effects or carcinogen in nature have already been prohibited in Taiwan.

The government of Taiwan is also devoted to minimizing risks from the use of pesticides in agriculture (Lin 1996). At the central governmental level, the Council of Agriculture supervises pesticide management that is carried on by research institutions, lower levels of governments, farmers' associations and several private sectors. Regulatory control of pesticide toxicity and residue is accomplished by the establishment of pesticide tolerance levels and safety harvest intervals of crops. Workers in pesticide safety-use working stations also routinely survey the pesticide residue levels in reservoirs and groundwater. Currently, multi-residue analysis methods using GC and HPLC, and rapid bioassay methods based on enzyme reaction of acetylcholine esterase are the two major techniques routinely applied to monitor pesticide residue problems. Various district agricultural improvement stations (DAIS) and county governments are taking the responsibilities to educate farmers the reasonable and safety application of pesticides. Laws have been established to punish those who violate the rules of pesticide application.

Development of Non-pesticide Plant Protection Methods

Diseases and insect pests are considered the major limiting factors of agricultural production in Taiwan. Although pesticides can be used to control some pests rapidly and effectively, not all pest problems, such as systemic and soil-borne diseases, can be solved by using chemicals. In addition, health and environmental safety are increasingly more important issues in view of the toxicity and residual effects of the pesticides. Reduce the amount of pesticides used in agricultural production by non-chemical control measures has been a major research subject in Taiwan for the last 20 years. The following describes techniques developed which have effectively controlled diseases and insect pests in the fields in Taiwan.

Non-chemical Measures for Disease Management

(1) Utilization of resistant or tolerant varieties/cultivars

The use of resistant varieties is the most functional and economic way to control plant diseases and to protect the environment at the same time. Resistant and tolerant varieties of various crops have been bred and released to the farmers in Taiwan during the past four decades (Huang 1991).

a. Conventional crop breeding

Breeding varieties resistant to disease and/or insect pests is normally confined to agronomy crops and important horticultural crops. Registered varieties of rice, sugarcane, corn, sorghum, peanut, soybean, tomato, cucumber, papaya, radish, Chinese cabbage, potato, and other crops resistant to disease(s) and/or insect pest(s) have been bred for commercial production in Taiwan (Chen 1996).

b. Induced mutation

One of the successful instances is the selection of resistant clones through tissue culture to combat the Panama disease in banana. Several cultivars including Taiwan Banana No. 1 and Clone No. 218 resistant to the fusarium wilt disease caused by race 4 of *Fusarium oxysporium* f. sp. Cubense have been officially released to farmers. Another example is the mutants of rice Tainung 67 obtained through treatment with sodium azide. Offspring showed a wide spectrum of resistance to rice blast, bacterial leaf blight, brown plant hopper, as well as other diseases (Huang 1991).

c. Breeding through genetic engineering

Biotechnology has been used extensively in breeding plants resistant to diseases and insect pests with very significant results in the past decade. Successful examples included papaya, rice, and melon resistant to virus diseases and cabbage resistant to insect pest. However, the transgenic plants are still in the isolated nurseries for repeated examination and testing due to the strict regulation set by the government.

d. Resistant root stock

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

(2) Utilization of pathogen-free planting materials

Numerous crop diseases are disseminated by planting materials contaminated with pathogens, especially those that infect plant tissues systemically, such as viruses, phytoplasmas, fastidious bacteria, some vascular-inhabited fungi and bacteria. Diseases can be transmitted through seeds or by asexually propagated materials. The use of pathogen-free planting materials has been proved to be effective, dependable, and economical in preventing the epidemic of diseases. In Taiwan, the production systems of pathogen-free seedlings in citrus, banana, passion fruit, potato, sweet potato, red sugarcane, green bamboo, asparagus bean, oncidium, anthurium, lily, gladiolus, strawberry, tuberose, etc., have already been established.

One remarkable example of high international reputation is the project of producing *Fusarium*-free banana plantlets through tissue culture. By developing fast, low-cost, and reliable techniques screening for virus infection, virus-free passion fruit seedlings and asparagus bean seeds can be produced in quantity for commercial production by the farmers (Chang 1997).

(3) Application of induction in plant resistance

Some special microbes or chemical substances can induce plants to synthesize anti-pathogen substances such as phytoalexin and phenol compounds. The induced resistance in the host plants is called "systemically acquired resistance (SAR)" or "induced systemic resistance (ISR)". Soil microorganisms such as *Trichoderma* or *Giocladium* were shown to have this kind of function. A similar effect is found in salicylic acid and phosphorus acid.

Recently, a simple method of phosphorous acid application was developed in Taiwan (Ann et al. 2000). It consists of dissolving equal amount of phosphorous acid (H_3PO_3, 92–95%, industry grade) and potassium hydrochloride (KOH, 92–98%, industry grade) in water (1 g each in 1 l of water is suitable in most cases). The solution is not phytotoxic to plants and can be used to control the following diseases in crops: late blight of potato and tomato caused by *Phytophthora infestans*, blight of pepper by *P. capsici*, papaya fruit rot by *P. palmivora*, root and fruit rot of citrus by *Phytophthora* species, root rot of avocado by *P. cinnamomi*, black rot of orchid by *P. palmivora* and *P. parasitica*, blight of lily by *P. parasitica*, root and basal stem rot of gerbera by *P. cryptogea* and fruit blight of litchi by *Peronophythora litchii*.

(4) Application of cross-protection techniques

Cross-protection is a technique of using a pre-inoculated mild virulent strain of pathogens to protect host plants from infection by another highly virulent strain. When mild strain-inoculated papaya seedlings were planted, the epidemic of papaya ring spot virus disease could be delayed for several months. Recently, this strategy was also shown effective in controlling viral diseases in cucurbit and zucchini squash.

(5) Biological control

Biological control of crop diseases is one of the most important practices in sustainable agricultural production (Lo 1996 & 1997, Wu 1992). The mechanisms of the 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. It shows promise in reducing the use of fungicides and hence benefiting the balance of ecosystem at the same time.

Experimental results indicated that there were several successful examples of using biological agents to control plant diseases in the field. These included (a) the use of *Bacillus cerus* to control root knot nematode and disease complexes caused by the nematode and *Rhizoctonia solani* in tomato, (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 et al. 2000), and (d) the application of *T. koningii* to control the root rot disease in adzuki bean (Liu 1991).

(6) Soil amendment

Soil amendments are mainly used to control soil-borne diseases such as Pythium and Rhizoctonia damping off, *Fusarium* wilt, southern blight and nematode diseases (Huang 1996, Sun 1989). The mechanisms involved are (a) direct inhibition of soil pathogens, (b) activation of soil microbial activities, (c) promotion of plant growth and induction of plant resistance.

A well-known soil amendment, designated as S-H mixture, is effective in reducing the incidence of *Fusarium* wilt in watermelon, radish and pea, club root in Chinese cabbage, and damping-off in cucumber, etc. Another amendment, LT mixture, was reported to control citrus nematodes and grape root knot nematodes. Other soil amendments such as FBM-5A and AR-3-2 developed in Taiwan have been shown effective for the control of *Fusarium* wilt in lily and southern blight in many crops, respectively.

(7) Application of formulated nutrient solutions

A formulated nutrient solution named CH100 was developed and commercialized for the control of leek rust and plum freckle in Taiwan. The solution is prepared from a fermented mixture of cabbage leaves, tobacco leaves, calcium chloride, beef extract, SH mixtures and Hoagland solution. This interesting result promises a new direction of research on non-chemical control of crop diseases.

(8) Application of high molecular polymers

Some anti-transpiration agents can form a membrane layer on the leaf surface to protect plants from infection by pathogens. Recent studies in

Taiwan showed that some polyelectrolytes, thin membrane forming materials, can be used to control gray mold in lilies (Hsieh & Hwang 1993).

(9) Application of non-chemical pathogen-killing material

The mixture (named MR) of methionine, riboflavin and cupric sulfonate is a photodynamic pathogen-killing agent with low toxicity and no residual effect to the environment. The products of the photodynamic reaction of MR, i.e., oxygen derivatives such as O_2, H_2O_2 and OH, are strongly toxic to pathogens. In Taiwan, a commercial product with the name of "Digi" is available for the control powdery mildew in squash crops.

(10) Cultural practices

Better cultural practices are simple and effective ways to reduce disease incidence. The following methods have been recommended to the farmers for crop management: (a) appropriate application of fertilizers to maintain the crops at stronger status to resist disease infection, (b) soil liming to control club root disease in cabbage, (c) rotation of upland crops with paddy rice to control soil-borne diseases of many crops, (d) change of planting date to escape disease infection, (e) inter-cropping with other crops to reduce disease prevalence due to slower dissemination speed, (f) 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, (g) use of protection facilities such as net house, vinyl house, and tunnel covered with plastic sheets to protect plants from pathogens, especially *Phytophthora*. (h) bagging fruit to prevent disease infection and maintain high quality, (i) other practices such as soil mulching, solarization, grassing and stand cultivation to decrease the severity of soil-borne diseases (Liu 1995).

Non-chemical Measures for Insect Pest Management

(1) Biological control (Chen & Lo 1991)

a. application of *Trichogramma* wasps to control Asiatic corn borer

The Asiatic corn borer (ACB), *Ostrinia fumacalis,* is the most important insect pest of corn in Taiwan. Yield loss can be as high as 30% of total production. Application of *Trichogramma* egg parasitoids in Taiwan has been very successful since mid 1980's. The *Trichogramma* wasps are also important egg parasitoids of many major insect pests. Among the 18 species reared, the exotic wasp *Trichogramma embryophagum*, wasp was introduced to fortify the biological control of Asiatic corn borer in Taiwan.

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 ACB not only prolong the duration of pathogenicity under sunlight, but also stimulate the feeding of the borers and therefore greatly improve the control effect.

b. use of predators to control spider and leaf mites

Thirty species of native predators have been recorded as natural enemies of spider mites. *Amblyseius womersley* was identified as the most important. This species, along with three exotic species of *A. californicus, A. fallacis* and *Phytoseiulus persimilis,* have been effectively used for the biological control of spider and leaf mites on citrus, pear, mulberry, tea, strawberry, and papaya in Taiwan.

c. biological control of coconut leaf beetle by *Tetrastichus brotispae* parasitoid

Coconut leaf beetle (*Brontispa longissima* Gestro) was once an important insect pest of coconut in southern Taiwan. The beetles seriously injure the leaf buds, resulting in failed development of new leaves and killing of the palms. *T. brontispae,* a pupal parasitoid of the coconut leaf beetle, was introduced from Guam in 1983 and has been used effectively in controlling the beetles (Chin & Chen 1985).

d. development of microbial pesticides

In addition to the bacteria of *Bacillus thuringiensis* as mentioned above, entomopathogenic fungi used as microbial pesticides include *Metarhizium anisopliae, Beauveria bassiana, Nomuraea rileys* and *Verticillium lecan.* Of these, *M. anisopliae* has been effectively used to control some insect pests of vegetables and rice.

e. application of green lacewing

The green lacewing, *Mallada basalis,* is an effective predator to small insect pests such as leaf mites, aphids, whiteflies, scale insects, and leaf miners (Chien et al. 2000). Recently, entomologists in Taiwan developed a fully automated machine to produce encapsulated artificial diets for mass-rearing the green lacewing (Lee 1995). The low-cost and labor-saving system enables the production of large quantities green lacewings within a short period of time, and hence facilitates the improvement of integrated pest management. Green lacewings have been applied to papaya, strawberry, Indian jujube, and tea for the control of spider mites, aphids, scale insects and whiteflies (Chen & Yu 1998).

(2) Insect sex pheromone

More than 17 types of insect sex pheromones serving as attractants to control different insect pests have been developed domestically (Hung & Hwang 1993. The sex pheromones can also be used as attractants for monitoring insect pest populations, which is important in determining the proper strategy of economic insect pest control. Field application of these pheromones has proved effective in controlling insect pests on many crops such as legume, sweet potato, vegetable, tea and many ornamental plants.

(3) Yellow sticky cards

Yellow sticky cards can be used as an efficient tool to monitor the populations of miners, aphids, thrips and whiteflies as these insect pests are attracted by 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 whiteflies in vinyl house produced vegetables. In gebera production under the protected facilities, 23% of *L. trifolii* were trapped if the cards were placed at a 2-m spacing within each row.

(4) Fruit fly attractants

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

(5) Bagging fruits

Bagging has been a traditional practice adopted by farmers for controlling insect pests on fruits and squash, especially for squash flies and oriental fruit flies (Ann et al. 1998). Bagging is also a good method to prevent fruits and squash from becoming contaminated with pesticides. In addition, bagging is useful in the prevention of bird and wind damage.

(6) Disposable PET bottles

The use of disposable PET bottles to control flat snails on grapevines is a pest management innovation in sustainable 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 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.

(7) Hot water treatment

Soaking of gladiolus and lily bulbs in water for 2 hours at 40º C or 0.5–1 hour at 45º C before storage can completely kill bulb mites, *Rhizoglyphus robini* Claparede. This treatment is more effective than the chemical treatment (Lee & Leu 1988).

Other Measures Adopted for Sustainable Agriculture in Taiwan

Integrated Pest Management

Sustainable farming is a management-intensive method of cultivating crops at a profit while concurrently minimizing the negative impact on the environment, improving soil health, increasing biological diversity, and controlling pests. Integrated pest management (IPM) is a fundamental component of sustainable agriculture. IPM incorporates a better approach by attempting 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 farmers' associations, IPM strategies such as resistant crop varieties, pest identification, population monitoring, pest management options, etc. are recommended to the farmers to assist in controlling their farm pests.

In spite of many channels for farmers to acquire necessary information to meet their farming needs, the Internet is a new and effective communication tool of posing questions and obtaining information about pest management in sustainable agriculture. Useful resources in agricultural production, especially those on the management of diseases insect pests, have been widely constructed in the respective homepages of agricultural research organizations in Taiwan.

The implementation of the Good Agricultural Practice (GAP) Project

To facilitate reasonable application of chemicals for the management of crop diseases and insect pests, the government of Taiwan has launched the project of Good Agricultural Practice (or Good Agricultural Products, GAP). The principles of GAP are to grow specific crops in the right place at the right time, use reasonable plant protection methods and a safe interval of harvest after the application of chemicals. Through a series of measures of education, guidance, inspection, and control, groups of farmers are allowed to use the mark of GAP on their products. The farmers are required to take records of their cultural management and periodically inspected by the authorities. Their products are guaranteed as high quality and free from pesticide residues to consumers and therefore enjoy higher prices at the market.

As of April of 2001, 1,108 groups (449 for vegetables and 659 for fruits), comprising 14,480 farmers (4,389 for vegetables and 11,016 for fruits), were permitted to join the GAP project. Their annual production, about 117,000 tons of vegetables (4.9% of total) and 226-thousand tons of fruits (10.7% of total), accounted for 7.6% of total production in Taiwan.

The GAP project has been very successful during the past four years. The progress of sustainable agriculture is possible only when the amount of chemicals used can be continuously reduced. The amount of GAP production is expected to increase significantly in the near future with cooperation among governments, farmers associations and other agricultural production sectors.

Rapid Bioassay of Pesticide Residues (RBPR) in Fruits and Vegetables

The technique of rapid bioassay of pesticide residues is a rapid, reliable, cheap, and easy tool for detecting possible toxicity of insecticide residues in vegetables and fruits before they are auctioned and sold in the markets. When a large quantity, e.g., 40 or 50, of samples are being tested, the average time needed for an individual sample is only 2-5 minutes. The cost is as low as US$0.15 per sample. On the other hand, conventional quantitative chemical tests require days and are much more expensive for similar analyses. Therefore, RBPR can be considered an effective measure for monitoring pest management and a safeguard for consumer safety as well.

The core of the method is the use of the enzyme acetylcholinesterase purified from a special strain of housefly. The enzyme is sensitive to two major categories of neurotoxic pesticides, organophosphorus and carbamates. The reaction catalyzed by the enzyme is inhibited, expressed by a percentage of inhibition, if pesticide residues are present in vegetables or fruits. A standard assay procedure and a working kit have been developed and used for over 10 years. Currently, more than 120 stations, including governmental institutions, municipal and wholesale markets, farmers' associations, cooperative farms, food industries, and supermarkets are using the RBPR technique for the purposes of educating the farmers and students and for screening for contaminated agricultural products. More than 150,000 samples were tested by this method in the year 2000 (Chin et al. 1991).

The RBPR method has gained respect from farmers and producers, as well as a high reputation and confidence from consumers. It enables the farmers to pay more attention to the safety of their products. Other examples, on the consumer side, are students' lunch program in major cities and in the armed forces that require suppliers to have their vegetables and fruits tested by RBPR to be qualified to bid. The RBPR method has also been introduced to many Asian countries such as Korea, Thailand, Vietnam, Philippines, etc. The rapid bioassay method for detecting fungicides has also been developed and operated by a number of stations around the country.

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