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Organic Farming Research at AVRDC-The World Vegetable Center: Developing Systems for Smallholder Farmers in the Tropics

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Introduction

Fruits and vegetables account for a large share of the global pesticide market. Pesticide residues are often attributed to the failure of farmers to restrain applications before harvest and to the use of prohibited pesticides (PALADA ET AL., 2006). Aside from the effects on farmers, consumer health and the environment, pesticide residues have significant trade implications as well (WEINBERGER AND LUMPKIN, 2005). For example, MAUSCH ET AL. (2006) reported that export standards introduced by the food industry, like EurepGAP, present a challenge for Kenyan export-oriented horticulture, which is targeting almost exclusively the European market.

AVRDC-The World Vegetable Center is a not-for-profit international agriculture research center whose mission is to reduce malnutrition and poverty among the poor through vegetable research and development. Part of its mandate is to develop safe and sustainable vegetable production systems through the use of Integrated Crop Pest Management (ICPM) and/or Organic Farming production technologies (PALADA ET AL., 2006). Millions of subsistence farmers particularly those located in remote rural areas in developing countries are organic practitioners by default since they often cannot purchase synthetic fertilizers and pesticides due to a lack of capital or limited access to input markets. On the other hand, intensive agricultural production activities can be seen in both urban and peri-urban areas in developing countries, where synthetic fertilizer and pesticide use is rapidly increasing (ANH ET AL., 2004). Pesticides also tend to be over-used and abused where they are affordable (RAJOTTE ET AL., 2005). Farmers that are 'organic by default' can benefit from information and training on improved science-based organic vegetable production techniques for increased productivity (PALADA ET AL., 2005). Under conditions of low natural productivity and low external inputs, well-managed organic farming can even increase yields compared to conventional agriculture (RAMESH ET AL., 2005; BADGLEY ET AL., 2007). Farmers involved in intensive agricultural production activities may also benefit from including organic methods such as green manure cultivation using legumes because these can reduce their input costs (IFAD, 2005), while producing food which can be considered to be safer for farmers, consumers and the environment.

In this article we first provide an overview of our work during the last three years. We then introduce our research work related to agroforestry, discuss possible advantages of intercropping, and briefly discuss land-use practices to reduce climate change impacts on agricultural production. We then discuss factors in addition to research that need to be developed in order to establish organic vegetable systems in developing countries where farmers, particularly in remote rural areas face 'low-input' ('resource-poor') conditions due to a lack of capital or limited access to input markets. Finally, we present a few key results of our on-farm study in Taiwan under tropical/subtropical climatic conditions, where we compared the plant vigor, fruit yield, lycopene and other phytochemicals in tomatoes grown under conventional or organic management systems (see page 5). The case study provides information on the crop management of one very successful organic vegetable farmer and suggests what may be needed for developing other successful smallholder organic vegetable farms in developing countries.

Developing and initiating the implementation of AVRDC's Organic Vegetable Program

The Organic Vegetable Program (OVP) is located at AVRDC Headquarters in the tropical southwest of Taiwan. Mean monthly maximum and minimum air temperatures are about 28.9 °C and 20.7 °C respectively. Mean annual precipitation is about 1670 mm (Central Weather Bureau, Station Tainan near Shanhua, 1971-2001). However, precipitation is unevenly distributed during the year. The mean precipitation during the hot-wet season from April to September is 2150 mm and during the cool-dry season from October to March is 160 mm (AVRDC Weather Station Records, 2004-2006). The soil type is Sandstone-Shale Alluvial with lime concretions. The surface soil texture of most research fields is silty loam. Soil pH ranges between 7.2 and 7.8. The natural soil fertility is high. Irrigation and drainage facilities are available and furrow irrigation is mostly used.

A six-hectare conventionally farmed research area at AVRDC has been converted to an organic farm over a three year period starting in 2004, and crop management has adhered to the 'Production Standards for Organic Agricultural Products - Crops' of Taiwan (COA Taiwan, 2007). At present, just a few bio-pesticides are officially registered for use in organic farming in Taiwan. We rely mostly on *Bacillus thuringiensis* (*Bt*) and neem oil products to control insect pests. For plant disease control, a limited number of microbial pesticides (e.g. *Trichoderma* spp., *Bacillus subtilis*) and botanical pesticides (e.g. Chinese soapberry, cinnamon oil) are available, either developed by local researchers or imported. However, just a few results are available on the efficacy of these products under field conditions in Taiwan. Therefore, recently we started initial research on controlling fungal diseases in various vegetable crops using promising above mentioned bio-pesticides, both under field and greenhouse conditions (MA, pers. comm., 2007). Copper products cannot be used in organic farming, thus, we have limited options for controlling important fungal diseases such as late blight in tomato.

In addition to research in organic vegetable production technologies, field crops (rice, sweet corn, and sweet potato), green manures (sunnhemp, sesbania, green manure soybean), catch crops, banana, and tropical fruit trees are grown organically to increase the biodiversity of the area. In December 2005, we finished planting the field boundary in order to minimize pesticide drift from adjacent conventional fields. We also established an agroforestry plot of about one hectare for the intercropping of vegetables with tropical fruit trees. This area also includes a pond where *Azolla* (water fern, 'a natural green manure') is multiplied and fish raised. Recently, we established a small-scale organic 'home-garden', mainly for demonstration purpose. Various leafy vegetable species are produced there among other vegetable crops such as okra. These vegetables are donated to provide meals to AVRDC staff through the Center's cafeteria.

Many farmers in developing countries do not exclusively cultivate vegetables, but they also grow field crops such as rice, sweet potato, sweet corn, and banana. Such crops have been included in our OVP and the experiences gained may therefore be relevant to the situation of many smallholder farmers. The field crops were grown primarily to widen the crop rotation and secondarily for commercial purposes. The research staff involved is predominantly engaged in research projects and the limited income from small scale crop sales cover few activities of the OVP. Organic rice and sweet corn have been sold to traders, AVRDC staff and the cafeteria, and the organic banana and sweet potatoes were exclusively sold to AVRDC staff at discount prices.

Research on organic production technologies at AVRDC initially focused on tomato, vegetable soybean, and common cabbage (heat tolerant mini-cabbage). In 2007, research work also started on organic sweet pepper, cucumber, broccoli, cauliflower, Chinese cabbage, and kohlrabi. From 2004 to 2007, on-station and on-farm studies were undertaken within the OVP (e.g. LUMPKIN, 2005; VISPO, 2005; MA ET. AL., 2006; JUROSZEK ET AL., 2007a). Most of the field studies were carried out without protective structures except in the case of common cabbage where net tunnels were used to exclude insect pests (MA, pers. comm., 2007) and in on-station experiments in tomato where such nets were used to exclude birds for exact yield assessment. Therefore most of the results were gained in the open-field; similar to the conditions of 'resource-poor' farmers who usually produce in the open-field as well. Our results were gained under tropical/subtropical conditions also representative of most developing countries, which are generally subjected to high temperatures, often strong rainfalls, and year-round prevalence of diseases and insect pests that together are major causes of crop losses. In our on-station field experiments, we frequently applied commercial insecticides (e.g. *Bt*- and neem products) approved for organic farming in Taiwan. We also intensively used sticky traps and pheromone traps, and applied nutrients in organic form at rates similar to those recommended for conventionally produced crops. Under these conditions, we realized in some field experiments marketable and total yields of cabbage, cucumber, sweet pepper, and tomato similar (sometimes even higher) to the ones in previous AVRDC field trials using conventional farming techniques. In general, the quality of our organically produced vegetables was good, sometimes even better than that of vegetables grown in adjacent conventionally managed fields. For example, organic compared to conventionally-grown cherry tomatoes had significantly higher lycopene content in an on-farm comparison field study in 2006. A second field trial will be established in 2007 to approve this one-year result (MA, pers. comm., 2007). The results gained were derived under high soil fertility conditions and are therefore not representative of most agricultural land area in both developed and developing countries. In spite of these limitations, a few key results of our research work gained on-farm in Taiwan will be presented and discussed (see page 5) in the context of developing organic vegetable production technologies for farmers in the tropics.

Funding for AVRDC's-OVP at the Headquarter in Taiwan is provided by three donors who support a total of six projects:

1. 'Development and Implementation of AVRDC's Organic Vegetable Program' (Donor: BMZ/GTZ, Germany, PostDoc Program, three years duration starting 2005, approved in 2004)
2. 'Comparison of Plant Vigor, Fruit Yield, Lycopene and other Phytochemicals in Tomatoes grown under Conventional vs. Organic Management Systems' (Donor: The Organic Center for Education and Promotion (TOC), USA, two years duration starting 2004)
3. 'Development of AVRDC's Organic Research Fields' (Donor: TOC, USA, two years duration starting 2004)
4. 'Evaluation of Tomato Varieties under Organic Management' (Donor: Council of Agriculture (COA), Taiwan, one year duration in 2006)
5. 'Integration of Production Technologies for Organic Vegetable Soybean' (Donor: COA, Taiwan, three years duration starting 2006)
6. 'Investigation of the Quality and Safety of Crop and Soil under an Organic Farming System' (Donor: COA, Taiwan, four years duration starting 2006, model crops are cherry tomato, green manure soybean, and common cabbage)

In addition, outreach activities proposed for East Africa through our AVRDC-Regional Center for Africa (AVRDC-RCA) are in progress. Research has been started in marketing and socioeconomic issues related to organic vegetable production in East-Africa, managed by a colleague supported by CIM, Germany (see SAXENA, 2007, this volume). Outreach activities proposed for Asia are also in progress through our AVRDC-Asian Regional Center (AVRDC-ARC) in Thailand. A two-hectare conventionally farmed research area at AVRDC-ARC will be converted to an organic farm starting in October 2007 (WORAWIT, pers. comm., 2007).

Intercropping of vegetables with fruit trees (agroforesty) at AVRDC's organic fields

Since September 2006 experiments have been carried out on the intercropping of about 14 different vegetable species with 12 different species of tropical fruit trees or bushes. This project is supported by the U.S. Agency for International Development (USAID) under its Sustainable Agriculture and Natural Resource Management Collaborative Research Support Project (SANREM CRSP). The project title is 'Agroforestry and Sustainable Vegetable Production in Southeast Asian Watersheds', in which AVRDC is one of the project partners. The project focuses on using Integrated Crop Pest Management (ICPM) technologies; but the involvement of AVRDC also includes organic production methods (PALADA, pers. comm., 2007).

From September 2006 to July 2007 various economically important vegetables have been grown in 8-m alleys between fruit tree hedgerows. Vegetable crops included tomato, sweet pepper, chili pepper, eggplant, cucumber, broccoli, cauliflower, common cabbage, Chinese cabbage, radish, okra, yardlong bean, and sweet corn. Vegetable crop yields are recorded in order to calculate the economic return of the vegetables, based on average market prices (WU AND PALADA, pers. comm., 2007). The rationale for this is that the major objective of intercropping vegetables with fruit trees is to maximize, and provide early income to farmers in developing countries. While fruits cannot be harvested immediately after planting trees, vegetables produced between the trees can be sold within months, thus, providing farmers with valuable food and income in the meantime. It is well established that food production per unit area can be increased by using intercropping. In hot and dry areas, vegetable species or varieties that are tolerant of shading might benefit from the cooler and more humid micro-climate provided by trees, provided that competition between plant species for above and below ground resources is minimized. Such agroforestry systems might be even appropriate to help farmers to buffer their production systems against climatic variability (WORLD AGROFORESTRY CENTRE, 2007).

Land use patterns and climate change influence each other (DALE, 1997). In arid environments LE HOUEROU (1996) concluded that the impact of expected climatic fluctuations would have a trivial consequence as compared with the impact of humans. In some locations clear cutting of rainforest areas has altered rainfall patterns, and removal of vegetation in arid areas by the actions of humans and their livestock can exacerbate desertification processes. DALE (1997) concluded that climate-change effects are influenced by land-cover patterns (e.g. forest or crop), and that land-use practices (e.g. monocropping or agroforestry) set the stage on which climate alternations can act. Thus land use activity such as tree cultivation might reduce the impact of climate change. Vegetable farming may not alter climates as much as trees but their quick returns could make reforestation economically viable if they are a part of the system.

'Low-input/resource-poor' environments and the development of input and output markets

Breeding of modern varieties is mostly conducted under high input situations; therefore breeding has systematically missed out on exploiting genetic differences expressed at low levels of inputs (CECCARELLI, 1996). However, 'low-input/low-fertility' production systems may spread world-wide (JUROSZEK ET AL., 2007b) because important inputs such as high-grade phosphate could be depleted in this century (RUNGE-METZGER, 1995). One approach to manage this challenge is the use of varieties which have more efficient nutrient uptake and use, and are more appropriate for so called 'low-input' production systems (CECCARELLI, 1996). For example, MOURA ET AL. (2001) found in a pot experiment a large variation in the phosphorus uptake efficiency of 10 tested sweet pepper lines, suggesting that genetic improvement programs aimed at increasing these characteristics in sweet pepper will be successful.

Many 'resource-poor' farmers with little or no use of external inputs have not benefited from the spectacular yield increases achieved by the combination of modern breeding varieties and use of inputs (CECCARELLI, 1996). There is no doubt that it is challenging to repeat results (e.g. yields and quality) gained under 'resource-rich' conditions in 'resource-poor' conditions where important inputs for successful organic vegetable production are completely missing or used in lower amounts and/or less frequently. For example, organic farming in general relies on improved superior vegetable varieties with disease resistance to compensate for the lack of effective fungicides to control some economically important plant diseases. However, in many of the rural areas of developing countries seeds of improved varieties are often not available at all or are in short supply (WEINBERGER AND LUMPKIN, 2005; NATH, 2007). Most vegetables do require relative high levels of specific inputs to achieve economic yields or quality that is marketable. Severe low input systems may not work for some vegetables. So it is important that markets to supply essential inputs are developed side-by-side with vegetable production systems. Therefore in addition to addressing the research needs of 'resource-poor' farmers, input and output markets should be developed. Input markets respond to profitable opportunities, but require investments and in many cases the overcoming of regulatory hurdles. Attention to markets and regulatory issues must proceed hand-in-hand with the development of any new technology if it is to be successfully adopted (RAJOTTE ET AL., 2005).

Key elements for successful organic farming according to an on-farm study in tomato

From 19-24 October 2005, replicated field trials were established in three organic and three conventional farms (three matched farm pairs) in order to compare the fruit yield and quality of tomatoes grown on-farm under organic versus conventional management systems. Two determinate processing tomato varieties with geminivirus resistance were evaluated using a randomized complete block design with four replications in each of the sites. Both varieties had similar maturity and cultural requirements and were identified to develop high lycopene content in fruits. Thus, all farmers used the same two varieties, planted and harvested at the same date within each farm pair. Aggregated data across farms were statistically analyzed by combined analysis of variance using the PROC MIXED procedure of the Statistical Analysis System (SAS Institute, 1981). Mean differences within each farm pair were compared using the Tukey's-test.

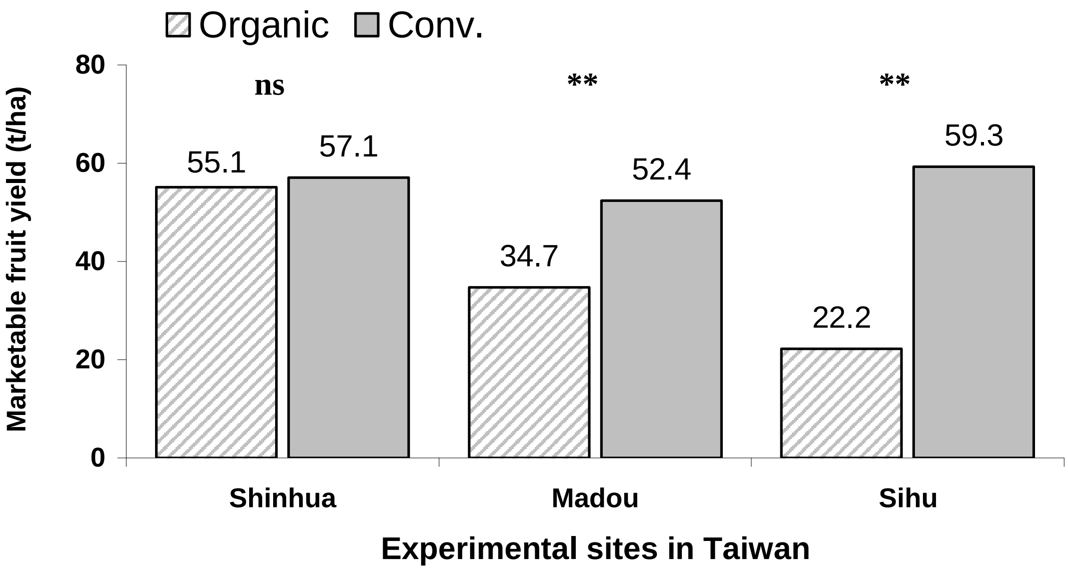

Figure 1: Mean marketable tomato fruit yield (t/ha FW) across two processing varieties at three matched farm pairs (organic vs. conventional) in 2006 in Taiwan (according to JUROSZEK ET AL., 2007a); differences within each farm pair are ^{ns}(not significant) and **(significant at P<0.01) respectively according to Tukey's-test; within each farm pair same harvesting dates (in total three harvesting dates within 93-135 DAT).

The conventionally-produced tomatoes had significantly higher marketable yields compared to the organically-grown ones in two out of three farm pairs (Figure 1). In these two cases the conventional farmers were able to produce more vigorous tomato crops with significantly higher vine height and crop ground cover values (not shown). The performance of the conventional farmers was quite similar with a range of marketable fruit yields from 52.4-59.3 t/ha, whereas the performance of the organic farmers was quite variable with marketable fruit yields ranging from 22.2–55.1 t/ha (Figure 1). Field observations suggest that the organic farmer in Sihu using a heavy soil with high water holding capacity irrigated his crop too much. It must be assumed that root growth under these conditions might have been poor so reducing the above ground development of the tomato plants throughout the entire growing season resulting in the lowest yield of all six farms included in the study. In contrast, although the organic farmer in Madou irrigated his tomato crops more appropriately, the crop suffered in the middle of the growing season from a heavy infestation of tomato fruit worm (*Helicoverpa armigera*) and cut worm (*Spodoptera litura*) resulting in severe damage to the crop. The management of the organic farmer in Shinhua, appeared to be superior to the other two organic farmers. He irrigated his crop moderately, and sprayed an effective *Bt*-product immediately after the detection of tomato fruitworm and tobacco cutworm, and was therefore able to prevent severe damage to his crop. A combination of (1) high soil fertility, medium soil texture, and good soil structure, (2) appropriate climatic conditions during winter for tomato fruit ripening (3) high crop management skills, (4) timely application of a bio-pesticide based on frequent crop monitoring, and (5) the availability of an effective commercial bio-pesticide (*Bt*-product) were most likely the reasons for his success.

In general, the production strategy of the organic farmer in Shinhua appeared to be simple (basal fertilization at 167 kg/ha N applied only, thereafter no side dressings applied). Nevertheless, his tomato crop was very vigorous and the fruit quality in general was good. For example, his tomato fruits had the highest lycopene content with about 12.0 mg/100 g FW among all farms (Figure 2).

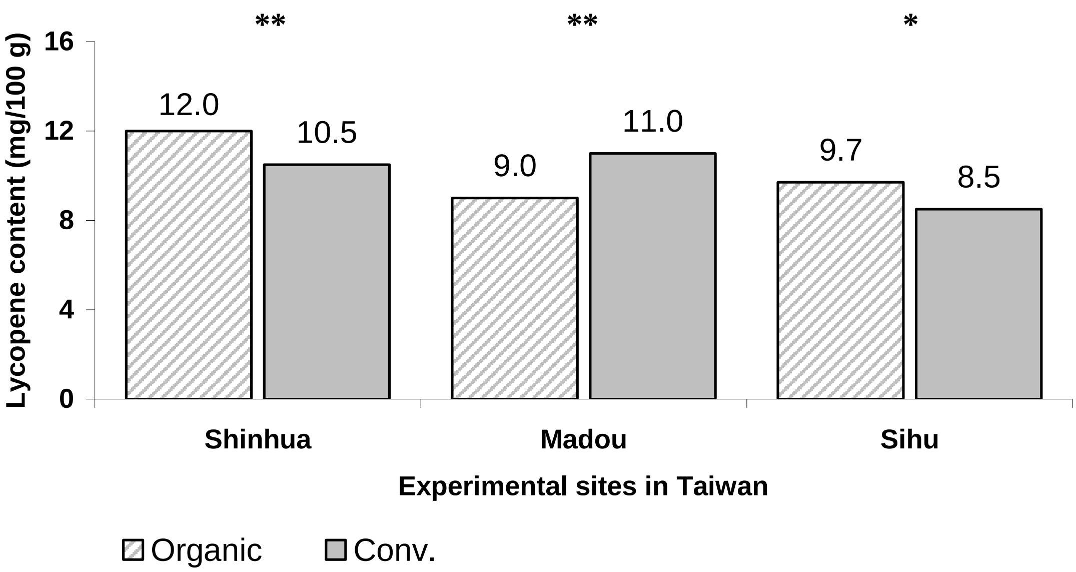

Figure 2: Mean fruit lycopene content (mg/100 g FW) by farm pairs across two processing varieties at three matched farm pairs (organic vs. conventional) in 2006 in Taiwan (according to JUROSZEK ET AL., 2007c); differences within each farm pair are *(significant at P<0.05) and **(significant at P<0.01) respectively according to Tukey's-test; within each farm pair same harvesting date [Shinhua (119 DAT), Madou (113 DAT), and Sihu (126 DAT)].

Lycopene is the major carotenoid in tomato fruit. It serves as a pigment, contributing to the red color of tomato fruits. It is well established that fruit lycopene content in red-fruited tomatoes increases during ripening process (STEVENS AND RICK, 1986). The lycopene content of the fruits produced by the organic farmer in Shinhua was more than 2.0 mg/100g FW higher than that of the fruits of the other organic farmers, and significantly higher compared to the fruits of his conventional counterpart in Shinhua located 100 m away (Figure 2). All farmers used the same varieties, planted and harvested at the same date within each farm pair, yet mean fruit lycopene levels varied considerably within each farm pair, suggesting that in our on-farm study the individual farmers' management skills is the most important factor influencing high lycopene contents in tomato fruit. The tomato fruit lycopene content varied even more strongly across farm pairs, indicating that other factors have also influenced lycopene content such as fruit health, harvest date, soil characteristics and the climatic conditions of the production site (JUROSZEK ET AL., 2007c).

Farmers' crop management skills and timely application of inputs based on frequent crop monitoring are an important component for successful organic vegetable farming. Development projects related to organic vegetable farming will need to include training programs right from the beginning to upgrade individual farmers' knowledge. Farmers starting in organic farming or vegetable farming might need to start with easily managed crops such as amaranths or with an easier to mange variety of a 'challenging crop' such as tomato in order to encourage them. It is also important to choose a location and planting time that will help enhance and strengthen the natural growth and defense mechanisms of the crop, although off-season production of vegetables might offer much higher market prices. Farmers need to pay special attention to maintaining or improving soil fertility and health as a key requirement of successful crop management. The knowledge gained from our organic farming systems research in Taiwan is developing approaches that are relevant in other tropical and sub-tropical countries with many small-scale farmers who are seeking to expand their organic agriculture programs. Conclusions to come out of our on-farm studies so far are:

1. At least a few key inputs are needed for successful organic vegetable production. This may include disease resistant varieties and *Bt*-products. The natural defense mechanisms of crops will not totally solve any plant protection problem, particularly not those related to insect pest infestation. Markets to supply superior vegetable seed and other key inputs for organic farming need to be developed side-by-side with addressing important research needs.
2. Vegetables do need a certain amount of inputs to realize adequate yield and quality levels. There are natural limitations to how much inputs such as water, nutrients and natural pesticides can be reduced without making production uneconomic. A key should be to keep crop management simple and low-cost.
3. Improved varieties and other key inputs are needed, however, without improving and maintaining soil health and fertility, and without skilled and timely management these will be of limited use. It is important to provide training to upgrade farmers' knowledge and skills through extension services such as farmers' field demonstrations and crop production guides.

In general, organic vegetable production systems will need to be adapted to site-specific conditions. For example, tomato crops need to be grown in environments suitable for fruit development and ripening. This is in agreement with KRISTIANSEN ET AL. (2006) who stated that to ensure that organic agriculture is the answer to the sustainability problem, it has to be adapted to local farming, social, geographical and climatic factors.

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