AVRDC-THE WORLD VEGETABLE CENTER'S PRESENT AND FUTURE APPROACHES TO GOOD AGRICULTURAL PRACTICES

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ABSTRACT

The mission of AVRDC-The World Vegetable Center is to reduce malnutrition and poverty in the developing countries through vegetable research and development. To accomplish this, AVRDC is building partnerships and mobilizing resources from private and public sectors to promote vegetable production and consumption in the developing world. Worldwide concern about food safety, health, environmental quality and sustainability in food production has mandated AVRDC to develop technologies that will contribute to the production of safe and nutritious vegetables in the tropics. These technologies are consistent with the objectives and goals of good agricultural practices (GAPs). AVRDC's strategy for addressing this problem is to develop varieties resistant to major diseases and cultivate them with GAPs that will reduce fertilizer and pesticide use. Current strategic research on GAPs for vegetable production at AVRDC are discussed in this paper.

Key words: GAP, vegetable production, Asia

INTRODUCTION

AVRDC's Role and Mission

The Asian Vegetable Research and Development Center (AVRDC)-The World Vegetable Center was established in 1971 as a not-for-profit international agricultural research institute whose mission is to reduce malnutrition and poverty in the developing countries through vegetable research and development. Over the past 30 years AVRDC has developed a vast array of international public goods. The center plays an essential role in bringing international and interdisciplinary teams together to develop technologies, empower farmers and address major vegetable-related issues in the developing world.

In its unique role, AVRDC functions as a catalyst to 1) build international and interdisciplinary coalitions that engage in vegetable nutrition issues; 2) generate and disseminate improved germplasm and technologies that address economic and nutritional needs of the poor; 3) collect, characterize and conserve vegetable germplasm resources for worldwide use; and 4) provide globally accessible, user-friendly and science-based appropriate technology (AVRDC 2005).

In enhancing and promoting vegetable production and consumption in the developing world, AVRDC's research programs contribute to the increased productivity of the vegetable sector, equity in economic development in favor of rural and urban poor, healthy and more diversified diets for low-income families, environmentally friendly and safe production of vegetables and improved sustainability of cropping systems (AVRDC 2002).

Recent achievements at AVRDC that greatly impact tropical horticulture in the developing world include virus-resistant tomatoes raising farmers' income, hybrid peppers breaking the yield barrier in the tropics, flood-tolerant chilies opening new market opportunities, broccoli varieties for monsoon season, pesticide-free eggplant and leafy vegetables that are safer to grow and consume and fertilizer systems that protect the environment (AVRDC 2005). Beyond vegetable crops, AVRDC is playing an important role in expanding and promoting research and development efforts for high-value horticultural crops including fruits, ornamentals and medicinal plants through its new Global Horticulture Initiative (Palada and Lumpkin 2005; Weinberger and Lumpkin 2005). AVRDC believes that horticulture crop production provides jobs and is an engine for economic growth. This paper will stress the important role AVRDC-The World Vegetable Center plays in developing and promoting good agricultural practices (GAP) in vegetable production.

Global Concern on Food Safety, Health and Environmental Quality

Fruits and vegetables together account for a large share of the global pesticide market, in most years between 26-28% of total pesticide use, or around US$8.4 billion a year (Dinham 2003). Almost 25 kg/ha of active pesticide substances are used on average in fruit and vegetable production in the European Union (EU) (Organization for Economic Cooperation and Development 1997). Fruit and vegetable production accounts for less than 2% of the United States' crop area, but 14% of its total pesticide use (Osteen 2003). Pesticide residues are often attributed to the failure of farmers to restrain application before harvesting and the use of prohibited pesticides. Aside from the effects on farmer and consumer health and the environment, the presence of pesticide residues has significant trade implications as well. Fruits and vegetables are also at risk of contamination from heavy metals and waste products. Several studies have reported high heavy metal contamination in fruits and vegetables, such as arsenic, lead and cadmium in Bangladesh (Alam *et al.* 2003) and lead in fruits, vegetables and medicinal herbs in Egypt (Mansour 2004). Toxicity of fruit and vegetable produce also occurs due to human and animal waste use in crop production (Midmore and Jansen 2003). In the future, production of safe food products will become even more important than it is now. Food safety legislation in the EU and the US will soon institute stricter standards (Weinberger and Lumpkin 2005).

Challenges in Sustainable Production of Safe and Nutritious Vegetables

Significant yield loss caused by various diseases and insects is a great concern in vegetable production. Spraying pesticides is a highly common behavior of vegetable farmers. Misuse and overuse of pesticides are harmful to the health of farmers as well as the environment. The high pesticide residue concentrations found on vegetables are harmful to consumers. Because fruits and vegetables are often traded and consumed in fresh forms, biological contamination and pesticide residue are serious issues. The sanitary and phytosanitary standards (SPS) of the World Trade Organization (WTO) define that countries can pursue their own levels of food safety standards. SPS issues are sometimes used as a protectionist tool against imports since multilateral trade agreements have reduced the ability to protect domestic production with tariffs and quotas (Cerrex 2003; Henson and Loader 2001). SPS regulations are probably the most important barrier to international trade in fresh fruits and vegetables (Unnevehr 2000). Thus exporters from less-developed countries must be provided with training opportunities and access to information on how to produce and supply safe products to developed economies (Weinberger and Lumpkin 2005). AVRDC's strategy for addressing this problem is to develop varieties resistant to major diseases and techniques of GAP that will reduce the use of pesticides.

CURRENT STRATEGIC RESEARCH ON GAPS FOR VEGETABLE PRODUCTION AT AVRDC

Integrated Pest Management (IPM) for the Production of Safe Vegetables

IPM research at AVRDC is focusing on important tropical insect pests and diseases. The main research strategies for insect control include biological control (use of predators and parasitoids, sex pheromones, biopesticides, etc.) and cultural practices.

Vegetables are very important crops in Asia and are cultivated in an area of 37.22 million hectares with annual production of 630.75 mt (FAO 2004). Vegetable production is seriously affected by several insect pests and diseases in tropical Asian climatic conditions. The needs to obtain greater yields and to produce attractive vegetables that fetch higher prices encourage farmers to apply prophylactic sprays of pesticides to prevent damage by insect pests. For instance, a survey of pesticide use in Central Luzon in the Philippines indicates that farmers there spray up to 56 times with chemical insecticides during a cropping season to protect their eggplant crop against eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis* Guen. The total quantity of pesticide used per hectare for eggplant was about 41 L of various brands belonging to the four major pesticide groups (IPM CRSP 1993; Orden *et al.* 1994). Such pesticide use, besides being detrimental to the environment and human health, also increases the cost of production making this humble vegetable expensive for poor consumers. The share of the cost of pesticide to total material input cost was 55% for eggplant and it ranked first when compared with tomato (31%) and cabbage (49%) (Orden et al. 1994).

Many pesticides commonly available in Asia are classified by the World Health Organization as extremely hazardous and are either banned or severely restricted for use in the developed world. Prolonged exposure to pesticides has been associated with several chronic and acute health effects like non-Hodgkin's lymphoma, leukemia, as well as cardiopulmonary disorders, neurological and hematological symptoms and skin diseases. A report titled "The impact of pesticides on farmer health: a medical and economic analysis in the Philippines" (Pingali, et al. 1995) claims that the value of crops lost to pests when pesticides are not used is invariably lower than the cost of treating diseases caused by their use. The health costs incurred by farmers exposed to pesticides are 61% higher than those of farmers who are not exposed, it added.

Hence, AVRDC is working to develop sustainable, economic and eco-friendly IPM techniques to combat the noxious insect pests in vegetable production systems. The IPM strategy is based on the manipulation of the customary cultural practices, use of sex pheromone to continuously monitor and/or trap the pest adults, use of resistant varieties, releases of natural enemies like parasitoids and predators, application of biopesticides and withholding of pesticide use to allow proliferation of local predators and parasitoids to restore natural balance. Some of the sustainable pest management techniques developed at AVRDC are discussed in the following sections.

Habitat Management. Removal and destruction of the pest-infested plant parts will reduce the subsequent population build-up of certain insect pests, for instance, EFSB larvae bore inside tender eggplant shoots, especially before fruit set, and cause wilting of shoots. The insects inside these damaged shoots eventually develop into pest adults that spread and lead to future yield losses. Hence, it has been demonstrated that prompt destruction of freshly wilted shoots harboring pest larvae has potential to control EFSB effectively (Alam *et al.* 2003). Similarly, keeping the environment clean reduces pest incidences. EFSB, for example, is a specific pest of eggplant. It was initially believed that a newly planted eggplant crop becomes infested via EFSB moths that either emerge from pupae in the soil or migrate from neighboring eggplant crops. These two sources of EFSB infestation remain important. However, Alam *et al.* (2003) identified a new source of the pest insect: eggplant stalks from previous crops. Most farmers store these plants around their fields or dwellings and use the dried stalks as fuel for cooking. Hence, it has been suggested that prompt elimination of eggplant stubble from old plantings will prevent carryover of EFSB from season to season and this will help reduce EFSB damage to new eggplant crops.

Net barriers in pest management. Leafy vegetables are fast-growing crops and they are rich sources of vitamins A and C, iron, calcium, folic acid and dietary fiber. They are highly perishable and need to be sold in the market within a few hours of harvest. Hence, these vegetables are usually grown in peri-urban production areas. Increasing biotic pressures on these crops induce the farmers to spray heavily with pesticides. AVRDC has developed techniques to grow these vegetables under protective structures and it has been demonstrated that fifteen cycles of various leafy vegetables, free of any pesticide use, without loss of yield or quality of the produce can be cultivated (Talekar *et al.* 2003). These structures vary in size and the protective materials used to construct them. The most economical and widely used structure is a 2 m-high iron infrastructure with a single door and covered with nylon netting. The netting is usually 16-mesh, which allows free flow of air, minimizes build-up of temperature inside the nethouse, and reduces radiation levels by only about 15%. The porous nature of the net helps it to withstand strong winds without much damage.

Pest control by irrigation management. Pests can be controlled by optimizing the quantity of irrigation water in a cropping system. For instance, onion thrips, Thrips tabaci Lind., is a destructive pest of onion wherever this crop is grown. Adults lay eggs in onion foliage tissue and larvae and adults feed on leaves by rasping the leaf surface and sucking the plant sap. Leaves become blotchy with white spots, which damage the quality of produce where leaves are sold as vegetables, and reduce bulb yield. Onion thrips larvae usually pupate in the soil. Hence, keeping the soil moisture high throughout the growing season could reduce thrips' damage to onion. The experimental results between 1996 and 1998 showed that the higher the irrigation level (1,000 L/week), the lower was the thrips' damage; also, the higher the irrigation level, the greater was the yield (Tables 1-2; AVRDC 1999). Thus, keeping the soil moist throughout the season, besides being a good agronomic practice, helps to reduce onion thrips' damage. Flooding the soil for up to 48 hours causes heavy mortality of soil-inhabiting immature stages of striped flea beetle, Phyllotreta striolata and common armyworm, Spodoptera litura in crucifer leafy vegetable production systems (AVRDC 2002).

Overhead sprinkler irrigation would significantly reduce the diamondback moth (DBM), *Plutella xylostella* L., infestation. The DBM larvae and pupae populations was consistently less with sprinkler irrigation than with drip irrigation. The aphid population was also less in the sprinkler irrigation. The number of marketable heads and total yield were significantly greater in sprinkler irrigation (AVRDC 1984). Sprinkler irrigation presumably drowns and washes away the DBM larvae and aphids feeding on the leaf surface, and the aphids.

Sex pheromones. Sex pheromones are chemicals produced by one sex of an insect, generally females, to attract the opposite sex, the males, for mating. These chemicals have been well exploited in pest management by developing trapping lures with the pheromone chemicals which can trap the adult insects, and

Table 1. Onion foliage damage rating and bulb yield under three irrigation treatments (AVRDC 1999)

Date (1997)	Foliage damage rating[a] for irrigation rate of: 1000 liters/ week	650 liters/ week	350 liters/ week	LSD (5%)
13 January	1.25	1.23	1.33	0.13
20 January	1.50	1.58	1.95	0.50
27 January	1.30	1.45	1.68	0.35
4 February	1.73	2.05	2.28	0.58
11 February	2.43	2.58	2.78	0.29
17 February[b]	2.10	2.25	2.40	0.50
24 February[b]	2.20	2.40	2.50	0.36
3 March	2.60	3.28	3.28	0.87
10 March	3.08	3.48	3.80	0.71
9 April: Yield (t/ha)	15.86	10.00	8.71	3.55

[a] Damage rating on scale of 0-5, where 0=no foliage damage, 1=20% damage, 2=40%, 3=60%, 4=80%, and 5=100% foliage damage

[b] Irrigation treatment suspended during rain showers Transplanting date was 21 November 1996

Table 2. Onion thrips damage to onion foliage under two irrigation/mulching treatments (AVRDC 1999)

Observation date	Damage rating[a] for irrigation rate/mulch treatment of				LSD (5%)
	1000 liters week		400 liters/ week		
	Straw	No Straw	Straw	No Straw	
1997					
26 December	0.82	0.90	0.92	1.00	0.16
1998					
2 January	0.88	1.03	1.13	1.20	0.21
9 January	1.43	1.77	1.67	1.83	0.22
16 January	1.73	2.17	2.10	2.37	0.31
23 January	2.52	2.93	3.03	3.10	0.58
30 January	2.40	2.87	2.88	3.03	0.41
6 February	2.80	3.00	2.95	3.03	0.24
13 February	2.87	3.17	3.10	3.27	0.26
20 February	3.20	3.48	3.40	3.53	0.17
27 February	3.50	3.68	3.58	3.96	0.71
6 March[b]	3.32	3.38	3.42	3.47	0.12

a On a scale of 0-5, where 0=no foliage damage, 1=20% damage, 2=40%, 3=60%, 4=80% and 5=100%
b Irrigation treatment suspended during heavy rain showers

thus preventing mating and subsequent population build-up. These chemicals are highly species-specific. For instance, use of pheromone traps in eggplant attracted large numbers of EFSB male moths when traps were baited with 100:1 proportion of (E)-11-hexadecenyl acetate to (E)-11-hexadecen-1-ol (Alam *et al*. 2003). However, care should be taken while using the pheromone traps if the insect pest is polyphagous in nature, like tomato fruitworm (TFW), *Helicoverpa armigera*, because, in areas where multiple cropping is followed, the immigration of mated insects from the nontarget crop to the treated crop will make the use of sex pheromone for TFW control almost impractical (AVRDC 1990a).

Biological control. The natural enemies like parasitoids, predators and pathogens can be used to control the insect pests in vegetable production systems. The insect pathogenic bacteria, *Bacillus thuringiensis* can effectively be used in the control of several insects like DBM, imported cabbage worm, *Pieris rapae* (AVRDC 1990c) and TFW (AVRDC 1990b). Entomo-pathogenic fungi like *Beauveria bassiana* and *Metarhizium anisopliae* have been proved to be more effective in controlling TFW (AVRDC 1992) and DBM (1999), respectively. A new nuclear polyhedrosis virus (NPV) infecting the legume pod borer, *Maruca vitrata* has been identified and being characterized by AVRDC (Srinivasan *et al.* 2005). The egg parasitoids like *Trichogramma chilonis* could effectively be used to control the TFW (AVRDC 1992). The larval parasitoids like *Diadegma semiclausum* and *Cotesia plutellae* and the pupal parasitoid, *Diadromus collaris* have been successfully introduced and used in the management of DBM in tropical lowlands as well as highlands of Asia and Africa due to the sustained efforts made at AVRDC for more than two decades since 1983. A larval parasitoid of EFSB, *Trathala flavo-orbitalis*, is present in many countries in South Asia and also in Thailand. Wherever pesticides are used sparingly, the activity of the parasitoid is restored, which helps in EFSB control (Alam *et al.* 2003).

INTEGRATED DISEASE MANAGEMENT

Strategic research on integrated disease management includes breeding for disease resistance, grafting on resistant rootstocks and other cultural practices.

Breeding for Durable and Multiple Disease Resistance

Planting materials with good resistance to diseases is the simplest control method for farmers. Therefore, it has been AVRDC's main focus to improve varieties of important vegetables like tomato with durable and multiple disease resistance. Our research work on tomato breeding is used as example below to highlight our strategies.

Pathogen variation and durability of resistance. Multi-location testing is a common method to evaluate the durability of disease resistance. In the evaluation of a set of 20 tomato varieties derived from different resistance sources to bacterial wilt in four Southeast Asian countries, the location effect was found to be highly significant (Table 3; Hanson *et al.* 1996). Results also clearly showed that certain resistance sources contributed to better durability. The same strategy was used to identify Hawaii 7996 to be the most durable resistance source by testing 36 resistant tomato entries in 12 locations worldwide (Wang *et al.* 1998). The different performance of resistant varieties over location or over time could be due to the presence of different pathogen strains. Large variations have been observed in *Ralstonia solanacearum*, *Phytophthora infestans*, or whitefly transmitted geminiviruses (WTG). Thus, it is important to continue monitoring the pathogen population to understand the distribution of variable strains and to select proper strains for resistance screening. For example, characterizing a population of 42 strains, the large variation in aggressiveness was observed in *R. solanacearum* (Fig. 1; Jaunet and Wang 1999). Using strains from each aggressiveness group to characterize different resistance sources, we confirmed Hawaii 7996 was one of the most durable resistance sources (AVRDC 2001). With continued monitoring, we have identified a major population shift of *P. infestans* in Taiwan (Table 4; AVRDC 2004). Strains isolated after 1998 were found to be more aggressive and many of the reported resistance sources could not provide resistance to these new populations. WTG consisted of diverse strains causing different symptoms on tomato and other hosts (Green and Kalloo 1994). New strains of WTG continued to be reported, but several wild tomato accessions were found to provide durable resistance to diverse strains based on multi-location testing in six countries (Table 5; AVRDC 2000b).

Pyramiding resistance genes for durable and multiple resistance. Pyramiding resistance to many pathogens or different strains of the same pathogen is a goal of our breeding effort. AVRDC tomato lines commonly carry resistance to tomato mosaic virus, fusarium wilt, gray leaf spot, and bacterial wilt. For example, in collaboration with Indian partners, three tomato

Table 3. Mean square (MS) from the combined analysis of variance and contrasts of tomato entries evaluated for bacterial wilt reaction in southeast Asia

Source of variation	df	MS
Survival[z]		
Locations	4	33260.3**
Entries	19	1652.9**
Location x entries	76	226.3**
Contrasts		
#1 CRA 66-derived (70.1)[y] vs. PI 129080-derived (53.2)	1	7613.4**
#2 L285 (83.8) vs CRA (70.1)	1	430.5[NS]
#3 AVRDC: 1970s (45.7) vs 1980s (59.4)	1	3507.5**

[z] Data were transformed to the arcsin of the square root for analysis.
[y] Number in parentheses is the group mean for percent survival.
[NS], ** Nonsignificant or significant at P=0.01, respectively.
(Source: Hanson *et al.* 1996)

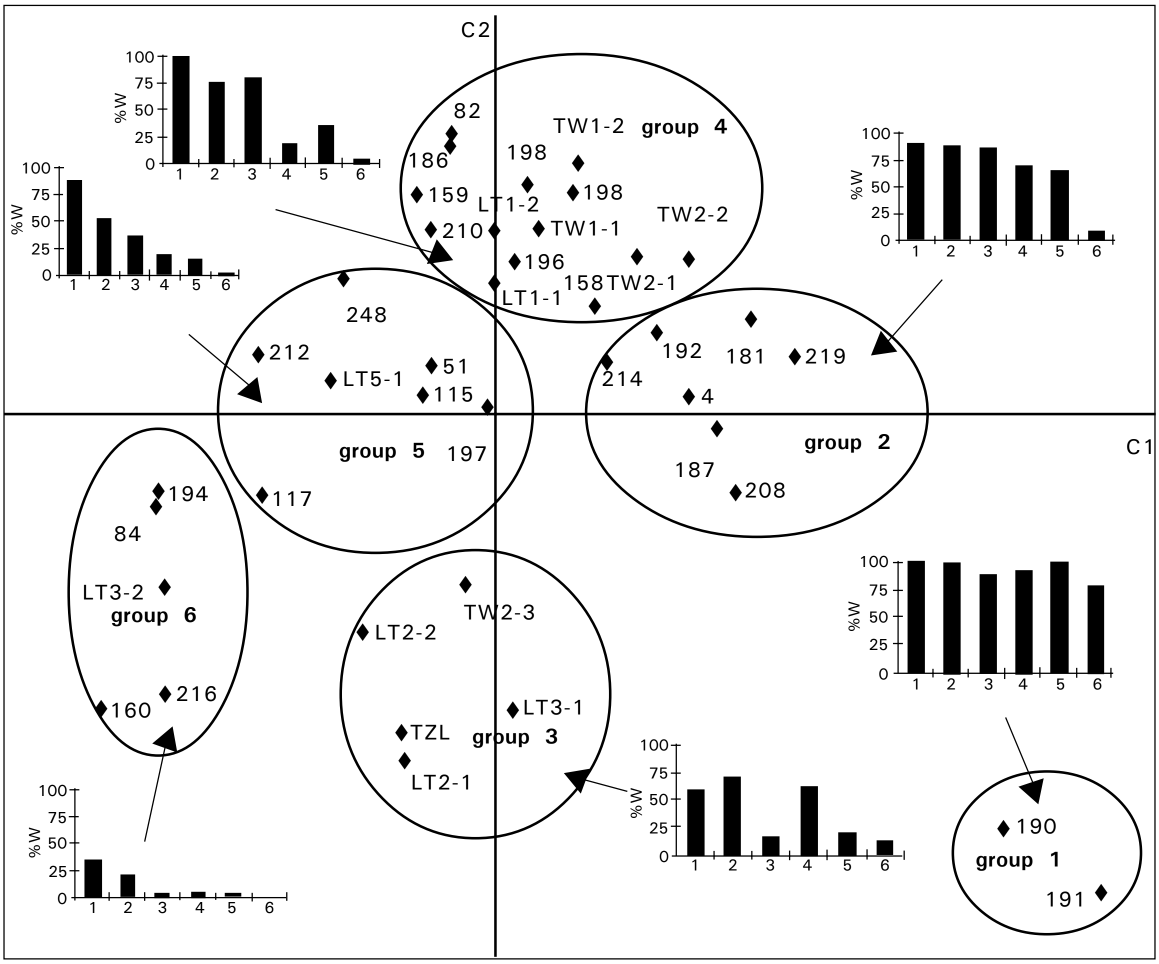


Fig. 1. Results of the principal component and cluster analysis on final percent wilting after inoculation of six tomato cultivars with 40 strians of *R. solanacearum* isolated from tomato in Taiwan. Projection of points corresponding to the strain int he plane defined with the two first components (C1*C2). Each aggressiveness group is characterized by a histogram of final percent wilting (%W) on six cultivares: 1=L 390, 2=Rodade, 3=CRA 66, 4=CLN 1463, 5=L 180-1, 6=Hawaii 7996. Histograms were constructed from average percent wilting from all strains within groups.
(Source: Jaunet and Wang 1999)

Table 4. The phenotype and genotype characteristics of *Phytophthora infestans* isolates collected in Taiwan during 1991-2003

Year	No. of isolates collected	Metalaxyl (100 ppm)		RG57[1]	
		Sensitive	Resistant	US-1	US-11
1991-1997	30	30	0	17	0
1998	33	6	27	2	5
1999	24	1	23	1	22
2000	36	0	36	0	36
2001	60	0	60	0	57
2002	58	0	58	1	57
2003	101	1	100	1	99

[1]DNA fingerprint analysis using the RG57 probe.
Source: modified from AVRDC 2004

Table 5. Summary of reactions of selected tomato entries against local whitefly transmitted geminiviruses in Bangladesh, India, Pakistan, Taiwan, Thailand and USA.

Line	Origin	Disease reaction[1]					
		TLCV Taiwan	TYLCV-Ban[2] India	TYLCV[3] Bangladesh	TYLCV[4] Pakistan	TYLCV[5] Thailand	ToMoV[6] USA
L. e. TY 52 (Ty1)	Israel	(S)	(S)	R→(MS)	(S)		S
L. e. H 24 (Ty2)	India	R	R	HR→R	HR	(MS)→S	S
L. *hirs.* LA1777	Israel	R	HR	HR→(R)	HR	HR→(R)	R
L. *per.* VL 215	France	HR	HR	HR	HR	(R)→(MR)	(S)
L. *chil.* LA 1969	USA	HR	HR	HR	HR	(R)	R
L. *chil.* LA 1932	USA	HR			HR	(R)	R
L. e. FL 744-6-9	USA	R	R	R→(MR)	(S)	(S)	(MS)
L. e. FL 736	USA	S	S	R→S	S	S	(MS)
L. e. FL 699	USA	HR	R	HR→(MR)	S	S	(MS)
L. e. FL 776	USA	MR	S	HR→(MS)	S	S	(MS)
L. e. FL 805	USA	MR	MS		NT	S	MR
L. e. FL 505	USA	R	HR	R→(S)	S	S	(S)
L.e. TK70 (S.CK)	Taiwan	S	S	S	S	S	S

[1] HR = highly resistant: 0% infection, negative hybridization test; R = resistant: 1-20% infection; MR = moderately resistant: 21-50% infection; MS = moderately susceptible: 51-75% infection; S = susceptible; 76-100% infection; ( ) = mild to moderate symptoms. [2]Data provided by Dr. V. Muniyappa, University of Agricultural Sciences, Bangalore, India; [3]H. Rashid, Bangladesh Agriculture Research Institute. [4]Dr. Saif Khalid, National Agricultural Research Centre, Islamabad, Pakistan; [5]Ms. K. Kruapan, Department of Agriculture, Dr. P. Chiemsombat, Kasetsart University, Kamphaengsaen, and Limagrain Vegetable Seeds Asia, Thailand; [6]and Dr. J.W. Scott, University of Florida, USA.
(Source: modified from AVRDC 2000a)

inbred lines were developed to have resistance to local WTG strains as well as bacterial wilt (Muniyappa *et al.* 2002). To increase pyramiding efficiency, molecular markers linked to *Ty2* was mapped (Hanson *et al.* 2000) and developed for marker-assisted selection. Mapping and marker development projects for tomato bacterial wilt and pepper anthracnose, among other things, are ongoing at AVRDC.

Grafting on Resistant Rootstocks to Control Tomato Bacterial Wilt and Other Soil-borne Diseases

When durable resistant varieties with good horticultural traits are not present, grafting on resistant rootstock becomes an attractive alternative to manage soil-borne diseases. For example, tomato or eggplant varieties with durable resistance to bacterial wilt can be used as rootstock (AVRDC 1999). The control efficacy of grafting depends on the degree of resistance present in both rootstock and scion (Table 6). The additional advantages of using eggplant rootstock include their tolerance to waterlogging condition and to tomato fusarium wilt. High incidence of blossom-end rot, delayed early development or smaller fruit size has been observed on tomato plants grafted with eggplant. However, soluble solid (Brix) was higher in our tested combinations, which could be a special feature attracting consumers.

Cultural Practices to Suppress Soil-borne Pathogen Density

Soil-borne pathogens like *R. solanacearum* are difficult to eradicate, once they are introduced into planting plots. However, the pathogen density can be suppressed by many cultural practices. When the pathogen density is low, the performance of resistant varieties can be more durable as well. For large-scale production, fumigants like methyl bromide are commonly used to control soil-borne pests and weeds. However, such an application is not economical and practical for small-scale vegetable farmers in developing countries. Moreover, its use will be phased out in many countries. Cultural practices that can suppress pathogen density include rotation with non-host crop, flooding, intercropping and applying soil amendment. Our studies showed that the density of *R. solanacearum* significantly

Table 6. Reaction to bacterial wilt on different grafting combinations between tomato lines with different resistance levels to bacterial wilt in the greenhouse

Rootstock		Scion		Wilt rate (%)[a]
BL986	R	BL986	R	3.3 e
BL986	R	FMTT22	MR	10.0 de
BL986	R	KY301	S	26.7 d
FMTT22	MR	BL986	R	66.7 c
FMTT22	MR	FMTT22	MR	76.7 bc
FMTT22	MR	KY301	S	93.3 ab
KY301	S	BL986	R	93.3 ab
KY301	S	FMTT22	MR	100.0 a
KY301	S	KY301	S	100.0 a

[a] Percentage of wilted plants 35 days after inoculation.
S = susceptible; MR = moderately resistant; R = resistant.
Data analysis was conducted using the Arc Sine transformed data. Means followed by the same letter do not differ significantly at $P<0.05$ (by Duncan's Multiple Range Test).
(Source: AVRDC 1999)

declined when the previous crops were non-host or were left to fallow, and the incidence of tomato bacterial wilt was correlated with the remaining pathogen amount (Michel *et al.* 1997). The efficacy of different cultural practices may differ over locations. For example, a soil amendment consisting of urea and calcium oxide was shown to be location-specific (Michel *et al.* 1996). Therefore, an integrated approach should be taken.

Online Information for Disease Diagnosis and Management

Proper disease diagnosis is the first step in disease management. However, lack of trained persons and information are common in developing countries. In response to this situation, AVRDC has designed a learning center in our homepage (http://www.avrdc.org/LC/home.html). The center is a collection of online books, bulletins, fact sheets and tutorials. Information on production, including disease diagnosis and management recommendation for selected vegetables, is compiled and can be downloaded from this Website.

INTEGRATED AND BALANCED FERTILIZATION FOR FRUIT AND LEAFY VEGETABLES

For the past ten years, the AVRDC Crop and Ecosystem Management Unit has been conducting studies on integrated and balanced fertilization for fruit and leafy vegetables. The major objectives are to increase fertilizer use efficiency and reduce nutrient loss through leaching into groundwater. Furthermore, balanced fertilization ensures optimum plant nutrient uptake thereby reducing accumulation on plant tissues at levels that may be harmful for human consumption. To address this issue, studies on the use of liquid and solid nutrient supplements to enhance efficacy of organic fertilizers were conducted on tomato, pepper and leafy vegetables. Later, studies also investigated on reducing fertilizer needs of vegetables through the use of composts and starter solution. To address the problem of nitrate accumulation on leafy vegetables, AVRDC developed an in situ nitrogen (N) monitoring technology for safe (low-nitrate) vegetable production.

Starter Fertilizer Solution Technology

In vegetable production systems, high application rates of chemical fertilizers result in inefficient use of nutrients and contribute to environmental risk due to soil and water contamination with fertilizer residues. Since most vegetable crops have short growing period, high fertilizer application rates are used to boost early growth and yield. Promotion of balanced fertilization using a combination of organic and inorganic sources may improve crop production leading to increased sustainability and profitability (Pinstrup-

Andersen and Rajul 1998; Steen 1995). Adequate application of NPK (nitrogen, phosphorus and potassium) fertilizers in soil solution from planting to harvesting is important for sustaining high yields. Research studies were conducted at AVRDC to develop a starter fertilizer solution technology for enhancing the early growth and overall yield of selected vegetable crops (AVRDC 2003; 2004).

Results from an incubation study showed the application of a starter solution enhanced nutrient release from chicken manure-amended soils (Ma and Kalb 2004). The starter solution brought the inorganic N level of such soils from 9.3 to 25 ppm, which became critical for a plant's initial establishment. The fertilizer effects on cabbage, cherry tomato, and sweet pepper using basal organic fertilizer supplemented with small amounts of concentrated liquid fertilizer solution at the early growth stages were studied. The initial growth of cherry tomato and sweet pepper was significantly enhanced by one starter solution application compared with those crops grown using either inorganic or organic fertilization practices alone (Table 7; Ma and Kalb 2004). Overall, the positive effects of the starter solution application on initial plant growth were evident. The starter solution could substitute for 30-50% of inorganic fertilizer and 50% of organic fertilizer used during the cropping season. These studies have developed efficient fertilization practices that can be used in developing countries, where fertilizers are especially costly for farmers. The technology is a low-input, soil-based approach, which can be applied to situations where excessive fertilizer use is common.

Table 7. The effects of starter solution applied with organic manures or inorganic fertilizers on the growth and yields of selected vegetables. (Ma and Kalb 2004)

Fertilizer treatment	Crop	Initial growth[1]: Top dry weight (g/plant)	Initial growth[1]: Root dry weight (g/plant)	Head or fruit yields (t/ha)
CM*2[2]	Cabbage	2.4 c[5]	0.21 b	30.1 b
CM+$St4_0$+St-12 DAT		3.9 a	0.29 a	34.4 a
CM+1/2 SI		3.1 b	0.24 b	27.2 b
Standard inorganic(SI)[3]		3.2 b	0.26 ab	26.3 b
CM[2]	Cherry tomato	11.1 b	0.67 b	38.6 b
CM+$St5_0$+Side[4] 63 DAT		17.1 a	0.85 a	48.1 a
CM+$St5_0$+St-21,63 DAT		15.6 a	0.82 a	47.7 a
Standard inorganic (SI)[3]		10.7 b	0.58 b	40.1 b
CM[2]	Sweet pepper	1.6 b	0.30 bc	32.6 b
CM+$St4_0$+St-12,25,36,88 DAT DAT		3.2 a	0.38 ab	35.5 ab
SI + $St4_0$		3.5 a	0.40 a	43.6 a
Standard inorganic (SI)[3]		1.7 b	0.28 c	33.9 b
CM[2]	Chili pepper	7.2 b	0.73 c	13.8 ab
CM+$St4_0$+St-12,25,36,72 DAT		11.3 a	1.03 b	16.6 a
SI+$St4_0$		14.2 a	1.29 a	14.7 ab
Standard inorganic (SI)[3]		7.2 b	0.74 c	13.4 b

[1]Surveys were made 12 DAT for cabbage, 21 DAT for tomato, and 16 and 25 DAT for sweet and chili peppers. DAT = days after transplanting.

[2]Chicken manure composts (CM) applied equivalent to 2x and 1x of N applied as inorganic solid fertilizer (i.e., 22.3 and 11.2 t/ha of CM*2 and CM for cabbage, 14 t/ha CM for cherry tomato and sweet pepper and 10.4 t/ha for chili pepper, respectively)

[3]Standard inorganic fertilizer (SI) consisted of a basal application of 60N–39P–50K kg/ha and side-dressings of 60N–0P–33K kg/ha at 12, 25 and 36 DAT for cabbage; basal application of 90N–39P–75K kg/ha, side-dressings of 60N–26P–50K kg/ha at 21 and 63 DAT; and 60N kg/ha at 42 and 84 DAT for cherry tomato; basal application of 80N–41P–75K kg/ha and 40N–4P–17K kg/ha at 12, 25, 36 and 50 DAT; 30N–3P–13K kg/ha at 72 and 96 DAT for sweet pepper and chili pepper, respectively.

[4]Side = side-dressing; applied as 60N–26P–50K kg/ha solid inorganic fertilizer at 63 DAT.

[5]Mean separation within columns by Duncan's Multiple Range Test, $P \leq 0.05$.

In 2003 and 2004, studies were conducted to develop the starter solution technology for chili pepper production. Results in 2003 indicated that the additional application of liquid starter solutions with either chicken manure or pig manure significantly boosted early plant growth compared with plants fertilized with chicken or pig manure alone, or with standard inorganic fertilizer (Table 8; Ma *et al.* 2005). Plots with organic fertilizers sustained higher yields (19-26%) longer into the harvest season compared with plots with inorganic fertilizers. In 2004, organically fertilized plots with starter solutions applied at early stages and solid fertilizers side-dressed at critical times yielded 6-10% higher than pig manure alone (Ma *et al.* 2005) These studies showed the potential of starter fertilizer solution technology in improving the yield of chili pepper. A small amount of inorganic fertilizer solution applied as a starter may build up high nutrient gradients in soil solution proving young plants with readily available nutrients before root development, thus, enhancing initial growth. Inorganic fertilizer solution also promotes the release of nutrients from organic fertilizers and composts.

In Situ N Monitoring for Safe Leafy Vegetable Production

Intensive cultivation of leafy vegetables is common in peri-urban areas. In this production system, high levels of N fertilizer are generally used creating a risk of harmful nitrate levels as well as environmental pollution cased by leaching of nitrates into groundwater supplies. Improved N management technologies are needed to produce safe leafy vegetables grown in protected structures or open fields. The methods for determining nitrate levels in plant tissue and for assessing potential available N in soil have been well established in laboratories. However, most methods of analysis take few days to obtain results. Recent advances in soil and plant N testing (e.g., the pre-side-dress soil nitrate test (PSNT), Cardy nitrate meter determination and leaf chlorophyll meter reading (LCMR) systems) provide opportunities for more efficient use of fertilizers and manure. A study on LCMR showed extremely rapid, in-situ measurement of leaf "greenness" which was as accurate as the PSNT in identifying N-sufficient sites.

Table 8. Effects of starter solution and fertilizer treatment on the initial growth and yield of chili pepper, autumn, 2003. (Ma *et al.* 2005)

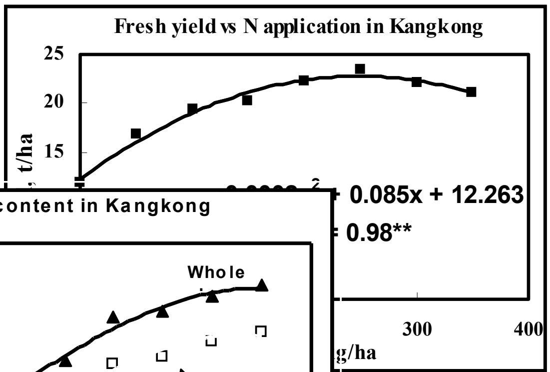
Fertilizer treatment	Starter sol'n application[y]	Above ground biomass (g/plant) Dry weight (25 DAT)	Index	Marketable fruit yield (t/ha) Harvests 1-6	Index
2CM[x]	—-	4.1f	56	12.7b	95
CM	—-	7.2e	100	13.8ab	103
CM + ST_0	LF_4	11.3bc	157	15.0ab	112
CM + ST_0 + ST_1 + ST_2 + ST_3 + ST_5	LF_4	9.6cd	134	16.6a	124
— + ST_0 + ST_1 + ST_2 + ST_3 + ST_5	LF_4	8.2de	114	15.8ab	118
CM + ST_0 + $Side_1$	LF_4	11.3bc	157	15.5ab	115
CM + ST_0 + $Side_{1,3}$	LF_4	12.2 ab	169	16.8 a	126
SI + ST_0	LF_4	14.2 a	197	14.7 ab	109
Standard inorganic (SI)[w]	—-	7.2 e	100	13.4 b	100

[x]Composted chicken manure (CM) applications were equivalent to 2x and 1x the rate of N applied as inorganic solid fertilizer (20.8 and 10.4 t/ha of CM)

[y]Starter solution (ST) was liquid compound fertilizer # 4 (LF_4,N-P_2O_5-K_2O=6%-12%-6%), diluted and applied at a rate of 240-480-240 mg of N-P_2O_5-K_2O in 50 ml water per plant (equivalent to 7.1-14.2-7.1 kg/ha N-P_2O_5-K_2O) for one application after transplanting (ST_0) and at 12, 25, 36 and 72 DAT(1st, 2nd, 3rd and 5th times of side-dressing, ST_1,ST_2 ST_3 and ST_5)

[w]Standard inorganic fertilizer (SI) comprised a basal application of N-P_2O_5-K_2O, 80-95-90 kg/ha, and 4 times side-dressing of N-P_2O_5-K_2O, 40-10-20 kg/ha at 12, 25, 36 and 50 days after transplanting and N-P_2O_5-K_2O, 30-7.5-15 kg/ha at 72 DAT and after 2^{nd} harvest.

Studies were conducted at AVRDC to develop rapid, low-cost, and non-destructive N diagnostic technologies for safe leafy vegetable production and to develop guidelines for GAPs for leafy vegetables in intensive rotation systems. Five leafy vegetables including amaranth (*Amaranthus tricolor*), kangkong (*Ipomoea aquatica*), Ethiopian kale (*Brassica carinata*), Choysum (*Brassica campestris* ssp. Parachinensis), and leafy lettuce (*Lactuca sativa*) were grown on raised beds in 32-mesh nethouse in randomized block design with four replications. The crops were fertilized with eight N levels: 0, 50, 100, 150, 200, 250, 300 and 350 kg/ha in three splits. At harvest, nitrate contents were determined in tissue sap of fully expanded leaf blades, petioles and whole plant using a Cardy nitrate meter. Chlorphyll content readings were also measured on the same leaf using a chlorophyll meter. Results showed that nitrate accumulations varied with vegetable species. Significant correlations existed between N fertilizer rate and nitrate content as well as chlorophyll and yield. Using N application rate of 200 kg/ha, nitrate accumulation in Ethiopian kale was highest (7,000 ppm), followed by kangkong (4,000 ppm), amaranth (3,500 ppm) and leafy lettuce (1,200 ppm). Figures 2a-d show this response in kangkong as an example. The correlation between leafy chlorophyll meter reading (LCMR) and nitrate content was also significant suggesting the feasibility of using Cardy nitrate meter test and LCMR for monitoring production of low-nitrate and safe vegetables. The Cardy meter was also sensitive in detecting soil nitrate-N below 20 ppm and is a rapid and reliable alternative to conventional distillation method (Ma and Palada 2005).



kangkong to
itrogen.

Fig. 2b. Relationship between nitrogen and leaf chlorophyll in kangkong.

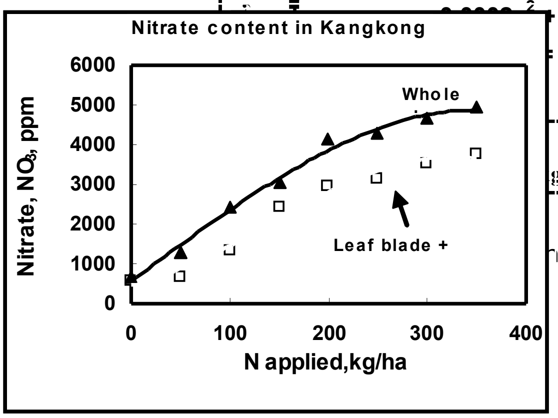


Fig. 2c. Nitrate-N content of kangkong leaves as influenced by nitrogen fertilizer rates.

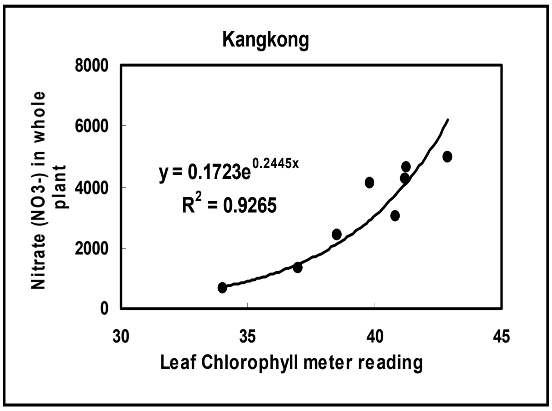


Fig. 2d. Relationship between nitrate-N and leaf chlorophyll in kangkong

Reference: Ma, C.H. and M.C. Palada. 2005. In-situ N monitoring for safe leafy vegetables using quick and advanced tools. HortScience 40:1074 (abstract).

IMPROVED WATER AND FERTILIZER USE EFFICIENCY IN VEGETABLES THROUGH DRIP IRRIGATION

Irrigation water and fertilizer application are standard management practices for vegetable production in developed countries, including Taiwan, as well as in developing countries where water and fertilizer are not limiting. Given these conditions, most farmers have the tendency to apply water and fertilizer at maximum levels, decreasing the economic efficiency of these resources. Excessive fertilizer application also leads to environmental pollution and degradation due to leaching of nutrients to waterways and underground water. Global climatic changes result in either scarcity of water (drought) or excess water (flood). Water is increasingly becoming a scarce resource even in the humid tropics. The situation is worse during the dry season in most of the developing countries. With this scarce resource, there is a need to develop technologies that promote efficient use of water and fertilizers in vegetable production. AVRDC has initiated a project on drip irrigation to address this problem. Compared with furrow irrigation, drip irrigation uses less water, improves yield and quality of vegetables, promotes efficient use of fertilizers and reduces the risk of groundwater contamination. Although drip irrigation of vegetables has been studied extensively and much literature is available elsewhere, studies on drip irrigation water requirement for most vegetables in the tropics during the wet and dry seasons are few.

Studies were conducted at AVRDC to 1) develop and adapt micro-irrigation technologies for year-round vegetable production; and 2) compare water and fertilizer use efficiencies of vegetables under furrow and drip irrigation systems. Vegetable crops including tomato, cucumber, chili pepper, cabbage, yardlong bean and pak choi were grown on raised beds and irrigated using furrow and drip irrigation. Each crop was fertilized with NPK based on AVRDC fertilizer recommendation. However, drip-irrigated crops received half of the total rate applied for furrow-irrigated crop. Results showed that yield and nutrient uptake varied with vegetable crops, but in general, water use by vegetable crops was reduced considerably under drip irrigation (Table 9; Palada and Wu 2005). Water use in drip irrigation was 45-77% less than in furrow irrigation and yields achieved under drip irrigation were almost similar or better than yields under furrow irrigation. Furthermore, nutrient uptake was more efficient in drip-irrigated vegetables (Palada and Wu 2005).

Table 9. Water use and total fertilizer applied in six vegetable crops grown under drip and furrow irrigation during hot-wet and hot-dry season, 2004. Data are means of three rainshelters (Palada and Wu 2005).

Crop	Irrigation	Irrigation water use (liters/plant)	Drip water use efficiency (WUE) (%)	Fertilizer applied N-P_2O_5-K_2O (kg/ha)
Tomato	Drip	29.7	52.5	180
	Furrow	62.5	-	360
Cucumber	Drip	34.1	45.4	240
	Furrow	62.5	-	420
Chili pepper	Drip	39.3	60.7	219
	Furrow	100	-	420
Cabbage	Drip	24.4	72.1	99
	Furrow	87.5	-	180
Yardlong bean	Drip	24.7	75.3	90
	Furrow	100.0	-	180
Pak choi	Drip	1.1	61.7	18
	Furrow	2.9	-	46

DEVELOPMENT PROJECTS ON GAP AT AVRDC FOR TECHNOLOGY DISSEMINATION

Without proper dissemination, the developed GAP technologies would not reach farmers and adapt them in their farming system. Specific efforts have been made to disseminate the technology AVRDC has developed. AVRDC has ongoing development projects that promote good agricultural practices. These projects include 1) sustainable development of peri-urban agriculture for Southeast Asia (SUSPER); 2) IPM of eggplant fruit and shoot borer in South Asia; and 3) integrated disease management (IDM) of tomato bacterial wilt in Taiwan.

Sustainable Development of Peri-urban Agriculture (SUSPER)

The world's population is projected to increase to more than 8 billion by 2025. Much of this growth will take place in urban areas, whose population will double to 3.4 billion. This wave of population growth is creating unprecedented pressures on the environment and infrastructure in cities. Safe and affordable food must be available year-round to these fast-growing urban centers. AVRDC is responding to this challenge through its peri-urban vegetable research programs in major Southeast Asian cities including Manila, Phnom Penh, Vientiane and Hanoi. AVRDC is introducing technologies for safe vegetable production as top priority. Innovative technologies, such as insect barriers and pheromone traps, are reducing the need to spray insecticides. This strategy, verified in tests by farmers, produces safe vegetables with little or no pesticide use. Disease-resistant varieties are a natural means to fight diseases. Organic fertilization strategies are also being used to improve soil and reduce the dependence on chemical fertilizers (AVRDC 2002; 2004). Farmers benefit from reliable yields and consumers enjoy the assurance they are eating safe food.

IPM of Eggplant Fruit and Shoot Borer in South Asia

Eggplant fruit and shoot borer is the most serious and destructive pest of eggplant in Asia and Africa. It is common for farmers to spray their crop 80 or more times to combat the pest. Moreover, farmers use inappropriate and unapproved pesticides. With the support of the Department for International Development (DFID) from the United Kingdom, scientists at AVRDC and their counterparts in Bangladesh, India, Sri Lanka and Thailand have developed a simple IPM strategy. This approach involves clipping damaged shoots to remove larvae, using sex pheromones to trap moths and allowing natural predators to attack the borers. This method is now being extended to farmers throughout the region (Alam *et al.* 2003).

IDM of Tomato Bacterial Wilt in Taiwan

Farmer's knowledge, behavior and perception on disease management are important information to design a technology dissemination strategy and to identify future research directions. A study showed that tomato farmers in two villages in Taiwan were already practicing GAP (AVRDC 2004a). For example, 79-89% of farmers are already adapting crop rotation regularly. Most farmers take positive actions when seeing the disease, but some still apply pesticide despite its ineffectiveness (Table 10). When presented with different control methods, majority of farmers preferred planting resistant varieties with good fruit characters. Therefore, a host resistance-based integrated disease management would be most acceptable and sustainable.

NEW RESEARCH INITIATIVES

AVRDC is expanding its programs to new regions of the globe, and reaching out to a broader base of clientele. Some of the research initiatives closely related to good agricultural practices are organic vegetable production and soil health management.

Organic Vegetable Production

Millions of subsistence farmers do not purchase chemical inputs. These farmers can increase their crop yields if they were provided with information and training in science-based organic production techniques. An international

Table 10. Disease management practices followed by farmer-respondents in controlling tomato bacterial wilt on the current crop, Kuantian (KT) and Chiunglin (CL), Taiwan, fall 2002. (AVRDC 2004a)

Management methods	KT	CL
1. Remove diseased plants and bring them out from the plot	31.6	47.4
2. Water management (Reduce irrigation frequency or avoid water movement in diseased areas)	31.5	22.8
3. Spray or drench pesticides	14.7	12.3
4. Do nothing	11.6	10.5
5. Remove diseased plants and leave them in the plot	4.2	1.8

survey recently concluded that there is a lack of research in organic agriculture systems (Stoll 2003). Many of AVRDC's existing technologies are compatible with organic farming and can be integrated into improved organic vegetable production. The organic vegetable program will focus on components that solve problems specific to organic farming systems including sustainable soil management, disease-resistant cultivars and biological pest control methods (Palada *et al.* 2005).

Soil Health Management

Soil health can be defined as the capacity to sustain plant and animal productivity, maintain or enhance water/air quality and promote plant and animal health (van Bruggen and Semenov 2000). It is a good indicator for sustainability. Among the different soil components, soil biological component has been considered as a good indicator for soil health, as it contributes to many soil functions. With the development of better monitoring and identification methods for soil microorganisms and communities, more studies are looking into the relationship of microbial dynamics and disease suppressiveness (Garbera *et al.* 2004) and productivity (Webburn *et al.* 2004). We believe that it is an important research component for promoting sustainable production in the developing countries. The challenge would be on how to identify key research foci and translate theories and concepts into actual applications for the diverse vegetable production systems. AVRDC can play a role in identifying good soil management practices that are suitable for developing countries, while conducting strategic research in developing good and easy-to-measure indicators for soil health.

CONCLUSION

Providing improved varieties and other GAP technologies for national agricultural research systems (NARS) and private sectors is AVRDC's approach for enhancing productivity in developing countries. This is achieved through present and future research strategies on GAP for vegetable production. Emphasis is given on IPM, IDM, balanced fertilization and improved water and nutrient management for increased efficiency. The increased awareness on the sustainability of the agro-ecosystem and the safety of agricultural products by consumers and producers makes our tasks even more important.

To make research outcome actually used by farmers, several social and technical steps need to be made. First, the technology needs to be modified to fit local conditions. Second, farmers have to be convinced for accepting new technologies and concepts. It is often difficult to change farmers' behaviors. Thus, the joint-force of IARC, NARS and nongovernmental organizations in delivering GAP technologies is a must to disseminate GAP technology.

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