

Developing an Integrated Pest Management Program for Tomatoes in the Red River Delta of Vietnam: A mini review

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Abstract - Ecologically based approaches to pest management in crop production have been embraced in recent decades due to their validity and effectiveness. Integrated Pest Management (IPM) is not a new concept. It has been adopted in various regions in Vietnam, particularly in tomato production, an economically important vegetable crop in the Red River Delta (RRD). Given the occurrence and development of tomato pests are influenced by many factors such as soil types, crop varieties and growth habits, production practices, local climatic conditions, and growing seasons, this paper therefore developed an IPM program for tomatoes in the RRD based on the defined major pests in the region. Detailed factsheets for six major pests were developed and different components of the IPM were explored and employed for the ease of identification and management. Practical suggestions for tomato growers were also presented.

Keywords: Bio-control; Environmental impacts; Crop losses; Cultural Practice; Integrated pest management

Introduction

Tomato (*Lycopersicon esculentum* Mill.) (Solanaceae) is one of the most consumed and high value vegetable crops in the Red River Delta (RRD) of Vietnam. An expansion of cultivated area for the crop has been evident due to the recent market demands (Ha, 2015, Wijk and Everaarts, 2007). As a common issue associated with conventional production practices in vegetable crops, tomato growers in the RRD have experienced significant crop losses due to pest damages (Pham et al., 2002). Over reliance on chemical pesticides (10 – 12 times/plant life cycle) has induced pesticide resistance, destruction of natural enemies (Tran et al., 2008) and many other unintended consequences such as economic loss, food poisoning, negative environmental and human health effects (Ha, 2011, Ha, 2014e, Ha, 2014d, Ha, 2014c). Additionally, recent market demands in terms of clean horticultural produce have been in an increasing trend in Vietnam (Ha, 2014b, Ha et al., 2015). Therefore, adoption of the more eco-friendly production practices is required to address the issues and public concerns (Ha and Nguyen, 2013, Ha, 2014a).

Integrated Pest Management (IPM) has been widely adopted around the world as a rational strategy to manage pests in crop cultivation (Ha, 2014e). The IPM is defined as “a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner” (Prokopy, 2003). Although an IPM for tomatoes has been developed as the general guideline for sustainable production, tomato pest problems are affected by various factors such as soil types, local climate, planting and harvesting dates, etc. (Strand and Flint, 1998). Therefore, development of an IPM program for tomatoes in the RRD is important for extension workers to help local producers address the context-specific pests.

In the previous study (Ha, 2015), agronomic requirements and cultivation methods for tomatoes in the RRD have been presented as a general guide for tomato growers to produce healthy crops. In which, six major detrimental pests have been identified to provide background information for the detailed contents being discussed in this paper (Table 1). The objective of this paper is therefore to develop a comprehensive IPM program for tomatoes in the selected area.

Identification of Major Pests and Pest Fact Sheets

The following pests have been reported as the most common ones on tomato crops in the RRD and other regions of Vietnam (Ha, 2015). Details of factsheets of the pests and their respective management strategies are described in Appendix 2.

Table 1. Major pests, diseases and weeds on tomato crops in the RRD (Source: Ha, 2015) .

Pest groups	Common & botanical names	Names in Vietnamese	Authors reported
1. Insects	1.1. Silver-leaf Whitefly (<i>Bemisia tabaci</i>)	Ruồi trắng lá bạc	UK (1999), Tran (2005)
	1.2. Vegetable leaf miner (<i>Liriomyza sativae</i> Blanchard)	Ruồi đục lá	Hofsvanget <i>al.</i> (2005), Tran (2005)
2. Diseases	2.1. Tomato early blight (<i>Alternaria solani</i>)	Bệnh tàn lụi sớm cây cà chua	Tran (2005), Nguyen (2008)
	2.2. Tomato yellow leaf curl (pathogen: tomato yellow leaf curl virus) (a geminivirus of the family Geminiviridae).	Bệnh vàng xoắn lá cà chua	Tran (2005), Nguyen (2008)
3. Weeds	3.1. Billy-goat weed, Chick weed, Goatweed, Whiteweed (<i>Ageratum conyzoides</i> L.)	Cây hoa cúc lợn	ACIAR (2008), Burgresset <i>al.</i> (2008)
	3.2. Spiny amaranth (<i>Amaranthus spinosus</i> L.)	Đền gai	ACIAR (2008)

The IPM Program for Tomatoes

As the nature of the IPM itself, the word “integrated” means a coordination of different methods in managing pests to lessen their populations to acceptable levels (Galea, 2010). In fact, eradication of the major pests is unfeasible since it is costly (Galea, 2010, VCE, 2005). Meanwhile, previous studies have revealed many reverse impacts of the overuse and sole application of chemical pesticides in irradiating major pests, which resulted in various unintended consequences such as environmental contamination, human health effects (Pimentel, 2009, Ha, 2014e), resurgence of primary pests and outbreaks of secondary pests as the result of natural enemy destruction (Ciancio and Mukerji, 2007).

Many studies have recently demonstrated the effectiveness of the IPM for tomatoes where different components have been utilized. Those include cultural methods (Baysal *et al.*, 2009), bio-control (Jacobson, 2008, Kay and Hall, 1998), physical techniques (Jacobson, 2008, Chellemi *et al.*, 1997), host plant resistance (Eigenbrode, 2007), interference techniques (Trumble and Alvaradorodriguez, 1993) and chemical measures (Baysal *et al.*, 2009, Kay and Hall, 1998). Khaderkhan *et al.* (1998) found that adoption of the IPM could reduce pesticide use remarkably from 17 to 8 times per season. Furthermore, tomato yield increased by 26% and thus higher income for tomato producers.

Therefore, to address pest damages on tomato crops in the RRD, particularly the six aforementioned major pests, different IPM components should be employed appropriately. These would help to bring about higher product quality, a more sustainable production system and consequently higher economic returns for the local growers. In addition, the approach could minimize negative environmental and human health effects. Understanding of the pests’ biology, ecology and their interactions are of crucial importance in developing an IPM program (Galea, 2010). In this sense, different techniques below, which utilize all available resources, are based on these facets to reduce pest population to a threshold where minimal chemical inputs are required.

Preparation Prior to Planting

It is important for crop advisors and/or extension workers to provide local tomato growers with a checklist of items to be checked and prepared before planting. This can be used as a reminder and a helpful guide for the ease of practice (see Appendix 1 for details).

Pest management During the Cultivation Period

Monitoring and sampling: checking crop status is advised on regular basis for early identification of insect, disease and weed development on the crop. Decisions on whether manual removals of infested plants and weeds or application of chemical pesticides are made according to levels pest development in the field. Besides the traditional random sampling of pests on leaves (Annex 2), yellow sticky traps can also be used to monitor insect occurrence levels. For example, 10 adults per trap per week is the action threshold to suppress silver-leaf whiteflies (Subramaniam and Barro, 2006) (see Appendix 2 for details).

Timing: based on the biology of each pest and its occurrence and/or conditions for development, timing of its infestation is essential to define proper interventions. For instance, during a prolonged rainy period with high humidity, particularly in summer and early autumn in the RRD, early blight is likely to develop. Registered fungicides should be applied if the disease appears. In addition, monitoring helps farmer to know what types of weeds are present (Bloem and Mizell, 2009) and therefore timing of the weed emergence is necessary to schedule management methods such as manual weeding, chipping or applying herbicides.

Cultural practice: Inter-planting or using bait crops would be useful to make a complex environment, assisting better pest management (Galea, 2010). To reduce crop damages caused by Silver-leaf Whiteflies (SLW), tomatoes can be intercropped with capsicum or cucumber (FED, 2009b). Bait plants such as squash should be used to attract the SLW (Antignus, 2007).

Rotation can also be an effective method to modify the environment which is unfavourable to pests. Hoi (2002, cited in Tran, 2005) reported that rotation between paddy rice and tomatoes could significantly reduce pest damages. Additionally, fertilizers should be applied adequately according to guidelines since unbalanced fertilizers or an excessive input of Nitrogen engenders unhealthy plants which are susceptible to pests.

Mulching techniques by using straw or plastic materials is useful to control both weeds and fungus development, especially *A. solani*, from the soil. Moreover, reflective plastic mulch can be used to prevent landing insects (Galea, 2010). Bloem and Mizell (2009) asserted that using reflective plastic covers could reduce population of the SLW by 50%. Overuse of irrigation water should be avoided to reduce the possible occurrence of early blight disease, while drip irrigation is preferable (Bloem and Mizell, 2009).

Mechanical measures: trapping insects can be physically eliminate insects from tomato crops (Galea, 2010). Yellow sticky traps can be used to control the SLW and vegetable leaf-miner (FED, 2009b, Capinera, 2007). This is particularly beneficial in protected environments. However, in the open-field production, this would be costly. It depends on the cost-benefit analysis and affordability of local growers to make appropriate decisions. Manual removal of infected plants and weeds is also important to reduce plant impairments. Other common practices such as deep ploughing and flooding techniques, weeding, deep burials and burning plant residues and weeds after harvest, etc. can also be employed (see details in Appendix 2).

Bio-control: biological control is of the integral components in an IPM program (Kogan, 1998) where employment of natural enemies is encouraged (Dent, 1995). Adapting to the tomato production system in the RRD, natural enemies, including predators, pathogens and parasitoids of the major pests should be utilized (see Annex 2 for details). Tomato growers are recommended to buy commercial products to incorporate into their management programs. In addition, bio-pesticides should also be used to effectively manage pest populations.

Chemical control: though using synthetic chemicals may negatively affect the surrounding environment, populations of natural enemies and human health, it is still needed when other pest management measures appear to be ineffective (Van Emden and Peakall, 1996). Narrow-spectrum and registered pesticides are recommended for tomato growers. Spraying of pesticides should be based on monitoring results to avoid unnecessary use.

Postharvest Management

Mechanical management would be very important during this period. Burning and destroying weeds and plant residues should be carried out to reduce their emergence in the next seasons. According to Bloem and Mizell (2009), removal of crop debris could effectively limit transmission of germiniviruses by the SLW. In addition, ploughing, flooding and solarisation techniques should be applied to kill pathogens and weeds.

Conclusions

Understanding of agronomic requirements, crop environments and commonly emergent pests in the RRD region is of equal importance for formulating appropriate management strategies. This paper has presented an overall IPM program for tomatoes with detailed factsheets of the major pests in the region for the ease of identification and adequate management. This can be used as a practical guide to manage the pests in an ecologically based way where all available resources are utilized. Consequently, low inputs, higher economic efficiency and more sustainable production are expected.

Moreover, understanding of the interactions amongst pests is essential for developing a systems approach and cost-efficient management strategies. Better management of the SLW would also reduce the likelihood of disease occurrence caused by Tomato Yellow Leaf Curl Virus (TYLCV).

Overuse of agrochemicals, including fertilizers and pesticides, apparently causes environmental contaminations. Thus, chemical fertilizers should be used appropriately according to production guidelines. Chemical pesticides should only be used when pests are present beyond the action threshold levels and when other measures appear to be ineffective. Furthermore, chemical residues may remain in tomato fruits due to the use of pesticides. Hence, bio-pesticides and registered chemicals should be used. Narrow-spectrum pesticides are encouraged to avoid destruction of natural enemies.

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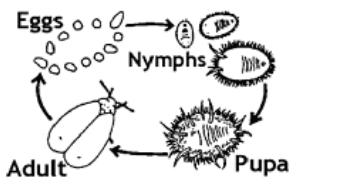
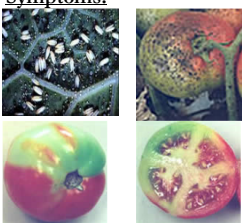

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Appendix 1. Checklist of items to be prepared by farmers prior to planting tomatoes
 Please use the following checklist to make sure that you have prepared for the following items:

ITEMS TO BE CHECKED	
1. I have contacted suppliers regarding the availability of the following items to order:	
• Resistant cultivars	<input type="checkbox"/>
• Certified weed- and disease-free seeds	<input type="checkbox"/>
• Bio-products such as natural enemies and bio-pesticides	<input type="checkbox"/>
• Yellow sticky traps	<input type="checkbox"/>
• Fertilizers (organic and chemical)	<input type="checkbox"/>
• Registered pesticides (insecticides, herbicides, fungicides)	<input type="checkbox"/>
2. Field preparation	
• I have removed and destroyed all weeds and crop residues.	<input type="checkbox"/>
• I have applied deep ploughing to kill potential weeds and pathogen sources.	<input type="checkbox"/>
• I have covered soil surface with a polyethylene layer to solarise the soil.	<input type="checkbox"/>
• I have applied a flooding technique to kill potential insect pupae.	<input type="checkbox"/>
3. Planning items	
• I have received specific instructions from the local extension station regarding the forecast of weather and possible emergence of pests before the cropping season.	<input type="checkbox"/>
• I have made compost muck for the basal application well before planting.	<input type="checkbox"/>
• I know that excessive use of the N fertilizer input will make tomato plants susceptible to pest attacks.	<input type="checkbox"/>
• I have chosen a crop to intercrop with tomatoes (in case resistant tomato cultivars are not available).	<input type="checkbox"/>
• I have chosen some bait plants to grow on the field to distract whiteflies from the tomato crops.	<input type="checkbox"/>
• I have bought insect-proof nets to prevent insect (whitefly) attacks on plants at seedling stages.	<input type="checkbox"/>
• I have prepared materials for staking and mulching to avoid the development of soil-borne insects, weeds and fungi.	<input type="checkbox"/>
• I know that high plant density is favourable for development of diseases, particularly early blight.	<input type="checkbox"/>





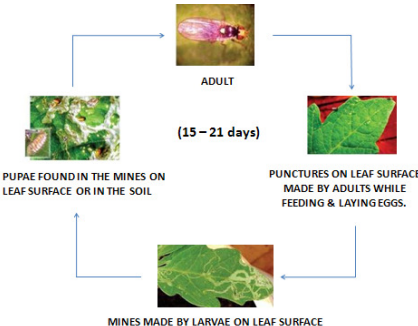


(Note: please tick the items that you have done)

Appendix 2. Factsheets of the major pests - *Fact sheet 1. Silver-leaf whitefly (Bemisia tabaci) (SLW)*

OCCURENCE:		Having 8 - 12 generations/year in sub-tropical region, but occurring with high populations in Spring and Summer (warm weather).									
DESCRIPTIONS											
Eggs: (0.2 mm) 	Nymphs: (0.3 - 0.6mm) 	Pupae: (0.6- 0.8mm) 	Adults: (0.8-1.2mm) 	Life cycle: 	Symptoms: 						
<ul style="list-style-type: none"> - Eggs with a pointed end attached to the underside of leaf surface, usually young leaves. - New eggs are whitish yellow, turning to brown colour and hatching within 7 - 10 days. 		<ul style="list-style-type: none"> - Crawlers (the 1st instar nymphs) are small (0.3 mm), flattened, greenish-yellow. - The second to third instar nymphs (0.4 - 0.6mm) are light yellow, invisible legs, sticking to leaf surface to suck sap. 		<ul style="list-style-type: none"> - Pupae and/or red-eye nymphs are dark yellow. In the late pupal stage, they stop feeding and transform into adults, leaving the empty white exuviae on leaf surface. - Pupal stage: 4 days. 		<ul style="list-style-type: none"> - Adults are more active in the morning, congregating on the underside of young leaves. Females can lay about 160 eggs (50-400). More eggs are laid under warm weather. - Adults can live for 8-12 days. 		<ul style="list-style-type: none"> - A total life cycle from eggs to adults: 18-28 days in warm weather, 30-48 days in winter. 		<ul style="list-style-type: none"> - Adults and nymphs concentrate on leaves, sucking saps; - Causing sooty mold and irregular ripening. 	
DAMAGES:											
(1) Direct feeding by adults and nymphs leads to stunted growth and defoliation. High population may induce desiccation and death; (2) Injection of toxic saliva into plants causes blotchy ripening and internal damage of fruits; (3) excretion of honeydew promotes the development of sooty mold, reducing photosynthetic capacity; and (4) Transmission of Gemini viruses such as tomato leaf curl virus and tomato yellow leaf curl virus.											
IPM STRATEGIES											
Monitoring & sampling:	Biological management:	Cultural practice:	Mechanical management:	Chemical control:							
<ul style="list-style-type: none"> - Regular check field margins (twice/week) as these areas are usually infested first. Random sampling of 30 leaves (from 7:00 to 9:00am); Treatment threshold: 4 adults per leaf. - Yellow sticky traps can be used (3 -5 traps per ha) to monitor its occurrence and level of development. - A hand lens (10x) can be used for monitoring nymphs. 	<ul style="list-style-type: none"> - Predators: raise predatory mites (<i>Amblyseius spp.</i>, <i>Typhlodromus spp.</i>), predatory thrips, lacewings, rove beetles or ladybird beetles. - Pathogens: use some commercial fungi such as <i>Verticillium lecanii</i>, <i>Beauveria bassiana</i>, <i>Paecilomyces fumosoroseus</i>. - Parasitoids: parasitic wasps (e.g. <i>Encarsia formosa</i>, <i>E. guadaloupe</i>; <i>E. haitiensis</i>) - Bio-pesticide: use neem-based pesticides with 0.1-0.5% soft soap. 	<ul style="list-style-type: none"> - Crop management: Avoid surplus of N fertilizers. Use insect netting at the seedling stage. - Intercropping with capsicum or cucumber. - Useresistant cultivars to reduce diseases transmitted by SLW. - Sanitation: remove weeds, crop residues before planting. Fields should be weed-free. 	<ul style="list-style-type: none"> - Use yellow sticky traps: clean traps on regular basis to remove insects and other debris, then apply new sticky substance. Only use traps when SLW appear and stop using when the population decreases since the traps also catch the natural enemies. - Use a hand-held vacuum: Most effective in early morning, and at start of SLW infestation. 	<ul style="list-style-type: none"> - Spraying is based on monitoring. SLW are only susceptible at nymph and adult stages. Thus, application of registered insecticides(4-5 times) is needed at 5 - 7 day intervals. Read labels carefully. - Apply pesticides at the underside of leaves. Correct calibration is needed. Application of pesticides to the soil before or after planting is more effective than foliar application. 							


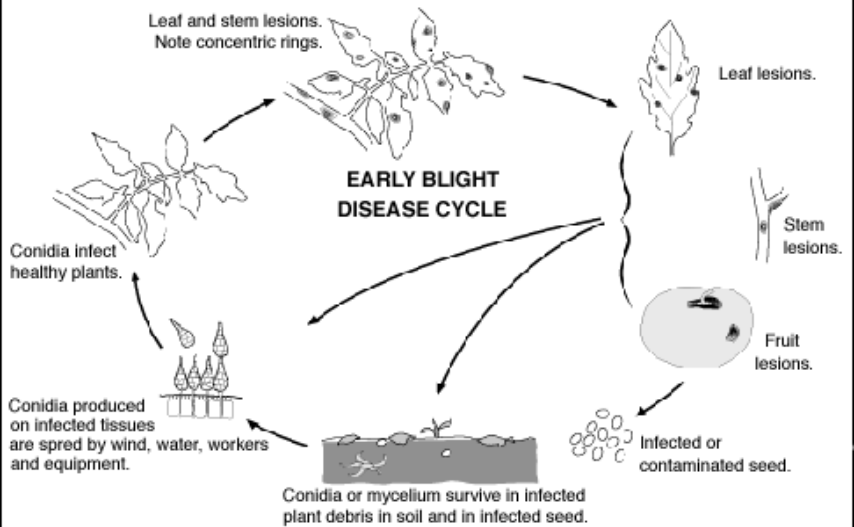
(Source: Siva-Subramaniam et al., 2007, Drees and Jackman, 1998, Stansly, 2010, FED, 2009b, Hoddle, 1999, CAES, 2006, UC, 2008b, Paine et al., 2009, Barrett, 2001)

Fact sheet 2. Vegetable Leaf-miner (*Liriomyza sativae*)

OCURRENCE:		There are many overlapping generations/year. Leafminers are infrequent in cool months; but usually reach a high population & damaging level during mid-summer.			
DESCRIPTIONS					
Eggs: (0.23mm) 	Larvae: (2.25 mm) 	Pupae: (1.5 mm) 	Adults: (1.3-1.5mm) 	Life cycle and symptoms:  <p>The average life cycle of a leaf-miner is typically about 21 days, but it can be shorter (15 days) under warm conditions.</p>	
DAMAGES: Severe infestation, especially by larvae, which may cause (1) dying-off of young plants; (2) leaf necrosis and defoliation, and (3) sun scalds on fruits. Damaged leaves are susceptible to wind and pathogens.		IPM STRATEGIES			
Monitoring & sampling: - Use yellow sticky traps or sweep nets to monitor the occurrence of flies. - Monitor the foliage for presence of mines, larvae. The action threshold for leaf-miners is 0.7 larva per plant for insecticidal spraying.	Biological management: - Parasitoids: using parasitic wasps can effectively control larvae: + <i>Diglyphusisaea</i> works better in summer. + <i>Dacnusa sibirica</i> works better in winter. - Predators: ants. - Bio-pesticides: apply a neem product (Neemos®) (25-50g/L) to reduce fecundity, longevity of flies; disrupt larval development.  	Cultural practice: - Sanitation: remove weeds and all debris after harvest. - Apply an adequate N level and use row cover. - Rotate tomatoes with other crops of different families. - Plant tolerant cultivars.	Mechanical management: - Use yellow sticky traps on large scale. - Hand-picking and destroying mined leaves. - Deep ploughing and flooding help to kill pupae.	Chemical control: - Leafminers easily develop resistance to insecticides. Thus, rotation of insecticide classes is recommended. - Application should be based on regular monitoring information. - Using narrow-spectrum insecticides to reduce risks to beneficial insects. - Cyromazine (Trigard®) and Abamectin (Avid) are two effective insecticides to kill larvae. - Applying in the morning is most effective.	



(Source: Chaput, 2000, Capinera, 2007, Sikora and Zebnder, 2000, Mau and Kessing, 2007, FED, 2010, OMAFRA, 2009, Schuster, 2007)

Fact sheet 3. Tomato early blight (caused by fungus *Alternaria solani*)

OCCURRENCE:	- Tomato early blight usually occurs in the early (July/August – October/November) and late (November – March/April) growing seasons in the RRD. It occurs at any age, especially at the early fruitset stage.
CONDITIONS FOR DEVELOPMENT:	- The disease thrives under moderate temperature (24-29°C) and high humidity, particularly under conditions of frequent rainfall, overhead irrigation or dew. Other preferred conditions for its development include: infested seeds, unhealthy plants, abundance of weeds, and high density planting.
SYMPTOMS:	<ul style="list-style-type: none"> - The disease symptoms appear on all upper parts of plants (stems, leaves and fruits) with small black or brown spots of 6-12mm in diameter. - It usually appears as leathery spots at older leaves first in concentric ring forms. - Affected stems and petioles have elliptical or concentric lesions. Corral rot may occur at the seedling stage. - Circular lesions on fruits, usually nearby the calyx end, are sunken and dry. 
DAMAGES:	- The disease infestation causes: (1) Defoliation (leaves turn to yellow, wither and drop); (2) Flower drop at the flowering stage; (3) Fruit drop (losing 30-50% of immature fruits); and consequently (4) lower yield and undersized fruits.
DISEASE CYCLE:	- The disease cycle can last for 5-7 days. However, there are many repeating cycles throughout a long growing season.
IPM STRATEGIES	<p>1. Monitoring: check the plants for the disease infection twice a week. If it occurs, apply registered fungicides.</p> <p>2. Cultural methods: - Use resistant cultivars. - Sanitation: Destroy weeds and plant debris after harvest. - Rotation: apply 3-4 year rotation with non-<i>solanaceous</i> crops. - Choose seeds from disease-free fruits; use fungicide-treated seeds and disease-free transplants. - Planting density: avoid high density growing. - Irrigation: avoid prolonged period of wetness on leaves. Avoid overhead irrigation. If it is used, irrigate in late morning. - Staking and mulching: to reduce fungus infection from the soil. - Fertilize properly to keep healthy plants, preferably organic fertilizers.</p> <p>3. Mechanical method: Deep ploughing should be practiced to eliminate spores.</p> <p>4. Biological control: Use the product “<i>Bacillus subtilis</i>” (trade name: Serenade Max), apply when seedlings reach 5-7cm, then repeat at 5-7 day intervals if needed. Read labels carefully.</p> <p>5. Chemical control: Soak seeds in 0.2% Thiram (30°C, 24h); Apply protectant fungicides such as carbamates, clorotalonil, cuprics at 7-10 day intervals when the symptom appears.</p>  <p style="text-align: center;">Figure 1. Disease cycle of tomato early blight (Source: Rueda, 1995)</p>



(Source: Tran, 2005, UC, 2008a, AVRDC, 2005, Kellebrew, 1998, Dicklow, 2009, Delahaut and Stevenson, 2004, Kinilitan-Bissdorf et al., 2010, Whiting et al., 2006, Rueda, 1995, COPR, 1983, Jones et al., 1991)

Fact sheet 4. Tomato yellow leaf curl virus (TYLCV)

OCCURRENCE:	TYLCV occurs in all growing seasons in the RRD, including Spring-Summer, Early, Main and Late seasons.	
CONDITIONS FOR AND DEVELOPMENT DISEASE CYCLE	<ul style="list-style-type: none"> - TYLCV is only transmitted by silverleaf whiteflies (SLW). Hot and dry conditions are preferable for whiteflies to spread TYLCV. - Viruses can be acquired by SLW after feeding on infected plants for 15-20 minutes. After 24 hour incubation in whiteflies, the viruses can be transmitted to other plants after 15 minute feeding by SLW. Theviruses can be retained in SLW for up to 20 days. - Active adults of SLW is more likely to spread TYLCV. 	
SYMPTOMS:	<ul style="list-style-type: none"> - Stunted growth with erect shoots. Internodes are shortened. Shoots have a bushy type. - Reduced leaf size, leaf distortion, leaf curling, yellowing and chlorosis on leaf margins. - Sometimes, infected plants show excessive branching and flower abscission. 	 
DAMAGES:	<ul style="list-style-type: none"> - Fruit production is substantially reduced with smaller sizes, dry and unsalable fruits. - Severe infection by TYLCV at an early stage can cause 100% lossess. 	<p><i>Fig. 2. Left: A diseased plant shows multiple, thickened shoots with deformed yellow leaves. Right: A healthy plant.</i></p> <p><i>Fig.3. Left: A typical foliar symptom of TYLCV. Upper right: new leaflets with the symptom of yellowing veins & curling margins. Lower right: adult & nymphs of SLW, a vector of SYLCV.</i></p>
IPM STRATEGIES	<p>1. Monitoring: check plants regularly for whiteflies and symptoms of TYLCV. Yellow sticky traps can be used for monitoring. If some plants are detected as infested, remove these plants away from the field and destroy them.</p> <p>2. Cultural method:</p> <ul style="list-style-type: none"> - Use virus- and whitefly- free transplants. - Plant seedlings in insect-proof net-houses (50 mesh or finer) to avoid whitefly attacks. - As whiteflies prefer young plants, transplanting should be carried out when seedlings reach 30 days old. - Rotation: rotate tomatoes with other crops that are not vulnerable to whiteflies. - Isolate new plants with old tomato fields to reduce disease transmission. If possible, plant maizes as a border crop around new tomatoes. <p>- Mulching: use straw, sawdust, plastic or UV-reflective mulches to diminish the landing of SLW.</p> <p>- Use resistant cultivars as recommended in Ha (2015).</p> <p>- Grow some bait plants in the tomato field to attract whiteflies, then spray pesticides to kill them.</p> <p>3. Mechanical methods: remove weeds and volunteer tomato and tobacco plants to reduce inoculum sources. Deep ploughing, remove plant residues or burn them right after harvest.</p> <p>4. Biological methods: use neem-based products to control whiteflies. Or use 1% soap to spray to the leaf under-surfaces.</p> <p>5. Chemical control:- Spray infected plants before removing them to reduce the likelihood of spreading to neighbouring plants.</p> <ul style="list-style-type: none"> - Use Imidacloprid-based systemic insecticides (e.g., Admire® Pro, Provado®) to control both nymphs and adults of SLW; Pyrethrins and pyrethroid-based insecticides can be used to control adult SLW. Spirotetramat (Movento™), with methylated seed oil plus silicone surfactant, and insecticidal oils, soaps, and other extracts can be used to effectively kill SLW at all stages. Remember to rotate pesticide groups and read labels before use. 	




(Source: Tran, 2005, Cerkauskas, 2004, Nono-Wondim et al., 2005, UC, 2008c, Thomas and Persley, 2007, FED, 2009a, Tesoriero and Azopardi, 2006, Melzer et al., 2009, Polston, 2007)

Fact sheet 5. Billy-goat weeds (*Ageratum conyzoides* L.)

OCCURRENCE:	<ul style="list-style-type: none"> - Billy-goat weed is a common weed in most of agricultural lands of Vietnam with the year-round flowering characteristic. It is distributed from sea level to an elevation of 2400m, growing in between crops, along footpaths, plantations, pasture areas, riparian zones and highlands. It occurs in both light and heavy soils.
DESCRIPTION:	<ul style="list-style-type: none"> - Billy-goat weed is an annual herb. The plants are erect, often branched. Plant height can reach 1.2m at flowering. Leaves and stems are hairy. Leaves are opposite with long and hairy petioles. Flowers have light blue, white or violet colors. Fruit is an achene, having an aristate pappus. - A plant can produce up to 40,000 seeds, in which half of those can germinate. The seeds are small and are easily spread by wind and water. The seeds germinate quickly. The optimum temperature for germination is 20-25°C. The seed viability can be lost after 12 months. - The plants grow vigorously, particularly in rich, moist and mineral soils. It can complete its life cycle in less than 2 months. 
DAMAGES:	<ul style="list-style-type: none"> - Billy-goat weeds compete nutrients, water and light with tomatoes. In addition, the weed can produce bioactive metabolites through its roots and shoots, inhibiting growth of surrounding plants. Consequently, tomato yield is significantly reduced. - The weed also acts as a host for some pathogens, causing diseases on tomatoes such as bacterial wilt (<i>Ralstonia solanacearum</i>) and TYLCV. This is associated with whitefly vector.
MANAGEMENT:	<p>1. Monitoring:</p> <ul style="list-style-type: none"> - Monitoring and timing of seedling emergence is important to control the weed. <p>2. Cultural method:</p> <ul style="list-style-type: none"> - Mulching: use straw or plastic materials to reduce germination of Billy-goat weed. - Crop rotation: can change the environment that is unfavourable to the Billy-goat weed. In this case, paddy rice should be used as an effective rotating crop. <p>3. Mechanical method:</p> <ul style="list-style-type: none"> - Burning plant debris and weeds after harvest can destroy the seeds of Billy-goat weeds. Deep ploughing should be practiced to bury the weed seeds. - Hand weeding and chipping weeds regularly under dry conditions. - Keep canal banks free from Billy-goat weeds since the seeds can be transferred from irrigation water. <p>4. Bio-control:</p> <ul style="list-style-type: none"> - There are a range of <u>natural enemies</u> of Billy-goat weed listed by ACIAR (2008), in which the agrimyid fly (<i>Melanagromyza metallica</i>), which is present in Vietnam, is the most effective one since it targets only at billy-goat weed. Eggs are laid on apical shoots, the larvae then bore into pith area of stems, moving towards the roots. At the final instar stage, larvae cut an exit hole at stem base.  <ul style="list-style-type: none"> - <u>Bio-pesticide</u>: use commercial products of plant extracts from parthenin and eucalyptus (volatile essential oils). <p>5. Chemical control:</p> <ul style="list-style-type: none"> - Pre-emergence treatment: use simazine, atrazine, diuron, oxadiazon, oxyfluorfen, methazole or metribuzin. - Post-emergence: use 2,4-D.

(Source: Burgess et al., 2008, ACLAR, 2008, Pagad, 2009, Kashina et al., 2003, Adigun, 2005, Umali-Stuart and Stinart-Santiago, 2009, PIER, 2008)

Fact sheet 6. Spiny Amaranth (*Amaranthus spinosus* L.)

OCCURRENCE:	<ul style="list-style-type: none"> - Spiny amaranth is a summer-growing annual, germinating from seeds which occurs from late winter through to summer. - The weed appears in various areas, including cultivated and fallow fields, nearby footpaths and waste areas.
DESCRIPTION:	<ul style="list-style-type: none"> - Typical characteristics: plants possess many pairs of stiff spines (1cm long), emerging from the leaf base. - Stems: stout, branched and erect or slightly decumbent, occasionally red. Average plant height: 50 - 100cm (sometimes reaching 1.2m). Mature stems are stiff and angular. - Alternate leaves, dull green color; spearhead-like shape; having slender stalks. Leaf blades can reach 4cm wide and 8cm long with a large number of veins spread out from the midrib. - Flowers: long tail-like spikes, comprising many papery greenish – white florets. - Fruits: small capsule (1-2mm), having 1 single seed, enclosed by pale papery bracts. - Seeds: small seeds (0.7-1mm), ripe seeds have shiny black or dark brown colors and a pinhead-like shape. A mature plant can produce more than 200,000 seeds per season. Seeds are spread by water and wind. Seeds can be viable under the soil for several years. - It can grow in both dry and wet lands, but cannot withstand with waterlogging. Poor growth and flowering can be seen under shade and cool temperatures. <div style="display: flex; justify-content: space-around; align-items: center;">    </div>
DAMAGES:	<ul style="list-style-type: none"> - Since having a relatively large size, spiny amaranths can compete nutrient, water and light with tomato crops. - The rigid middle-like spikes can be a nuisance to farmers while working on the farm.
MANAGEMENT:	<ol style="list-style-type: none"> 1. Monitoring: - Regular check for the weed status and timing of their emergence are important to control this weed. 2. Cultural methods: <ul style="list-style-type: none"> - Using weed-free seeds; mulching by straw, hay or polyethylene; deep ploughing and solarization. 3. Mechanical methods: <ul style="list-style-type: none"> - Rooting up the whole plant is recommended since mowing or slashing may lead to the re-growth of the weed. Since the weed usually sheds ripe seeds in Autumn, digging and removing plants gently are recommended to avoid seed drop. - Disposal methods: deep burial (1.5m) or burning. 4. Biological methods: Some effective natural enemies of this weed should be used such as: agromyzid fly <i>Haplopedes minutus</i>, beetle <i>Cassida nigricornis</i>, moth <i>Coleophora versurella</i> and the weevil <i>Hypolixastrum calatus</i>. 5. Chemical controls: - Spiny amaranth is resistant to some herbicides. Rotation of herbicide groups is therefore recommended to avoid its resistance. <ul style="list-style-type: none"> - Herbicides should be applied at an early stage since older plants are more tolerant to herbicides. <ul style="list-style-type: none"> + Pre-emergence: use Metolachlor + atrazine or Trifluralin + simazine. + Post-emergence: apply 2,4-D dimethylamine.

(Source: http://luirig.altervista.org/schedeit/ae/amaranthus_spinosus.htm)