CHAPTER SIX - SUMMARY AND RECOMMENDATIONS

This research was developed as part of the IMP CRSP's[1] goal to establish integrated pest management systems for the Caribbean and other areas around the world. In fulfilling this goal, basic research was needed to identify tactics that could be incorporated into IPM systems. Hence, the objectives of this research were to identify key points in the epidemiology of *tobacco etch virus* (TEV), determine the effect of TEV on peppers at various stages of development, and use the information obtained to propose strategies that might best work in a sustainable integrated management system for TEV disease in peppers in Jamaica.

Research findings

1. Aphid flight in St. Catherine was seasonal, with the greatest abundance and diversity of species from mid-September through mid-May.
2. Over thirty species of aphids were collected on pepper farms in St. Catherine.
3. Twelve species of aphids were new records for Jamaica:
    - *Aphis amaranthi* Holman,
    - *Brachycaudus helichrysi* (Kaltenbach),
    - *Capitophorus hippophaes* (Walker),
    - *Geopemphigus floccosus* (Moreira),
    - *Hysteroneura setariae* (Thomas),
    - *Lipaphis erysimi* Hille Ris Lambers,
    - *Rhopalosiphum padi* (Linnaeus),
    - *Schizaphis graminum* (Rondani),
    - *Schizaphis rotundiventris* (Signoret),
    - Trichosiphonaphis poligoni (van der Goot),
    - *Uroleucon ambrosiae* complex (Thomas),
    - *Uroleucon pseudoambrosiae* (Olive)
4. Five known TEV vectors were found on pepper farms: *A. gossypii*, *A. craccivora*, *A. spiraecola*, *L. erysimi* and *M. persicae*.

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5. Field spread of TEV was closely associated with aphid flights (transient aphids).
6. Colonizing aphids might not be a major contributor to spread of TEV in peppers.
7. Increase in numbers of two aphid species with unknown TEV vector status, *A. amaranthi* and *U. ambrosiae* complex, were closely associated with increase in TEV incidence in one field study.
8. Some weeds and crops within and around fields were hosts of common aphid species. Colonies of *M. persicae* were found on peppers grown close to *Brassica* sp.; *A. gossypii* colonizes pepper as well as several vegetable crops, fruit trees, and weeds on pepper fields; *U. ambrosiae* forms dense colonies on *Parthenium hysterophorus; A. amaranthi* colonizes *Amaranthus* spp. and *T. nigriabdominalis* colonizes the roots of grasses. *P. hysterophorus, Amaranthus* spp. and grasses are major components of the weed community on pepper farms. Many farmers in St. Catherine grow a species of amaranth as a vegetable crop.
9. Primary infections of TEV within fields were random throughout the plot and originated from outside pepper fields. Thereafter, field distribution of TEV was spatially correlated and occurred mainly by secondary spread within pepper fields.
10. Complete infection by TEV of the pepper plots studied occurred within ten to eleven weeks after the primary infection. The rate of spread of TEV followed the logistic curve.
11. Tissue blot immunoassay proved to be an efficient and convenient means whereby large numbers of field samples may be collected to conduct serological tests for viruses of pepper.
12. Tissue blot immunoassay confirmed that symptoms could be used to reliably assess TEV incidence in the field.
13. Scotch Bonnet pepper inoculated with TEV during the vegetative stage and at the onset of flowering (during the first month after transplanting) exhibited severe retardation in growth and yield although the developmental stages were not inhibited. Plants inoculated 7 and 28 day after transplanting were shorter, covered less ground area and produced fewer and smaller fruit than the control.

14. Scotch Bonnet pepper plants inoculated with TEV after the first stage of flowering (approximately two months after transplanting) were not significantly different from uninoculated plants in size or in yield.
15. Increases in Scotch Bonnet pepper yield, therefore, can be obtained by protecting plants from TEV infection during the seedling stage through first stage of flowering (approximately two months after transplanting).
16. West Indian Red pepper was confirmed to be tolerant to TEV infections.
17. Our study suggests that West Indian Red pepper might be most sensitive to TEV when inoculation occurs near 28 days after transplanting, which is about the time of flower initiation.
18. Covering nursery beds or seedling crates with aphid exclusion cages made with ordinary sheer curtain material is an economical way for farmers to protect pepper seedlings from aphid-borne viruses before transplanting.
19. Stylet oil alone, applied once weekly with a backpack mist blower (low volume, single nozzle and pressures of about 1000 kPa), delayed field spread of TEV by seven days and reduced TEV incidence by 24% in sprayed plots when compared to unsprayed plots.
20. Stylet oil and reflective mulch together delayed the incidence of TEV in pepper plots for over two months, even with high inoculum pressures of 33-67% infection from surrounding plants.
21. Stylet oil had no effect on growth of healthy plants. However, in one study, plants sprayed with stylet oil produced less total fruit than untreated plants but equivalent marketable number and weight of fruit as untreated plants.
22. Stylet oil appeared to prevent infestations of the broad mite, *Polyphagotarsonemus latus,* in sprayed pepper plots.

Future research

1. Determine whether *A. amaranthi* and *U. ambrosiae* are vectors of TEV and if they are, determine their relative transmission efficiencies compared to *A. gossypii* and *M. persicae*.
2. Conduct field studies to show that by using virus free seedlings and keeping pepper fields free of weed hosts (say within a distance of 50 m) of *A. amaranthi* and *U. ambrosiae*, the incidence of TEV can be significantly reduced. The targeted weed species should be totally eliminated from field plots. Other weed species should be kept under control, especially, by implementing weed management practices immediately after occurrences of rainfall.
3. Compare the efficiency of straw mulch and/or saw dust and stylet oil versus reflective mulch and stylet oil in controlling aphid-borne viruses in pepper.
4. Determine the economics of using stylet oil and mulch for adaptation on small pepper holdings in comparison with the use of targeted weed management and barrier crops.
5. Study the effect of increased planting densities on rate of spread of TEV. This could include the use of double rows (with plants staggered between rows – to make harvesting easier).
6. Investigate the effect of infecting West Indian Red pepper with TEV near the time of flower initiation.
7. Investigate the efficiency of stylet oil in managing broad mite infestations in pepper.
8. Fine-tune the proposed risk analysis for management of TEV in peppers.

Developing IPM for TEV in pepper

General discussion

In Jamaica, the main viruses affecting pepper are aphid-borne and nonpersistently transmitted. Only few aphids are required to spread these viruses in the field. Consequently, one cannot develop economic thresholds for the vectors. Furthermore, the earlier the crop stages at the time of infection, the greater the loss in yield. It is, therefore, imperative that virus disease management begins before the crop is planted. Pepper nurseries should be protected with aphid exclusion covers, and/or be established away from possible sources of inoculum, such as mature pepper fields.

Pepper grown for the winter market is transplanted during August and September so the crop is most vulnerable to virus infections when aphid flights are high. Farmers should either plant their crops earlier or implement strict management practices to delay and/or reduce TEV into the crop. Pepper is often grown in overlapping cycles in Jamaica and old fields are often abandoned but not destroyed. These practices provide a large reservoir of virus inocula for infection of newly established pepper fields. Weeds are a severe problem in most pepper fields, especially during periods of heavy rainfall. Weeds compete with crops for nutrients and light, and can harbor viruses as well as aphid vectors. Proper field sanitation alone could greatly delay the introduction, and reduce the incidence of viruses in new susceptible pepper fields.

TEV increases logistically within pepper plots and therefore the rate of spread is greatest during the middle of the infection cycle. Complete infection of plots <1 hectare takes place within ten weeks. This implies that roguing of pepper plants might not be an effective measure of control after the first two to three weeks of infection. This would require rigorous monitoring of plants and well-trained eyes to detect early infections of virus. Roguing would also require that the nearest neighbors of infected plants be removed even if they have no symptoms because they too could be infected (Broadbent 1969). Roguing requires good sanitation practices; rogued plants should be removed from within the plot and promptly destroyed so that they do not become a source for the virus or any vectors they might be harboring (Broadbent 1969). Replacing rogued plants with healthy ones would increase overall productivity per acre but the new plants are often less hardened and more susceptible to virus infections than other plants in the stand. Farmers might not have the time required to conduct efficient roguing.

Increasing the field size or the planting density might decrease the rate of spread of TEV (Carter 1961, Broadbent 1969). There would be more plants, requiring more time, to get infected. Additionally, increased field sizes would reduce the edge effects from the tendency of immigrant aphids to land on the borders of fields (Thresh 1976). Scotch Bonnet peppers grown at a density of 0.6 x 0.6 m produced more fruit than those grown at a density of 0.9 x 0.9 m (McGlashan personal communication). Intercropping and use of barrier crops could also help to delay the spread of TEV in pepper fields (Broadbent 1969). It would be advisable to plant barrier crops so they can get established before peppers are transplanted. Both barrier crops and intercrops need to be non-hosts to the virus and its vectors.

Reflective mulch and stylet oil together have been proven to be more effective in reducing and delaying the spread of TEV and other viruses than stylet oil alone (Mansour 1997). Plastic mulches will require the use of drip irrigation. Straw has been shown to repel whiteflies (Nitzany *et al.* 1964). Myers 1998/1999 reported that straw mulch can delay the incidence of TEV in pepper in Jamaica. Straw is biodegradable, less costly than plastic mulch and could be substituted if proven to work well in suppressing the spread of TEV in pepper. However, the reflective properties of straw are not as great and thus, may not repel aphids as well plastic mulches.

Simons *et al*. (1995) recommend that stylet oil applications begin after 5-6 winged aphids are caught in 9-inch water traps over 24 hours and that frequency of applications be increased to twice per week when $\geq$ 15 aphids are caught in 24 hours, and after heavy rains. Given the small size of the typical Jamaican pepper farm, and the typically low numbers of aphids trapped in pepper fields in Jamaica, it would be advisable that farmers start spraying stylet oil as soon as the seedlings are transplanted.

Risk analysis for managing TEV in pepper

The main decision making tool being proposed is a risk analysis to be used by the farmer. This proposal is only theoretical at this stage and more studies are needed to validate and fine-tune these recommendations. It is modified from Brown *et al.* (2000) and based on delaying virus introduction into the crop. Based on marketable weight of fruit, yield loss from TEV infection of Scotch Bonnet pepper at 1, 4 and 8 weeks after transplanting was approximately 80, 60 and 20%, respectively.

Farmers could be given a choice of management tactics with points indicating the advantage of using each. Farmers would select the methods that suit their objectives and tailor a management program accordingly. The amount of risk a farmer is willing to take will depend on the intended use of the crop (e.g., the market), market conditions, available resources (financial, manpower, etc.) and the farm conditions (e.g. water resources, land on flat/slope), etc.

Scores for tactics could be for example:

1.	Protected nursery	*3 points*
2.	Transplanting date:	
	June to July	*5 points*
	August	*3 points*
	September	*1 point*
3.	Reflective mulch:	
	Aluminum	*7 points*
	Other reflective materials	*5 points*
4.	Stylet oil	*3 points*
5.	Reflective mulch and stylet oil	*9 points*
6.	Removal of inoculum sources	*5 points*
7.	Removal of aphid sources	*5 points*
8.	Managing colonizing aphids	*3 points*
9.	Early planting of barrier crops	*5 points*

Farmers could be advised to have at least 20 points in addition to the three points from starting with virus free seedlings.

The method for management decision outlined above is applicable for other aphid-borne viruses. Risk analysis challenges the farmer to make pest management decisions before planting the crop. Maintaining good field sanitation and monitoring winged aphids daily will require diligence on the part of the farmer but the effort should pay off greatly.

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