K. Subramanya Sastry
Thomas A. Zitter

Plant Virus and Viroid Diseases in the Tropics

Volume 2: Epidemiology and Management

Springer

Plant Virus and Viroid Diseases in the Tropics

K. Subramanya Sastry · Thomas A. Zitter

Plant Virus and Viroid Diseases in the Tropics

Volume 2: Epidemiology and Management

Springer

K. Subramanya Sastry
Department of Virology
SV University
Tirupathi, Andhra Pradesh
India

Thomas A. Zitter
Department of Plant Pathology
and Plant-Microbe Biology
Cornell University
Ithaca, NY
USA

ISBN 978-94-007-7819-1 ISBN 978-94-007-7820-7 (eBook)
DOI 10.1007/978-94-007-7820-7
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2013933113

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

This textbook entitled “Plant Virus and Viroid Diseases in the Tropics-Volume 2: Epidemiology and Management” is an ideal introduction to the subject written for students, practitioners and researchers by Drs. K. Subramanya Sastry and T. A. Zitter. The authors focused on physical and biological factors that favor epiphytotics, including weeds that can constitute virus reservoirs as well as breeding foci for vectors. Virus properties, survival and spread by invertebrate vectors, nematodes and fungi, are followed by the description of spatial dynamics, disease gradients, forecasting, and mathematical modeling techniques. Seven important tropical diseases their ecology and epidemiological aspects are described in detail.

In the Chap. 1, the well organized overview of virus survival and spread, disease forecasting, disease gradients and progress curves, systems analysis and simulation models are covered.

The Chap. 2, the authors have presented the outlines of the management of tropical plant virus and viroid diseases, the selection of virus-free seed and propagules, techniques of production of virus-free plant materials by biotechnological strategies, barrier cropping, time of planting, eliminating of weeds, use of insecticides and use of transgenic plants-the most effective control measure.

The important role of plant quarantine is stressed. Certification schemes for seed-borne viruses in lettuce, barley, pea, beans, soybean, cowpea and peanuts, as well as production of virus-free plants and certification schemes through tissue culture techniques are discussed for cassava, citrus, potato, sugarcane and other plants. Cultural practices and phytosanitation in virus and viroid diseases, as well as cross-protection in fourteen virus diseases are described in detail.

Control of vectors by oil and insecticides are discussed in great detail, as is also the use of aluminum mulches for vector control. Sources of resistance and transgenic approaches to viral and viroid diseases, benefits and risks, are enumerated. Technical guidelines for exchange of germplasm and breeding lines, with detailed descriptions of methods of plant importation are described.

This authoritative review will provide a unique education platform to the readers, so that they can keep in touch with the latest developments in the field of tropical plant virus diseases. Drs. K. Subramanya Sastry and T. A. Zitter have substantial practice in tropical plant viruses and this invaluable book is meticulously researched. It will appeal to all those with an interest in tropical plant virus diseases and their control.

New Brunswick, USA Karl Maramorosch

Preface

Many of the world's most important food crops are grown in the tropics and major crops like rice, maize, wheat, sorghum, barley, tomato, chillies, okra, peas, peanut, sunflower, cucurbits, pigeonpea, etc., are raised through true seed, whereas cassava, potato, sweet potato, sugarcane, cocoa, avocado, apples, banana, and other fruit crops are grown through vegetative propagated materials like tubers, sets, rhizomes, cuttings, budwood, etc. Almost all these crops are affected by important virus and viroid diseases besides fungal and bacterial diseases. However, emergence of new viruses and virus strains of existing viruses, along with changing contexts due to agricultural intensification and climate change have been creating new challenges and demanding an even greater effort to overcome hurdles to increase agricultural productivity, food availability, and economic development. These diseases are responsible for heavy yield losses. We have definite chemical measures against fungal and bacterial diseases, whereas until now no promising viricides have been developed to control virus spread.

Disease-free crops and plants are of great economic and social importance in feeding the world population. The thrust of the book Volume-2 is on virus and viroid disease in the tropics in order to provide the latest information on ecology, epidemiology, and management of virus and viroid diseases in southeastern Asian countries, the African, and South American continents, which fall within the tropical zone. Plant viruses are a matter of great concern globally, but effective management measures against plant viruses requires a clear understanding of their ecology and epidemiology.

Environmental factors like rainfall, wind velocity, soil conditions, temperature, and moisture play a major role in crop production. Among the major virus diseases that are encountered in tropical zones are tungro, yellow mottle and hoja blanca in rice, mosaic in sugarcane, mosaic in cassava, tristeza in citrus, swollen shoot in cacao, sterility mosaic in pigeonpea, rosette and bud necrosis in peanut, necrosis in sunflower and legumes (vegetables and ornamental crops), leaf curl in cotton and tomato, and ringspot in papaya. Key factors for emergence of new plant virus and virus-like diseases include the intensification of agricultural trade (globalization), changes in cropping systems (crop diversification), and climate change.

In this second volume, the list of plant virus genus and species according to 9th ICTV classification and the latest techniques of plant virus diagnosis are included. In the Chap. 1 along with information on various aspects of ecology and epidemiology of plant viruses of tropics, we examine the physical and biological factors which are favorable for epiphytotics to develop. Various aspects related to survival and spread of virus and viroids are also presented as well. For an easier understanding of epidemiology, aspects of disease progress curves, mathematical modeling techniques, and systems analysis and simulation models are discussed.

In the Chap. 2, comprehensive information on plant virus management are included. The ultimate goal of plant pathologists is to effectively manage the virus and viroid diseases of tropical crops. This topic is quite extensively covered on various relevant aspects including integrated disease management practices. In this chapter, various aspects of disease management like the production of virus-free planting materials through certification schemes for crops like cassava, sweet potato, potato, citrus, banana, grapes, strawberry, pome, stone fruits, ornamental bulbous crops that helps in production of virus-free planting materials are discussed. Similarly, new steps on true seed certification schemes for certain legumes are provided. Cultural practices including rouging, border cropping, plant density, elimination of the virus sources, etc., are discussed. Vector control through the application of insecticides and oils or both are found to be effective in certain virus–host combinations are presented. Available success stories of different horticultural crops with cross-protection techniques are included. Development of pathogen-resistant transgenics for the management of virus and viroid diseases are also added. In the present world globalization, plant quarantines play a major role in almost all countries to exclude the entry of new diseases while importing the germplasm from other countries for research and agricultural purposes.

Information on the key factors of virus epidemiology in certain tropical countries is an important step towards the development of management measures against virus and viroid diseases. Identification of risk factors that contribute to virus outbreaks need to be intensified and integrated disease management (IDM) strategy in reducing the impact of these virus diseases needs to be continued throughout the tropical countries. Nevertheless, integrated control measures have evident benefits and should be fostered and promoted as a means of enhancing crop productivity to meet the increasing demands of burgeoning human population. Originally, the authors have planned to confine to the aspects of virus epidemiology and management of tropical zone only. But to provide more information and clarity of the subject, it was inevitable for us to include the research results of temperate crops also, since some of the crops are grown in both zones.

It is hoped that the information provided in this volume on various aspects of virus and viroid diseases of tropical crops would be useful to research scientists, seed companies, quarantine personnel and institutions of both research and teaching.

Tirupathi, India K. Subramanya Sastry
Ithaca, USA Thomas A. Zitter

Dr. K. Subramanya Sastry
Emeritus Professor
Department of Virology
SV University
Tirupathi, AP, India
Email: kssastry1944@yahoo.com

Dr. Thomas A. Zitter
Professor of Plant Pathology
Cornell University
Ithaca, NY 14853
Email: taz1@cornell.edu

Acknowledgments

In order to develop Volume-2 on Plant Virus and Viroid Diseases in the Tropics: "Epidemiology and Management", a large number of plant virologists of both National and International presence have immensely helped. We have been benefited by the critical suggestions and comments made by Prof. J. M. Thresh; Prof. F. J. Morales; Dr. G. P. Rao; Dr. N. Vinod Kumar; Dr. K. Bikas Mandal; Prof. H. R. Pappu; Prof. K. V. S. Sarma; Dr. R. A. Naidu; Dr. S. J. Singh; Dr. D. B. Parakh; Dr. S. V. Rao; Prof. V. Muniyappa; Dr. K Muralidharan; Dr. B Viswanath; Dr. A. M. Anthony Johnson; Dr. M. Vinayak Hegde; Dr. S. Edison; Dr. R. Selvarajan; Dr. G. Nagaraja, B. N. K. Kumari and others. The single person who has taken all the brunt and hardship in finalizing the manuscript is Prof. P. Sreenivasulu, Former Head of the Department of Plant Virology, SV University, Tirupathi (India) and we record appreciation for his sincere hard work and devotion to the plant virology subject. We are highly indebted to Dr. P. Lavakumar and IITA for allowing us to use the literature cited in the text. We profusely thank Prof. D. V. R. Saigopal, Head of the Department of Plant Virology, SV University, Tirupathi, for timely guidance, and critically going through all the chapters. Virologists helpful during my (Prof. T. A. Zitter) career include Dr. D. E. Purcifull, Dr. F. W. Zettler, Dr. E. Hiebert, Dr. J. R. Edwardson, Dr. R. Provvidenti, Dr. D. Gonsalves, Dr. J. A. Tomlinson and Dr. D. G. A. Walkey. We wish to thank our entomological colleagues including Dr. J. N. Simons and Dr. J. H. Tsai, and horticultural support from H. Y. Ozaki and V. L. Guzman. Special thanks are extended to the technicians Geisha Echenique, Louis Hsu and Jessica Drennan.

We thank Elsevier, CABI, Springer, Academic Press and other publishers for providing permission for using the illustrations and photographs from their earlier publications. Throughout preparation of the Volume-2, Mr. C. Nagaraja has devoted maximum time in computerizing the book for which the authors are highly indebted. Both the authors acknowledge the help provided by their family members during the preparation of this volume. The meticulous care taken by staff of Springer publishers in bringing out this publication at an early date with a nice display of the book is gratefully appreciated and acknowledged.

K. Subramanya Sastry
Thomas A. Zitter

Contents

Acronyms

ACMV	*African cassava mosaic virus*
AMV	*Alfalfa mosaic virus*
ACLSV	*Apple chlorotic leaf spot virus*
ApMV	*Apple mosaic virus*
ASSVd	*Apple scar skin viroid*
ASGV	*Apple stem grooving virus*
ASPV	*Apple stem pitting virus*
ArMV	*Arabis mosaic virus*
AGVd	*Australian grapevine viroid*
ASBVd	*Avocado sunblotch viroid*
BaMV	*Bamboo mosaic virus*
BBMV	*Banana bract mosaic virus*
BBTV	*Banana bunchy top virus*
BSV	*Banana streak virus*
BaMMV	*Barley mild mosaic virus*
BSMV	*Barley stripe mosaic virus*
BYDV	*Barley yellow dwarf virus*
BaYMV	Barley yellow mosaic virus
BCMV	*Bean common mosaic virus*
BDMV	*Bean dwarf mosaic virus*
BGMV	*Bean golden mosaic virus*
BGYMV	*Bean golden yellow mosaic virus*
BLRV	*Bean leaf roll virus*
BPMV	*Bean pod mottle virus*
BYMV	*Bean yellow mosaic virus*
BCTV	*Beet curly top virus*
BMYV	*Beet mild yellowing virus*
BtMV	*Beet mosaic virus*
BWYV	*Beet western yellows virus*
BYNV	*Beet yellow net virus*
BYV	*Beet yellows virus*
BYVMV	*Bhendi yellow vein mosaic virus*
BVY	*Blackberry virus Y*
BlCMV	*Black eye cowpea mosaic virus*

BMoV	*Blackgram mottle virus*
BlScV	*Blueberry scorch carlavirus*
BBSV	*Broad bean strain virus*
BBWV	*Broad bean wilt virus*
BMV	*Brome mosaic virus*
CabLCV	*Cabbage leaf curl virus*
CaCV	*Capsicum chlorosis virus*
CdMV	*Cardamom mosaic virus*
CLV	*Carnation latent virus*
CarMV	*Carnation mottle virus*
CNFV	*Carnation necrotic fleck virus*
CRSV	*Carnation ringspot virus*
CMoV	*Carrot mottle virus*
CMDV	*Carrot mottley dwarf virus*
CTLV	*Carrot thin leaf virus*
CBSD	*Cassava brown streak disease*
CBSUV	*Cassava brown streak Uganda virus*
CBSV	*Cassava brown streak virus*
CsCMV	*Cassava common mosaic virus*
CMD	*Cassava mosaic disease*
CVMV	*Cassava vein mosaic virus*
CaMV	*Cauliflower mosaic virus*
CeMV	*Celery mosaic virus*
CLRV	*Cherry leaf roll virus*
CMLV	*Cherry mottle leaf virus*
CRLV	*Cherry rasp leaf virus*
ChiLCV	*Chilli leaf curl virus*
CSNV	*Chrysanthemum stem necrosis virus*
CSVd	*Chrysanthemum stunt viroid*
CVB	*Chrysanthemum virus B*
CBLVd	*Citrus bent leaf viroid*
CDVd	*Citrus dwarfing viroid*
CEVd	*Citrus exocortis viroid*
CLBV	*Citrus leaf blotch virus*
CiLV	*Citrus leprosis virus*
CMBV	*Citrus mosaic badna virus*
CiMV	*Citrus mosaic virus*
CPsV	*Citrus psorosis virus*
CRSV	*Citrus ring spot virus*
CTV	*Citrus tristeza virus*
CVV	*Citrus variegation virus*
CYMV	*Citrus yellow mosaic virus*
ClYVV	*Clover yellow vein virus*
CNV	*Cocao necrosis virus*
CSSV	*Cocao swollen shoot virus*

CCCVd	*Coconut cadang-cadang viroid*
CFDV	*Coconut foliar decay virus*
CoRSV	*Coffee ringspot virus*
CoYMV	*Commelina yellow mottle virus*
CLCuV	*Cotton leaf curl virus*
CABMV	*Cowpea aphid borne mosaic virus*
CpBMV	Cowpea banding mosaic virus
CCMV	*Cowpea chlorotic mottle virus*
CpGMV	*Cowpea golden mosaic virus*
CpMV	*Cowpea mosaic virus*
CPMoV	*Cowpea mottle virus*
CPSMV	*Cowpea severe mosaic virus*
CGMMV	*Cucumber green mottle mosaic virus*
CMV	*Cucumber mosaic virus*
CuNV	*Cucumber necrosis virus*
CPFVd	*Cucumber pale fruit viroid*
CVYV	*Cucumber vein yellowing virus*
CABYV	*Cucurbit aphid-borne yellows virus*
CYSDV	*Cucurbit yellow stunt disorder virus*
CymMV	Cymbidium mosaic virus
DMV	Dahlia mosaic virus
DsMV	*Dasheen mosaic virus*
DBV	*Dioscorea bacilliform virus*
DLV	*Dioscorea latent virus*
EACMV	*East African cassava mosaic virus*
EMV	*Eggplant mosaic virus*
EMDV	*Eggplant mottled dwarf virus*
EMARaV	*European mountain ash ringspot-associated virus*
FBNYV	*Faba bean necrotic yellows virus*
GarMbLV	*Garlic mite-borne latent virus*
GFkV	*Grapevine fleck virus*
GLRaV	*Grapevine leafroll associated virus*
GLRV	*Grapevine leafroll virus*
GVA	*Grapevine virus A*
GBNV	*Groundnut bud necrosis virus*
GRSV	*Groundnut ring spot virus*
GRV	*Groundnut rosette virus*
HPV	*High plains virus*
INSV	*Impatiens necrotic spot virus*
ICMV	*Indian cassava mosaic virus*
ICRSV	*Indian citrus ringspot virus*
IPCV	*Indian peanut clump virus*
IYSV	*Iris yellow spot virus*
JYMV	*Japanese yam mosaic virus*
LYSV	*Leek yellow stripe virus*

LBVV	*Lettuce big vein virus*
LiYV	*Lettuce infectious yellows virus*
LMV	*Lettuce mosaic virus*
LNYV	*Lettuce necrotic yellows virus*
LSV	*Lily symptomless virus*
LLV	*Lolium latent virus*
MacMV	*Maclura mosaic virus*
MCMV	*Maize chlorotic mottle virus*
MDMV	*Maize dwarf mosaic virus*
MMV	*Maize mosaic virus*
MRFV	*Maize rayado fino virus*
MRDV	*Maize rough dwarf virus*
MSV	*Maize streak virus*
MSpV	*Maize stripe virus*
MNSV	*Melon necrotic spot virus*
MYSV	*Melon yellow spot virus*
MeYVMV	*Mesta yellow vein mosaic virus*
MLBVV	*Mirafiori lettuce big-vein virus*
MiLV	*Mirafiori lettuce virus*
MYMV	*Mungbean yellow mosaic virus*
OCSV	*Oat chlorotic stunt virus*
OSDV	*Oat sterile dwarf fijivirus*
ORSV	*Odontoglossum ringspot virus*
OLCV	*Okra leaf curl virus*
OkMV	*Okra mosaic virus*
OYVMV	*Okra yellow vein mosaic virus*
OLV-2	*Olive latent virus 2*
OYDV	*Onion yellow dwarf virus*
OrMV	*Ornithogalum mosaic virus*
OuMV	*Ourmia melon virus*
PMV	*Panicum mosaic virus*
PaLCuV	*Papaya leaf curl virus*
PRSV	*Papaya ring spot virus*
PYFV	*Parsnip yellow fleck virus*
PWV	*Passion fruit woodiness virus*
PEBV	*Pea early browning virus*
PEMV	*Pea enation mosaic virus*
PMV	*Pea mosaic virus*
PSbMV	*Pea seed-borne mosaic virus*
PLMVd	*Peach latent mosaic viroid*
PRMV	*Peach rosette mosaic virus*
PBND	*Peanut bud necrosis disease*
PBNV	*Peanut bud necrosis virus*
PCV	*Peanut clump virus*
PeMoV	*Peanut mottle virus*

PStV	*Peanut stripe virus*
PZSV	*Pelargonium zonate spot virus*
PepMV	*Pepino mosaic virus*
PMMV	*Pepper mild mosaic virus*
PMMoV	*Pepper mild mottle virus*
PeMV	*Pepper mottle virus*
PepRSV	*Pepper ringspot virus*
PVBV	*Pepper vein banding mosaic virus*
PVMV	*Pepper veinal mottle virus*
PYMV	*Pepper yellow mottle virus*
PVCV	*Petunia vein clearing virus*
PPSMV	*Pigeon pea sterility mosaic virus*
PMWaV	*Pineapple mealybug wilt associated virus*
PYMoV	*Piper yellow mottle virus*
PPV	*Plum pox virus*
PnLV	*Poinsettia latent virus*
PopMV	*Poplar mosaic virus*
PAMV	*Potato aucuba mosaic virus*
PLRV	*Potato leaf roll virus*
PMTV	*Potato mop-top virus*
PSTVd	*Potato spindle tuber viroid*
PVA	*Potato virus A*
PVC	*Potato virus C*
PVS	*Potato virus S*
PVT	*Potato virus T*
PVX	*Potato virus X*
PVY	*Potato virus Y*
PYDV	*Potato yellow dwarf virus*
PYMV	*Potato yellow mosaic virus*
PYVV	*Potato yellow vein virus*
PYV	*Potato yellowing virus*
PoLV	*Pothos latent virus*
PDV	*Prune dwarf virus*
PNRSV	*Prunus necrotic ringspot virus*
RBDV	*Raspberry bushy dwarf virus*
RpRSV	*Raspberry ringspot virus*
RBSDV	*Rice black streaked dwarf virus*
RDV	*Rice dwarf virus*
RGSV	*Rice grassy stunt virus*
RHBV	*Rice hoja blanca virus*
RNMV	*Rice necrosis mosaic virus*
RRSV	*Rice ragged stunt virus*
RSV	*Rice stripe virus*
RTBV	*Rice tungro bacilliform virus*
RTSV	*Rice tungro spherical virus*

RTV	*Rice tungro virus*
RWSV	*Rice wilted stunt virus*
RYMV	*Rice yellow mottle virus*
RGMV	*Ryegrass mosaic virus*
SDV	*Satsuma dwarf virus*
SLV	Shallot latent virus
ShVX	*Shallot virus X*
SBWMV	*Soil-borne wheat mosaic virus*
SrMV	Sorghum mosaic virus
SACMV	*South African cassava mosaic virus*
SBMV	*Southern bean mosaic virus*
SRBSDV	*Southern rice black streaked dwarf virus*
SbBMV	*Soybean blistering mosaic virus*
SbCMV	*Soybean chlorotic mottle virus*
SbDV	*Soybean dwarf virus*
SMV	*Soybean mosaic virus*
SSSV	*Soybean severe stunt virus*
SLCV	*Squash leaf curl virus*
SqMV	*Squash mosaic virus*
SqVYV	*Squash vein yellowing virus*
SLCMV	*Srilankan cassava mosaic virus*
SCV	*Strawberry crinkle virus*
SLRSV	*Strawberry latent ringspot virus*
SMoV	*Strawberry mottle virus*
SCRLV	*Subterranean clover red leaf virus*
SCSV	*Subterranean clover stunt virus*
SBYV	*Sugar beet yellows virus*
SCFDV	*Sugarcane Fiji disease virus*
SCMV	*Sugarcane mosaic virus*
SCSMV	*Sugarcane streak mosaic virus*
SCYLV	*Sugarcane yellow leaf virus*
SuCMoV	*Sunflower chlorotic mottle virus*
SNV	*Sunflower necrosis virus*
SHMV	*Sunn-hemp mosaic virus*
SPCSV	*Sweet potato chlorotic stunt virus*
SPFMV	*Sweet potato feathery mottle virus*
SPLV	*Sweet potato latent virus*
SPLCV	*Sweet potato leafcurl virus*
SPMMV	*Sweet potato mild mottle virus*
SPMSV	*Sweet potato mild speckling virus*
SPSVV	*Sweet potato sunken vein virus*
SPV	*Sweet potato virus*
SPVD	*Sweet potato virus disease*
TaBV	*Taro bacilliform virus*
TEV	*Tobacco etch virus*

TLCV	*Tobacco leaf curl virus*
TMGMV	*Tobacco Mild Green Mosaic Virus*
TMV	*Tobacco mosaic virus*
TNV	*Tobacco necrosis virus*
TRV	*Tobacco rattle virus*
TRSV	*Tobacco ring spot virus*
TSV	*Tobacco streak virus*
TStV	*Tobacco stunt virus*
TVCV	*Tobacco vein clearing virus*
TVMV	Tobacco vein mottling virus
TASVd	*Tomato apical stunt viroid*
TAV	*Tomato aspermy virus*
TBRV	*Tomato black ring virus*
TBSV	*Tomato bushy stunt virus*
ToCV	*Tomato chlorosis virus*
TCSV	*Tomato chlorotic spot virus*
TGMV	*Tomato golden mosaic virus*
TICV	*Tomato infectious chlorosis virus*
ToLCV	*Tomato leaf curl virus*
ToMV	*Tomato mosaic virus*
ToMoV	*Tomato mottle virus*
TPCTV	*Tomato pseudo-curly top virus*
ToRSV	*Tomato ring spot virus*
TSWV	*Tomato spotted wilt virus*
ToTV	*Tomato torrado virus*
TYLCV	*Tomato yellow leaf curl virus*
TriMV	*Triticum mosaic virus*
TBV	*Tulip breaking virus*
TCV	*Turnip crinkle virus*
TuMV	*Turnip mosaic virus*
TYMV	*Turnip yellow mosaic virus*
ULCV	*Urdbean leaf crinkle virus*
WBNV	*Watermelon bud necrosis virus*
WMV	*Watermelon mosaic virus*
WSMoV	*Watermelon silver mottle virus*
WSSMV	*Wheat spindle streak mosaic virus*
WSMV	*Wheat streak mosaic virus*
WCCV	*White clover cryptic virus*
WClMV	*White clover mottle virus*
WTO	World Trade Organization
WTV	*Wound tumor virus*
YMMV	*Yam mild mosaic virus*
YMV	*Yam mosaic virus*
ZYMV	*Zucchini yellow mosaic virus*

Chapter 1
Ecology and Epidemiology of Virus and Viroid Diseases of Tropical Crops

1.1 Introduction

Generally for distinguishing the differences between the terms ecology and epidemiology, there are no clear cut differences. The ecology describes the factors influencing the behavior of a virus in a given physical situation. These factors include host-range, tissue tropism, pathogenesis and host responses. It is a fundamental concept based on the relational properties of the virus and is not a property of the environment. Epidemiology is the study of the determinants, dynamics and distribution of disease caused by virus and virus-like pathogens in host populations over time and space. It includes a dimensional aspect of the factors determining the spread of a virus into a given situation, as it is influenced by environmental factors, rate of pathogen (virus), reproduction, mode of viral dispersal, efficiency of virus survival, level of aggressiveness of the virus, level of host plant resistance, and others. The epidemics is the progress of disease in time and space. The magnitude of disease intensity depends on the initial level of disease and the rate of increase, the disease intensity either low or high at a given time during the epidemics. A directory of plant pathology defines an epidemics as a "wide spread increase, usually limited in time, in the incidence of infectious disease". When the epidemics occur over large areas, with high levels of disease, it is known as pandemic. The epidemics may cause minor to moderate losses and occasionally epidemics may also get out of control and become extremely wide spread. For example, in sub-Saharan Africa, since 1900 there were more than 15 epidemics due to rosette virus in groundnut with losses of up to £ 200 million for epidemics. Similarly, *African cassava mosaic virus* epidemics have caused £ 40 million loss annually affecting 60,000 ha of cassava. The two terms, ecology and epidemiology are often interlink but each has a specific meaning (Hull 2002).

Kranz (1990) defines epidemiology subject as "the science of populations in populations of host plants, and the diseases resulting there from under the influence of the environment and human interferences". The foundations of the modern plant epidemiology were laid down by Gregory (1968). He examined in great detail how different forms of disease gradients in space arose and how these

K. S. Sastry and T. A. Zitter, *Plant Virus and Viroid Diseases in the Tropics*,

DOI: 10.1007/978-94-007-7820-7_1,

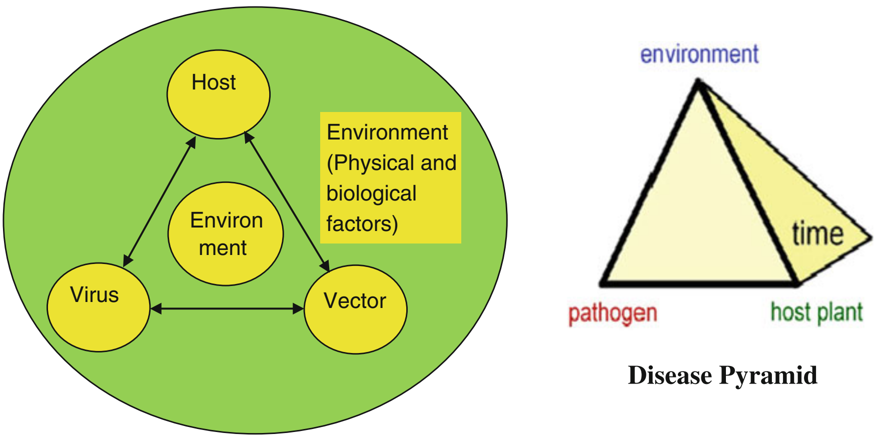

Fig. 1.1 Diagrammatic representation of interactions between plant-virus-vector as influenced by environmental factors

developed over time. For the past two decades molecular techniques are extensively used in ecological and epidemiological studies and the word molecular ecology is coined. The molecular ecology is most useful for the management of tropical plant virus diseases. Fargette et al. (2006) have extensively studied molecular ecological aspects of *Cassava mosaic virus, Rice yellow mottle virus,* and *Banana streak virus*. Concepts and techniques of molecular ecology are described in text books (Brown 2002; Beebee and Rowe 2004; Freeland 2005).

Understanding plant virus disease epidemiology is vital to formulating viable disease management practices in a given agro-ecosystem. Various factors that influence the development and progress of plant disease epidemics are variable from the region to region and hence researchers working in different regions have to understand disease epidemics before attempting to control the virus and virus-like diseases. Thus different groups of researchers are involved in studying the epidemiology of a particular crop-virus-vector-environment system (Fig. 1.1).

The factors responsible for virus disease epidemics are (1) The host should be susceptible. (2) The virus should be virulent to cause the disease. (3) The presence of a potential vector. (4) When the above cited factors are present, then several environmental factors play an important role in the disease development. For pedagogical purposes, the triangle is sometimes expanded to a square, pyramid (Fig. 1.1) or multi-dimensional structure to either emphasize the effects of time and / or space on disease, to reflect the influence of humans on diseases (Francl 2001).

Some pathologists represent the specific conditions required for disease development in the form of "Disease Pyramid". Specific conditions must be present for biotic disease to develop. There must be a susceptible host plant, the pathogen and environmental conditions conducive for disease development and must come together in a given point in time. These conditions make up what is called the "Plant Disease Pyramid". Biotic disease cannot occur if one of these pieces is missing (Fig. 1.1).

Due to the hectic work involved in the research of plant virus epidemiology, only a few research groups are engaged in studying the epidemiology of virus and viroid diseases. In addition, a very long time is required to generate meaningful data about particular crop-virus-vector system. Further, this study requires constant involvement and periodical visits to the fields to achieve a better understanding of the various factors that contribute to the virus disease epidemics. Even with all these limitations, a meaningful group of disease forecasting systems were developed against a number of virus diseases.

1.2 Epidemiological Concepts

Epidemiology is the science of disease in populations, and is a quantitative discipline with strong conceptual foundations and practical applications. Epidemics which is also known as epiphytotics, of plant diseases will have major impacts on agricultural and horticultural crops with major socio-economic and political consequences. The epidemics are defined as the phenomenon in which a pathogen spreads severely and affects many plant individuals within a population over relatively large area and within a relatively short time frame. An epidemiological tool-kit includes methodologies for analyzing disease progress in time and space, the derivation of key parameters determining the rate of epidemic progress and the extent of control required for disease management. The complexity of biotic interactions affecting plant epidemics is shown by introducing genetic variation in host and pathogen. Epidemic development of virus diseases is influenced by (1) Environmental factors, (2) Rate of virus/viroid replication, (3) Mode of virus dispersal, (4) Efficacy of virus survival, (5) Level of aggressiveness of the virus, and (6) Level of host plant resistance.

For more details on the epidemiological concepts, the reader may refer to representative books/review articles (Thresh 1974a, 1980; Harrison 1981; McLean et al. 1986; Thresh 1991, 2006a, b; Anderson 2005; Jeger 2009; Waggoner and Aylor 2000; Jones et al. 2010; Jones and Barbetti 2012).

To understand the intricacies of various factors that contribute to disease epidemics, involvement of plant virologists/plant pathologists, entomologists, crop specialists and statisticians are needed to facilitate the fruitful epidemiological investigations. Having this in foresight as early as 1978, a scientific society "International plant virus epidemiology" (IPVE) was formed under the chairmanship of Prof. Mike Thresh at the third "International Society of Plant Pathology" (ISPP) congress held at Munich, Germany. The first plant virus epidemiology symposium was held at Oxford, UK in 1981 and IPVE has conducted 11 workshops at 2 years intervals on this topic and the latest 12th Conference was held at Arusha, Tanzania in 2013. The proceedings of the IPVE were published (Plumb and Thresh 1983; McLean et al. 1986; Fereres et al. 2000; Thresh et al. 2004).

Basic information on plant virus ecology and epidemiology is available from different sources (Zitter 1977; Maramorosch and Harris 1981; Plumb and Thresh 1983; Jeger and Chan 1995; Waggoner and Aylor 2000; Zadoks 2001; Fereres et al. 2000; Thresh 2003; Thresh and Fargette 2003; Jeger et al. 2004; Anderson and Morales 2005; Fargette et al. 2006; Madden et al. 2007; Jones 2009; Makkouk and Kumari 2009; Pappu et al. 2009; Jones et al. 2010; Patil and Fauquet 2011; Jones and Barbetti 2012).

In addition, researchers have worked out the information related to plant virus ecology and epidemiology in different crop-virus-pathosystems, for example, exhaustive information is available on *Tospoviruses* (Reddy et al. 1983a; Van Os et al. 1993; Gitaitis et al. 1998; Culbreath et al. 2003; Wells et al. 2003; Coutts et al. 2004a; Jones 2004; Ranganath et al. 2006; Pappu et al. 2009; Naidu 2013); *Begomoviruses* (Muniyappa 1980; Cohen and Antignus 1994; Thresh et al. 1994; Sserubombwe et al. 2001; Fondong et al. 2002; Morales 2004; Morales and Jones 2004; Anderson and Morales 2005; Patil and Fauquet 2011); *Tomato mottle Geminivirus* (Polston et al. 1996); *Rice tungro virus* disease complex (Yadav and Mishra 1990; Anjaneyulu et al. 1994; Hibino 1996; Varma et al. 1999; Osmat 2000; Azzam and Chancellor 2002; Muralidharan et al. 2003; Chancellor et al. 2006; Krishnaveni et al. 2011); *Rice yellow mottle virus* (Reckhaus and Andriamasintscheno 1997; Fargette et al. 2006); *Rice hoja blanca virus* in rice (Morales and Jennings 2010); *Maize streak virus* (Rose 1978; Asanzi et al. 1994; Bosque-Perez and Buddenhagen 1999; Smith et al. 2000; Magenya et al. 2008); *Maize chlorotic dwarf virus* in maize (Madden et al. 1990a); PVY, PLRV in potato (Jones 1981; Shahid Ali et al. 2013); *African cassava mosaic virus* (Bock 1983; Fauquet et al. 1988; Fauquet and Fargette 1990; Thresh 1991; Fargette et al. 1993, 1994a, b; Holt et al. 1997; Legg et al. 1997; Calvert and Thresh 2002; Jeger et al. 2004) and *Cassava brown streak virus* in cassava (Jeremiah et al. 2013); *Cucumber mosaic virus* in chilli, tomato and eggplant (Kiranmai et al. 1998) and in lupine (Thackray et al. 2004); *Barley yellow dwarf virus* in barley (Irwin and Thresh 1990; Burges et al. 1999); *Yellow vein mosaic virus* in okra (Chellaiah and Murugesan 1976; Khan and Mukhopadhyay 1985; Pun and Doraisamy 2000; Kalita et al. 2005); *Tobacco leaf curl virus* in tobacco (Valand and Muniyappa 1992); *Tomato leaf curl virus* in tomato (Sastry et al. 1978; Saikia and Muniyappa 1989; Ramappa et al. 1998; Jeger et al. 2004); *Tomato yellow leaf curl virus* (Mazyad et al. 1979; Ioannau and Iordanou 1985; Cohen et al. 1988; Aboul-Ata et al. 2000; Czosnek 2007); *Yellow mosaic disease* of horsegram in *Macrotyla uniflorum* (Horsegram) (Muniyappa 1983); *Yellow mosaic disease* of soybean (Gupta and Keshwal 2003); *Soybean mosaic virus* in soybean (Irwin and Goodman 1981; Almeida et al. 1994; Irwin et al. 2000); *Pigeonpea-sterility mosaic virus* in pigeonpea (Singh and Rathi 1997; Kumar et al. 2008a); *Bean yellow mosaic virus* in lupin (Thackray et al. 2002); *Bean golden mosaic virus* (Anderson and Morales 2005); *Bean leaf roll virus* and *Chickpea chlorotic stunt virus* in legumes (Makkouk and Kumari 2009); *Groundnut rosette virus* (Naidu et al. 1998); *Indian peanut clump virus* in groundnut (Delfosse 2000); *Iris yellow spot virus* in onion (Pappu et al. 2007); *Tomato spotted wilt virus* in lettuce and pepper (Coutts et al. 2004a);

Tobacco streak virus in sunflower (Nagaraju et al. 2003; Shivasharanayya and Nagaraju 2003; Upendhar et al. 2006; Chandra Mohan et al. 2006; Lakhmod et al. 2007; Lokesh et al. 2008; Kumar et al. 2008a); and virus diseases in sweet potato (Alicai et al. 1999; Byamukama et al. 2004). Epidemiological studies were also carried out against major virus diseases of certain fruit crops viz., tristeza in citrus species (Gottwald et al. 2002); plumpox virus in stone fruits (Dallot et al. 2003; Budzanivska et al. 2011); *Blackberry yellow vein associated virus* in blackberry (Poudel et al. 2013); bunchy top virus in banana (Allen 1978; Smith et al. 1998).

All these cited examples are concerned to epidemiological studies of different virus diseases which have various types of insects as vectors. Epidemiological studies were also carried out on viroid diseases which have no insect-vectors and generally spread through true seed and vegetative plant material. Even weed and collateral hosts helps in viroid disease spread as seen in PSTVd in tomato and *Chrysanthemum mottle viriod* in chrysanthemum (Yamamoto and Sano 2006; Verhoeven et al. 2010).

1.3 Conditions Favorable for Epiphytotics

Virus and viroid pathogens will not always be able to cause a disease unless environmental conditions and suitability of the host are also favourable for survival, multiplication, and entry of the pathogen into the plant and further development of the disease. For causing (epidemics) epiphytotics, the pathogen has to be virulent in the first place; the host has to be susceptible, and the environmental conditions like temperature, relative humidity, soil moisture, soil pH, and soil type, need to be favourable (Nayudu 2008; Jones 2013). Disease will not develop if anyone of the three conditions is not fulfilled.

If all the criteria are not fulfilled, such as susceptible host and pathogen are present but the environment is not conductive to the pathogen infecting and causing disease, disease cannot occur. Likewise, if the host is susceptible and the environment favors the development of disease but the pathogen is not present, there is no disease (Fig. 1.2). Sometimes a fourth factor of time is added as the time at which a particular infection occurs, and the length of time conditions remain viable for that infection, can also play an important role in epidemics.

1.3.1 Physical Factors

(a) **Air temperature**

The changes in air temperature will alter the distribution and prevalence of viruses and vectors. However, one cannot anticipate the emergence of entirely new problems as a consequence of global warming.

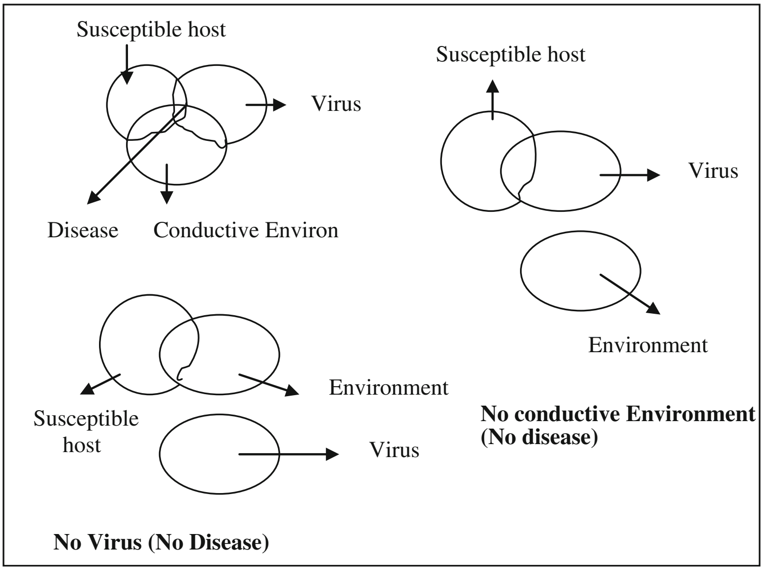

Fig. 1.2 Criteria for virus disease development

There is a close correlation between the air temperature and the insect vector population primarily the whitefly (*Bemisia tabaci*). Whitefly transmitted geminiviruses are major problems in almost all tropical countries. Among the major geminiviruses are: *African cassava mosaic virus* in Africa; *Bean golden mosaic virus* in Brazil, Puerto Rico and Guatemala; *Cotton leaf curl virus* in Pakistan and India; *Tomato leaf curl virus* and *Rice tungro virus* in southeast Asian countries and *Tomato yellow leaf curl virus* (TYLCV) in Israel, Spain, Italy and some other tropical countries. In recent years, *Torradoviruses* which includes *Tomato torrado virus,* has been associated with the green-house whitefly, *Trialeurodes vaporariorum* in Poland as well as *B. tabaci* elsewhere.

Weather data collected at UAS, Bangalore where experiments involving the incidence of TLCV and whitefly populations were conducted, indicated high temperature, low humidity and low rain fall from January to May, coincided with the increase in the whitefly vector population. The low whitefly populations during July–November were perhaps due to low temperatures, high rainfall, and high humidity (see Fig. 1.3).

The impact of the virus diseases on yield is presented in the Chapter-3 of Volume I. Temperature plays a key role in the population dynamics and activity of whiteflies.

Temperatures of 20–30 °C favour large populations of whitefly and are associated with high fecundity, and greater longevity (Cock 1986; Fargette et al. 1994a, b). In Latin America, *Bean golden mosaic virus* (BGMV) was transmitted by *B. tabaci*, and the optimum vector population was at the warmer temperatures of 26.7 °C (26.5 %) or above. Generally, the inciting virus is most important at

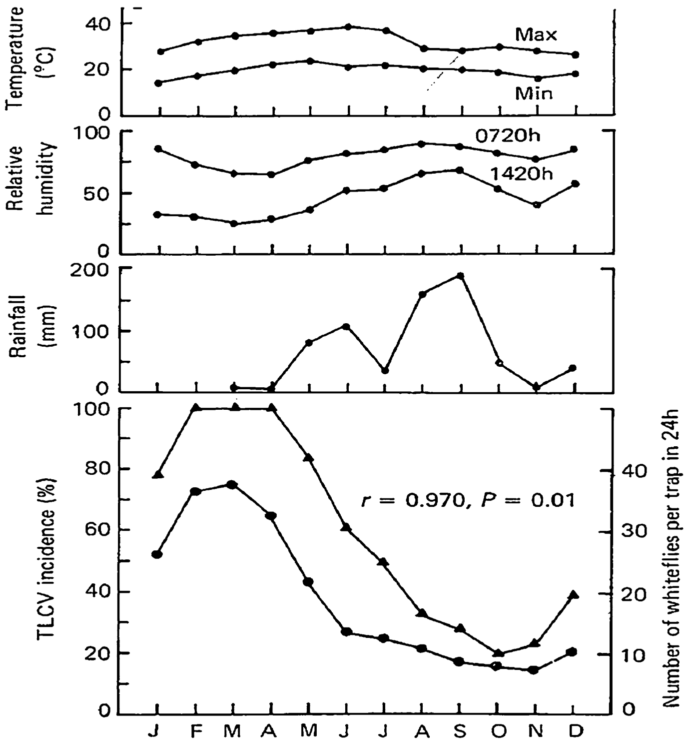

Fig. 1.3 TLCV incidence in relation to whitefly numbers and weather conditions during 1983; ●, whitefly density; ▲, TLCV level. *Source* Saikia and Muniyappa (1989)

elevations below 2,000 m, where whitefly populations, inoculum sources and warm temperatures are more common (Anderson and Morales 2005; Morales 2006).

In India epidemiological studies were conducted against *Tomato leaf curl virus* (TLCV) transmitted by *B. tabaci* by planting tomato crop in March, July and November months by Saikia and Muniyappa (1989). In the March (summer) planted tomato crop the TLCV incidence appeared 2 weeks after planting; spread was initially slow but from 5 weeks onwards the incidence increase rapidly, reaching 100 % by 11 weeks. In the July planted crops, symptoms of TLCV were first observed 3 weeks after planting, and then increased slowly in incidence, reaching 59 % at 14 weeks after planting. In the November planted tomato crop symptoms first appeared 4 weeks after planting and a maximum of 66 % TLCV incidence was observed 14 weeks after planting (Fig. 1.4).

The air temperatures will also have marked effects on the rate of multiplication and movement of airborne virus vectors. For example, aphid vector populations will be reduced at higher temperatures and with reasonably warm temperatures the winged alates tend to fly.

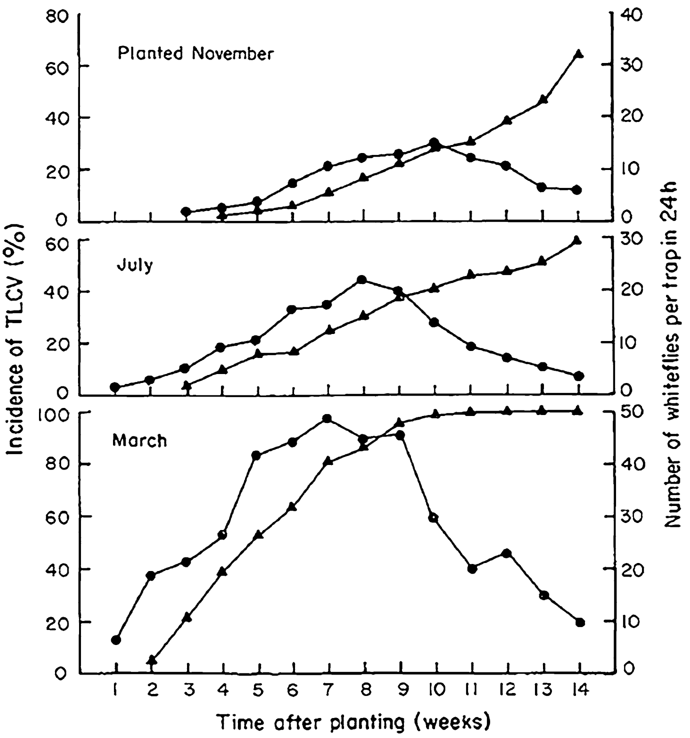

Fig. 1.4 Spread of TLCV in relation to whitefly numbers in different seasons during 1983; ●, whitefly, density; ▲, TLCV level. *Source* Saikia and Muniyappa (1989)

In central India growth of the potato crop under high temperatures (30–35 °C) and dry weather during September–October months favors thrips activity to the maximum extent and thus potentially cause higher incidence of *Groundnut bud necrosis virus* (GBNV). In the crops planted after October 15th, low activity of thrips and thus low GBNV incidence occurs. Therefore, potato planting after the end of October is helpful in reducing GBNV disease incidence by avoiding crop exposure to thrips vectors (Somani et al. 2007); similar studies have been reported for GBNV (also called *Peanut bud necrosis virus*) in greengram (Sreekanth et al. 2002). Similarly in India, the high incidence of *Tomato leaf curl virus* in tomato (Saikia and Muniyappa 1989) and *Indian peanut clump virus* (IPCV) in peanut (Delfosse 2000) are related to humidity and temperature.

The air temperature will also have marked effects on the rate of multiplication and movement of the air-borne virus vectors. For example aphid populations at higher temperatures will be reduced, while at reasonably warm temperatures the winged alates tend to fly.

An economically important virus of rice is *Rice tungro virus* which is caused by two viruses, *Rice tungro bacilliform* and *Rice tungro spherical viruses* which are