K. Subramanya Sastry

Plant Virus and Viroid Diseases in the Tropics

Volume 1: Introduction of Plant Viruses and Sub-Viral Agents, Classification, Assessment of Loss, Transmission and Diagnosis

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Foreword

The detection of a *contagium vivum fluidum* associated with a *mosaic* disease of tobacco in Europe at the close of the nineteenth century, was the beginning of a century of major achievements in the advancement of biological sciences. The demonstration in 1937 that *Tobacco mosaic virus* (TMV), was a nucleoprotein, and that its nucleic acid (RNA), contained the genetic information necessary to induce disease in tobacco, set the stage for the advent of genetics, molecular biology, transgenic technology, and the use of viruses as molecular tools. The physicochemical characterization of TMV also lead to the diffusion of modern technologies, such as virus purification (centrifugation), immunology, electrophoresis, electron microscopy, protein and nucleic acid sequencing, and atomic structure of nucleoproteins (X-ray analysis). These developments would eventually make a major contribution to the understanding of the structure of DNA by Watson and Crick in 1953. Finally, these breakthroughs then paved the way to the advent of Molecular Biology, bringing about the greatest revolution in the multiple fields of biological sciences.

However, TMV had a humble origin in the lowlands of tropical South America, where tobacco had been cultivated by the native societies, until the Spanish conquistadores turned it into a commercial export commodity during colonial times. In the nineteenth century, tobacco was being widely grown in Europe as a medicinal plant and, consequently, the stage was set for the emergence of one of the first global epiphytotics of a highly contagious plant virus. In 1887, Dmitri Ivanovsky was sent from the University of Saint Petersburg, the imperial capital of Russia, to investigate a disease affecting tobacco plantations in Ukraine. In 1892, Ivanovsky demonstrated that the causal agent was not excluded by a porcelain filter capable of retaining bacteria, the only known microbial pathogen at that time. In 1898, Martinus Beijerinck confirmed Ivanovsky′s observations in The Netherlands and, thus, the science of Plant Virology was born.

Despite the significant progress made in plant virology in the twentieth century, the detection and characterization of many plant viruses of economic importance remained elusive until the 1980s, particularly in the Tropics, where plant virology facilities were non-existent or very poorly equipped due to the difficult nature of

plant viruses (non-culturable) and lack of the expensive equipments needed to characterize these pathogens up to that decade. Consequently, the early plant virologist had to be thoroughly trained in the various fields of the agricultural sciences: agronomy, genetics, plant breeding, plant physiology, epidemiology, entomology, and plant pathology, in order to manage the viral diseases of crops, often without knowing the causal agent. The advent of molecular biology and the application of molecular techniques, such as the Polymerase Chain Reaction (PCR), to the detection and characterization of plant viruses possessing RNA or DNA genomes, completely changed the field of Plant Virology in the 1980s. All of the sudden, plant virologists only needed partial nucleic acid sequences and a relatively inexpensive PCR machine to detect and identify plant viruses, without the need to visualize, purify, conduct serological assays, or undertake lengthy and complex physicochemical assays to characterize plant viruses. All that was needed to identify viruses was a suitable pair of primers (a strand of nucleic acid that serves as a starting point for DNA synthesis) to obtain partial or total viral genome sequence data to compare to reported viral sequences freely available in databases such as GenBank.

The adoption of molecular techniques not only facilitated research on plant viruses, but it also changed agricultural education and research in areas of critical importance to the science of Plant Virology. Advances in tissue culture techniques, molecular markers, and the genetic manipulation of plant genomes rapidly shifted the attention from traditional plant breeding and traditional virus screening techniques to the promise of selection of virus resistant plant genotypes in molecular biology laboratories using molecular markers. More important, acquiring a basic knowledge in agricultural sciences was no longer required. Instead, a new generation of molecular biologists was formed to deal with any phytopathological problem regardless of the causal organism, be it a fungus, bacterium, or virus. Thus, the new virologist is usually a molecular biologist who chose to work with plant viruses, without former training in agricultural sciences.

Whereas the science of Plant Virology has immensely benefited from the adoption of the new molecular techniques; and conducting plant virus research without a basic working knowledge of molecular biology is no longer possible or desirable in this new millennium, the new generation of molecular virologists need to know the foundations of Plant Virology. Basically, the science of plant pathology, the agronomy of the plant species affected, and the genetic interaction of plant viruses with their plant hosts and vectors. Finally, any virologist must understand how plant viruses are disseminated in nature, and the various control measures available to manage the viral diseases of economically important food and industrial crops. Hence, the importance of a comprehensive book like this one written by Dr. K. Subramanya Sastry, presented in different volumes which describe the nature of plant viruses and viroids, their classification and identification, and the main viral and viroids pathogens that affect food production in the most challenging and dynamic agricultural system in the world: the Tropics.

The virus detection techniques described are completely up-to-date, including the latest molecular techniques developed in the world for the detection and characterization of viruses and viroids in general. The interested readers, professors, and students of agricultural sciences, and specially plant pathologists, will find this publication a complete source of information on the science of Plant Virology in the Tropics.

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Emeritus Scientist
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Preface

Virus and viroid diseases have become increasingly important constraints to sustainable crop production in the tropical countries. The climatic changes that are occurring throughout the world have impact on plants, vectors, and viruses causing increasing instability within virus–host ecosystems. Some of the threatening and economically important virus diseases in tropical zone which affect the food production 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, clump, and bud necrosis in peanut; necrosis in sunflower and legumes, vegetables, and ornamental crops; yellow mosaic in legumes; leaf curl in cotton and tomato; and ring spot 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.

Largest group of plant viruses exist in the family *Potyviridae* followed by *Geminiviridae* and *Bunyaviridae*. In tropical countries, whitefly transmitted begomoviruses are responsible for heavy crop losses in cassava, cotton, tobacco, tomato, potato, pepper, squash, okra. etc. The tospo- and ilarviruses are wide spread in tropics and affect several important field, horticultural and ornamental crops resulting in serious economic damage in crops like groundnut, sunflower, onion, watermelon, and vegetables like tomato, chillies, and potatoes. Divergence exists in the type of vectors and their population from country to country, for example Hemipterans (aphids, whiteflys, leafhoppers, mealybugs, and others) are the major vectors of plant virus and virus like diseases, comprising more than 80 % of insect-transmitted viruses which represents close to 400 virus species within 39 different genera.

The primary aim of this book is to provide to readers with latest information on different virus and viroid diseases of crops in tropical countries. This volume comprises of five chapters that give an overview of the progress made on virus and viroid diseases of crops of tropics. The first chapter deals with general information on tropics and climate, tropical countries and tropical agriculture; second chapter provides information on viruses, viroids, phytoplasma, and other subviral agents; third chapter on impact of virus and viroid disease on tropical crops; the fourth chapter on various modes of transmission of virus and virus-like agents. Various

methods for detection and diagnosis of viruses and viroid disease of tropical crops are extensively reviewed in the fifth chapter.

Since the inception of plant virology, phytoplasma is dealt along with plant viruses, hence a few pages were devoted in this book for providing background information about phytoplasma for traditional scientists/researchers. Even though the attempt is only to include the examples from tropical zone but it was not possible to confine to tropical examples as successful research outcomes are there from temperate zone; hence, some examples from temperate zone were also referred. If any omissions have occurred inadvertently in seeking permissions for figures and tables, it may please be condoned.

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.

K. Subramanya Sastry

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K. Subramanya Sastry

Acronyms

A1MV	*Alstroemeria mosaic virus*
ABMV	*Azuki bean mosaic virus*
AbMV	*Abaca mosaic potyvirus*
AbMV	*Abutilon mosaic virus*
ACLSV	*Apple chlorotic leaf spot*
ACMV	*African cassava mosaic virus*
AGVd	*Australian grapevine viroid*
AMV	*Alfalfa mosaic virus*
APLV	*Andean potato latent virus*
ApMV	*Apple mosaic virus*
ArMV	*Arabis mosaic virus*
ARSV	*Apple ring spot virus*
ASBVd	*Avocado Sunblotch viroid*
ASGV	*Apple stem grooving virus*
ASPV	*Apple stem pitting virus*
ASSVd	*Apple scar skin viroid*
AYRSV	*Artichoke yellow ring spot virus*
BaMMV	*Barley mild mosaic virus*
BaMV	*Bamboo mosaic virus*
BaYMV	*Barley yellow mosaic virus*
BBMV	*Broad bean mottle virus*
BBrMV	*Banana bract mosaic virus*
BBSV	*Broad bean stain virus*
BBTMV	*Broad bean true mosaic virus*
BBTV	*Banana bunchy top virus*
BBWV	*Broad bean wilt virus*
BCaMV	*Bean calico mosaic virus*
BCMNV	*Bean common mosaic necrotic virus*
BCMV	*Bean common mosaic virus*
BCTV	*Beet curly top virus*
BDBV	*Banana dieback virus*
BDMV	*Bean dwarf mosaic virus*
BGMV	*Bean golden mosaic virus*

BGYMV	*Bean golden yellow mosaic virus*
BICMV	*Black eye cowpea mosaic virus*
BLMV	*Blue berry leaf mottle virus*
BLRV	*Bean leaf roll virus*
BlShV	*Blueberry Shock Ilarvirus*
BMCTV	*Beet mild curly top virus*
BMoV	*Blackgram mottle virus*
BMV	*Brome mosaic virus*
BMYV	*Beet mild yellowing virus*
BNYV	*Broccoli necrotic yellows virus*
BNYVV	*Beet necrotic yellow vein virus*
BPMV	*Bean pod mottle virus*
BRSV	*Beet ringspot virus*
BSGFV	*Banana streak GF virus*
BSMV	*Barley stripe mosaic virus*
BSMV	*Beet stripe mosaic virus*
BSMyV	*Banana streak Mysore virus*
BSOLV	*Banana streak OL virus*
BSUgIV	*Banana streak Uganda I virus*
BSUgLV	*Banana streak Uganda L virus*
BSUgMV	*Banana streak Uganda M virus*
BSV	*Banana streak virus*
BtMV	*Beet mosaic virus*
BWYV	*Beet western yellows virus*
BYDV	*Barley yellow dwarf virus*
BYMV	*Bean yellow mosaic virus*
BYSV	*Bean yellow stipple virus*
BYSV	*Beet yellows stunt virus*
BYV	*Beet yellows virus*
BYVMV	*Bhendi yellow vein mosaic virus*
CABMV	*Cowpea aphid borne mosaic virus*
CaCV	*Capsicum chlorosis virus*
CaMV	*Cauliflower mosaic virus*
CarMV	*Carnation mottle virus*
CBDV	*Colocasia bobone disease virus*
CBMV	*Common bean mosaic virus*
CbMV	*Calibrachoa mottle virus*
CBRV	*Cabbage black ring virus*
CBSV	*Cassava brown streak virus*
CBSUV	*Cassava brown streak Uganda virus*
CbVd-1	*Coleus blumei viroid 1*
CbVd-2	*Coleus blumei viroid 2*

CCCVd	*Coconut cadang–cadang viroid*
CChMVd	*Chrysanthemum chlorotic mottle viroid*
CCMV	*Cowpea chlorotic mottle virus*
CCSV	*Cucumber chlorotic spot virus*
CCSV	*Calla lily chlorotic spot virus*
CCSV	*Cassava Colombian symptomless virus*
CdMV	*Cardamom mosaic virus*
CeMV	*Celery mosaic virus*
CEVd	*Citrus exocortis viroid*
CFDV	*Coconut foliar decay virus*
CFMMV	*Cucumber fruit mottle mosaic virus*
CFSV	*Cassava frogskin virus*
CGMMV	*Cucumber green mottle mosaic virus*
CGMV	*Cassava green mottle virus*
ChiLCV	*Chilli leaf curl virus*
CIBV	*Cassava ivorian bacilliform virus*
CiLV	*Citrus leprosis virus*
CiMV	*Citrus mosaic virus*
CiTLV	*Citrus tatter leaf virus*
CIVV	*Citrus infectious variegation virus*
CLCrV	*Cotton leaf crumple virus*
CLCuAV	*Cotton leaf curl Allahabad virus*
CLCuBV	*Cotton leaf curl Bangalore virus*
CLCuBuV	*Cotton leaf curl Burewala virus*
CLCuKV	*Cotton leaf curl Kokhran virus*
CLCuMV	*Cotton leaf curl Multan virus*
CLCuRV	*Cotton leaf curl Rajasthan virus*
CLCuV	*Cotton leaf curl virus*
CLRV	*Cherry leaf roll virus*
CLVd	*Columnea latent viroid*
ClYMV	*Clover yellow mosaic virus*
ClYVV	*Clover yellow vein* virus
CMBV	*Citrus mosaic badnavirus*
CMDV	*Carrot mottley dwarf virus*
CMV	*Cucumber mosaic virus*
CNV	*Cocao necrosis virus*
CoYMV	*Commelina yellow mottle virus*
CpBMV	*Cowpea banding mosaic virus*
CpCDV	*Chickpea chlorotic dwarf virus*
CpCSV	*Chickpea chlorotic stunt virus*
CPFVd	*Cucumber pale fruit viroid*
CpGMV	*Cowpea golden mosaic virus*
CpMMV	*Cowpea mild mottle virus*
CPMoV	*Cowpea mottle virus*
CpMV	*Cowpea mosaic virus*

CPSMV	*Cowpea severe mosaic virus*
CPsV	*Citrus psorosis virus*
CRSV	*Citrus ring spot virus*
CsALV	*Cassava American latent virus*
CsCMV	*Cassava common mosaic virus*
CSNV	*Chrysanthemum stem necrosis virus*
CSSV	*Cocoa swollen shoot virus*
CSVd	*Chrysanthemum stunt viroid*
CsVX	*Cassava virus X*
CTLV	*Carrot thin leaf virus*
CTV	*Citrus tristeza virus*
CuNV	*Cucumber necrosis virus*
CVMV	*Cassava vein mosaic virus*
CVMV	*Chilli veinal mottle virus* (*Syn. Pepper vein banding mosaic virus*)
CVV	*Citrus variegation virus*
CVYV	*Cucumber vein yellowing virus*
CymMV	*Cymbidium mosaic virus*
CymRSV	*Cymbidium ringspot virus*
CYMV	*Chicory yellow mottle virus*
CYMV	*Citrus yellow mosaic virus*
CYSDV	*Cucurbit yellow stunt disorder virus*
DAV	*Dapple apple virus*
DBV	*Dioscorea bacilliform virus*
DoYMV	*Dolichos yellow mosaic virus*
DsMV	*Dasheen mosaic virus*
EACMCV	*East African cassava mosaic Cameroon virus*
EACMV	*East African cassava mosaic virus*
ELCV	*Enation leaf curl virus*
EMDV	*Eggplant mottled dwarf virus*
EMV	*Eggplant mosaic virus*
FBNYV	*Faba bean necrotic yellows virus*
FLNV	*Freesia leaf necrosis virus*
GBLV	*Grapevine Bulgarian latent virus*
GBNV/PBNV	*Groundnut bud necrosis virus*
GFkV	*Grapevine fleck virus*
GFLV	*Grapevine fan leaf virus*
GLRaV-1	*Grapevine leafroll-associated virus-1*
GLRaV-2	*Grapevine leafroll-associated virus-2*
GLRaV-3	*Grapevine leafroll-associated virus-3*
GLRV	*Grapevine leafroll virus*
GMMV	*Gayfeather mild mottle virus*
GRSPaV	*Grapevine rupestris stem pitting-associated virus*
GRSV	*Groundnut ringspot virus*
GRV	*Groundnut rosette virus*

GSLV	*Guar symptomless virus*
GVA	*Grapevine Virus*-A
GVB	*Grapevine virus B*
GYSV	*Grapevine* Yellow Speckle Viroid
HgYMV	*Horsegram yellow mosaic virus*
HPV	*High plains virus*
HSVd	*Hop stunt viroid*
ICMV	*Indian cassava mosaic virus*
INSV	*Impatiens necrotic spot virus*
IPCV	*Indian peanut clump virus*
IYSV	*Iris yellow spot virus*
JMV	*Jatropha mosaic virus*
JYMV	*Japanese yam mosaic virus*
KGMMV	*Kyuri green mottle mosaic virus*
KMV	*Konjac mosaic virus*
LALV	*Lucerne Australian latent virus*
LBGMV	*Lima bean golden mosaic virus*
LBVV	*Lettuce big vein virus*
LCV	*Lettuce chlorosis virus*
LiYV	*Lettuce infectious yellows virus*
LMV	*Lettuce mosaic virus*
LNYV	*Lettuce necrotic yellows virus*
LTSV	*Lucerne transient streak virus*
LYSV	*Leek yellow stripe virus*
MCDV	*Maize chlorotic dwarf virus*
MCLCuV	*Melon chlorotic leaf curl virus*
MCMV	*Maize chlorotic mottle virus*
MDMV	*Maize dwarf mosaic virus*
MeCMV	*Melon chlorotic mosaic virus*
MLRV	*Myrobalan latent ringspot virus*
MMV	*Maize mosaic virus*
MNSV	*Melon necrotic spot virus*
MPVd	*Mexican papita viroid*
MRDV	*Maize rough dwarf virus*
MRFV	*Maize rayado fino virus*
MRMV	*Melon rugose mosaic virus*
MRSV	*Mulberry ring spot virus*
MSMV	*Melon severe mosaic virus*
MSpV	*Maize stripe virus*
MSV	*Maize streak virus*
MYMV	*Mungbean yellow mosaic virus*
MYSV	*Melon yellow spot virus*
NVMV	*Nicotiana velutina mosaic virus*
OGSV	*Oat golden stripe virus*
OkMV	*Okra mosaic virus*

OLCV	*Okra leaf curl virus*
OLV-1	*Olive latent virus-1*
OLV-2	*Olive latent virus-2*
ORSV	*Odontoglossum ringspot virus*
OYDV	*Onion yellow dwarf virus*
OYVMV	*Okra yellow vein mosaic virus*
PaLCuV	*Papaya leaf curl virus*
PAMV	*Potato aucuba mosaic virus*
PapMV	*Papaya mosaic virus*
PBCVd	*Pear blister canker viroid*
PBNV	*Peanut bud necrosis virus*
PCFV	*Peanut chlorotic fanspot virus*
PCFVd	*Pepper chat fruit viroid*
PCV	*Peanut clump virus*
PDV	*Prune dwarf virus*
PEBV	*Pea early browning virus*
PEMV	*Pea enation mosaic virus*
PepGMV	*Pepper golden mosaic virus*
PepLCBV	*Pepper leaf curl Bangladesh virus*
PepLCV	*Pepper leaf curl virus*
PepMoV	*Pepper mottle virus*
PepMV	*Pepino mosaic virus*
PeSV	*Pea streak virus*
PLMVd	*Peach latent mosaic viroid*
PLRV	*Potato leafroll virus*
PLRV	*Pea leaf roll virus*
PMiMV	*Pea mild mosaic virus*
PMMoV	*Pepper mild mottle virus*
PMTV	*Pepper mild tigre virus*
PMTV	*Potato mop top virus*
PMV	*Panicum mosaic virus*
PMV	*Pea mosaic virus*
PMV	*Peanut mottle virus*
PMWaV-1	*Pineapple mealybug wilt associated virus-1*
PMWaV-3	*Pineapple mealybug wilt associated virus-3*
PNRSV	*Prunus necrotic ringspot virus*
PopMV	*Poplar mosaic virus*
PoRSV	*Polygonum rings pot virus*
PPSMV	*Pigeon pea sterility mosaic virus*
PPV	*Plum pox potyvirus*
PRMV	*Peach rosette mosaic virus*
PRSV	*Papaya ring spot virus*
PSbMV	*Pea seed-borne mosaic virus*
PSMV	*Physalis silver mottle virus*
PStV	*Peanut stripe virus*

PSTVd	*Potato spindle tuber viroid*
PSV	*Peanut stunt virus*
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*
PYMoV	*Piper yellow mottle virus*
PYMV	*Pepper yellow mottle virus*
PYMV	*Potato yellow mosaic virus*
PYSV	*Peanut yellow spot virus*
PYVHV	*Pepper yellow vein huasteco virus*
PYVV	*Potato yellow vein virus*
PZSV	*Pelargonium zonate spot virus*
RBDV	*Raspberry bushy dwarf virus*
RDV	*Rice dwarf virus*
RGMV	*Rye grass mosaic virus*
RGSV	*Rice grassy stunt virus*
RHBV	*Rice hoja blanca virus*
RMV	*Rice mosaic virus*
RpRSV	*Raspberry ring spot virus*
RRSV	*Rice ragged stunt virus*
RSV	*Rice stripe virus*
RTBV	*Rice tungro bacilliform virus*
RTSV	*Rice tungro spherical virus*
RTV	*Rice tungro virus*
RTYV	*Rice transitory yellowing virus*
RWSV	*Rice wilted stunt virus*
RYEV	*Radish yellow edge virus*
RYMV	*Rice yellow mottle virus*
SACMV	*South African cassava mosaic virus*
SALCV	*Solanum apical leaf curling virus*
SbBMV	*Soybean blistering mosaic virus*
SBMV	*Southern bean mosaic virus*
SBWMV	*Soil-borne wheat mosaic virus*
SBYV	*Sugarbeet yellows virus*
SCBV	*Sugarcane bacilliform virus*
SCLV	*Soybean crinkle leaf virus*
SCMoV	*Subterranean clover mottle virus*
SCMV	*Sugarcane mosaic virus*
SCRLV	*Subterranean clover red leaf virus*
SCSV	*Subterranean clover stunt virus*
SCYLV	*Sugarcane yellow leaf virus*

SCFDV	*Sugarcane Fiji disease virus*
SgCSV	*Sorghum chlorotic spot virus*
SLCMV	*Sri Lankan cassava mosaic virus*
SLCV	*Squash leaf curl virus*
SLRSV	*Strawberry latent ring spot virus*
SLV	*Shallot latent virus*
SMMV	*Soybean mild mosaic virus*
SMV	*Soybean mosaic virus*
SMoV	*Strawberry mottle virus*
SMYEPV	*Strawberry mild yellow edge potexvirus*
SMYEV	*Strawberry mild yellow edges virus*
SNMoV	*Solanum nodiflorum mottle virus*
SoMV	*Sowbane mosaic virus*
SPCFV	*Sweet potato chlorotic fleck virus*
SPCSV	*Sweet potato chlorotic stunt crinivirus*
SPFMV	*Sweet potato feathery mottle potyvirus*
SPLCV	*Sweet potato leafcurl virus*
SPLL	*Sweet potato little leaf*
SpLV	*Spinach latent virus*
SPLV	*Sweet potato latent virus*
SPMMV	*Sweet potato mild mottle virus*
SPMSV	*Sweet potato mild speckling virus*
SPSVV	*Sweet potato sunken vein virus*
SPVD	*Sweet potato virus disease*
SPVMV	*Sweet potato vein mosaic virus*
SPYDV	*Sweet potato yellow dwarf virus*
SqMV	*Squash mosaic virus*
SRMV	*Sunflower rugose mosaic virus*
SrMV	*Sorghum mosaic virus*
SCSMV	*Sugarcane streak mosaic virus*
SuCMoV	*Sunflower chlorotic mottle virus*
SVBV	*Strawberry vein banding virus*
SYMMoV	*Squash yellow mild mottle virus*
SYNV	*Sonchus yellow net virus*
SYVV	*Sowthistle yellow vein virus*
TaBV	*Taro bacilliform virus*
TASVd	*Tomato apical stunt viroid*
TAV	*Tomato aspermy virus*
TBRV	*Tomato black ring virus*
TBSV	*Tomato bushy stunt virus*
TBV	*Tulip breaking virus*
TCSV	*Tomato chlorotic spot virus*
TCV	*Turnip crinkle virus*
TDLCV	*Tomato dwarf leafcurl virus*
TEV	*Tobacco etch virus*

TFMV	*Taro feathery mosaic virus*
TICV	*Tomato infectious chlorosis virus*
TLCPuV	*Tomato leaf curl Pune virus*
TLCrV	*Tomato leaf crumple virus*
TLCV	*Tobacco leaf curl virus*
TLCV	*Tomato leaf curl virus*
TMV	*Tobacco mosaic virus*
TNV	*Tobacco necrosis virus*
ToCMoV	*Tomato chlorotic mottle virus*
ToCV	*Tomato chlorosis virus*
ToLCD	*Tomato leaf curl disease*
ToLCGV	*Tomato leaf curl Gujarat virus*
ToLCKV	*Tomato leaf curl Karnataka virus*
ToLCNDV	*Tomato leaf curl New Delhi virus*
ToMoV	*Tomato mottle virus*
ToMV	*Tomato mosaic virus*
ToRSV	*Tomato ringspot virus*
ToSLCV	*Tomato severe leaf curl virus*
ToTV	*Tomato torrado virus*
ToYMV	*Tomato yellow mosaic virus*
TPCTV	*Tomato pseudo-curly top virus*
TPMVd	*Tomato planta macho viroid*
TriMV	*Triticum mosaic virus*
TRSV	*Tobacco ring spot virus*
TRV	*Tobacco rattle virus*
TStV	*Tobacco stunt virus*
TSV	*Tobacco streak virus*
TSWV	*Tomato spotted wilt virus*
TuMV	*Turnip mosaic virus*
TVMV	*Tobacco vein mottling virus*
TYFRV	*Tomato yellow fruit ring virus*
TYLCV	*Tomato yellow leaf curl virus*
TYMV	*Turnip yellow mosaic virus*
TYRV	*Tomato yellow ring virus*
TYVSV	*Tomato yellow vein streak virus*
TZSV	*Tomato zonate spot virus*
ULCV	*Urd bean leaf crinkle virus*
VTMoV	*Velvet tobacco mottle virus*
WBNV	*Watermelon bud necrosis virus*
WCMV	*White clover mosaic virus*
WCSV	*Watermelon chlorotic stunt virus*
WMV	*Watermelon mosaic virus*
WMV-1	*Watermelon mosaic virus-1*
WMV-2	*Watermelon mosaic virus-2*
WSBMV	*Wheat soil borne mosaic virus*

WSMoV	*Watermelon silver mottle virus*
WSMV	*Wheat streak mosaic virus*
WSSMV	*Wheat spindle streak mosaic virus*
YMMV	*Yam mild mosaic virus*
YMV	*Yam mosaic virus*
YVMV	*Yellow vein mosaic virus*
ZGMMV	*Zucchini green mottle mosaic virus*
ZLCV	*Zucchini lethal chlorosis virus*
ZYMV	*Zucchini yellow mosaic virus*

Contents

Chapter 1
Introduction to Plant Virus and Viroid Diseases in the Tropics

1.1 Introduction

There are more than 840 million under-nourished people worldwide who would benefit from substantial food production increases in the Tropics. Protecting the crops from pests and diseases would significantly reduce food deficits (FAO 2003). There are numerous ways by which agricultural productivity may be increased in a sustainable way, but farmers usually lack technical assistance other than that provided by agro-chemical companies. Unfortunately, fungal and bacterial diseases, and most arthropod pests can be chemically controlled, but plant viruses cannot, although some of their vectors can be chemically controlled. In this book the major virus and virus-like diseases of tropical plants are described in relation to their socio-economic importance, and the disease management practices shown to control crop yield losses caused by these pathogens.

Table 1.1 lists 169 countries that have part of their land mass between the Tropics of Cancer and Capricorn. Countries which are in brackets have less than half of their land in the tropics, while the rest, i.e., (Algeria), (Australia), (Bahamas), (Bangladesh), (Chile), (China), (Egypt), (Lybia), (Paraguay), (Saudi Arabia), (Taiwan), (United Arab Emirates), and (Western Sahara) have $< 50\%$ land area in the tropics (Table 1.1).

1.2 Tropics and Climate

Despite the position of the tropics with respect to the sun, some tropical regions can experience marked differences in temperature, particularly diurnal and nocturnal, during certain months of the year, both in the lowlands and highlands. These climate variations are usually related to the occurrence of 'dry' and 'rainy' seasons. These dry and wet seasons may present a uni-modal or bi-modal distribution during the year. Dry seasons are often associated with low diurnal or nocturnal temperatures, depending on their proximity to the equator and altitude.

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Table 1.1 List of Tropical Countries

North America	Central America	South America	Caribbean	Central Africa	East Africa	West Africa	South East Asia
Mexico	Belize	Bolivia	Anguilla	Angola	Burundi	Benin	Brunei
	Costa Rica	Brazil	Antigua and Barbuda	Cameroon	Comoros	Burkina Faso	Burma (Myanmar)
	El Salvador	Colombia	Aruba	Central African Republic	Djibouti	Côte d'Ivoire (Ivory Coast)	Cambodia
	Guatemala	Ecuador	Bahamas	Chad	Eritrea	The Gambia	East Timor
	Honduras	French Guiana	Barbados	Congo	Ethiopia	Ghana	Indonesia
	Nicaragua	Guyana	British Virgin Islands	Democratic Republic of Congo (Zaire)	Kenya	Guinea	India
	Panama	Paraguay	Cayman Islands	Equatorial Guinea	Madagascar	Guinea-Bissau	Laos
		Peru	Cuba	Gabon	Malawi	Liberia	Malaysia
		Suriname	Dominica	Sudan	Mauritius	Mali	Maldives
		Venezuela	Dominican Republic	Zambia	Mayotte	Mauritania	Philippines
			Grenada		Mozambique	Niger	Singapore
			Guadeloupe		Reunion	Nigeria	Sri Lanka
			Haiti		Rwanda	Saint Helena	Thailand
			Jamaica		Seychelles	Sao tomé and Principe	Vietnam
			Martinique		Somalia	Senegal	
			Montserrat		Tanzania	Sierra Leone	
			Netherlands Antilles		Uganda	Togo	
			Puerto Rico				
			Saint Barthelme				
			Saint Kits and Nevis				
			Saint Lucia				
			Saint Martin (France)				
			Saint Vincent and the Grenadines				
			Trinidad and Tobago				
			Turks and Cacaos Islands				
			U.S. Virgin Islands				

These phenomena create a large number of different eco-systems and a diverse biodiversity of plant and animal life in the tropics, which has allowed some plant pathogens and pests from Temperate countries to adapt to tropical and sub-tropical environments. The sub-tropics include regions adjacent to the Tropics of Cancer and Capricorn, which may suffer a 'spill-over' invasion of tropical pathogens and pests, or which may act as an entry point for temperate pathogens and their vectors into the tropics.

An additional problem encountered in the tropics is the extreme and highly variable environmental conditions found, particularly the high temperature and high humidity conditions, which cause accelerated degradation of tropical soils, making them highly acidic (pH < 5), toxic (high aluminum content), and deficient in critical nutrients, such as phosphorus. In the humid tropics, the relative importance of acid soils is greatest in Latin America (81 %), but also significant in Africa (56 %) and Asia (38 %). In rainforests and mountain slopes, the rapid degradation of tropical soils is noticed when there is total crop failure or when mountain soils lose their protective vegetation. In some tropical regions, the dry season may last for six months on average, impeding the cultivation of plants, unless irrigation is available in some wet-and dry tropical regions. This season is also associated with a significant increase in the increase of arthropod pests, many of which can act as virus vectors. However, irrigation tends to aggravate salinity problems and also favours the population increase of insect vectors of plant viruses. On the contrary, the wet season may be so intense that flooding occurs and crops are totally lost.

Based on the quantity of rainfall, tropical zones are defined as (1) arid: less than 400mm rainfall/year; (2) semi-arid: 400mm to 599mm rainfall/year; (3) sub-humid: 600mm to 1200mm rainfall/year; (4) humid: over 1200mm rainfall/year.

Besides the abiotic stresses, the dry weather, adequate humidity and temperature are quite favourable for insects like aphids, leafhoppers, whiteflies and thrips which are active vectors of some plant viruses and can cause severe direct damage to crops.

In West Africa, Atiri et al., (2000) have extensively studied some climatic factors in relation to the epidemiology of economically important virus diseases. Case studies of the *Maize streak mastre virus*, *Okra mosaic tymovirus* and *African cassava mosaic begomovirus* demonstrate that the most important factor that influences the incidence and spread of virus diseases is climate. In these cases, climate influences: (1) virus disease outbreaks; (2) the rate of development and activity of virus vectors and their migration; and (3) the phenology of crops, weeds and wild hosts that harbour plant viruses. Rainfall, temperature and wind are identified as key weather components in virus patho-systems involving maize (cereal), okra (vegetable) and cassava (root crop), and are therefore important factors determining the most suitable period in which to undertake crop protection measures. Loebenstein and Thottappilly (2003); Anderson and Morales (2005); Thresh (2006) and Sastry and Zitter (2013, II Volume) have also provided more details about virus and viroid disease situation, epidemiology and management aspects in tropical and sub-tropical countries.

1.3 Tropical Countries

The names of the tropical countries in Mesoamerica, Central America, South America, the Caribbean, Central Africa, East Africa, West Africa and South East Asia are listed Table 1.1 and in Fig. 1.1.

In the Western Hemisphere, tropical countries include part of Mexico; all of Central America; the Caribbean islands; and in South America; Colombia, Ecuador, Peru, Bolivia, Colombia, Venezuela, Guyana, Suriname, French Guiana, Brazil, northern Paraguay and the northern-most portions of Chile and Argentina.

In Africa, the only nations that cannot be called tropical countries are Morocco and Tunisia in the north and Lesotho and Swaziland in the south. All the rest lie either entirely, or at least partly, in the tropics. The Middle East has four tropical countries: Yemen, which is entirely in the tropics, and parts of Saudi Arabia, Oman, and United Arab Emirates. India, in southern Asia, lies mostly in the tropics, and all countries of Southeast Asia are tropical countries. Parts of Australia, Micronesia, the Marshall Islands, Kiribati, and most of the other island nations of Oceania in the South Pacific are tropical countries, as well.

The strongest link in explaining the wealth and poverty of nations is the relationship between ecological zones and per capita income, according to National Bureau of Economic Research (NBER). Yet, most recent cross-country analyses of economic growth have neglected the importance of physical geography.

Despite their varied economic, political, and social histories, almost all of the tropical countries remain underdeveloped at the start of the twenty-first century. Only two tropical-zone countries, Hong Kong and Singapore, rank among the 30 countries classified as high-income by the World Bank. All of the high-income regions (North America, Western Europe, Northeast Asia, the Southern Cone of

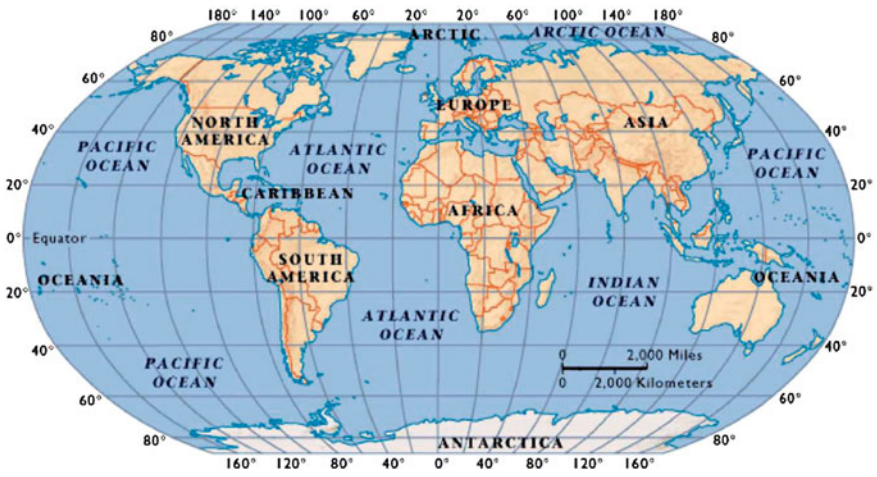

Fig. 1.1 World map with the tropical zone

Latin America, and Oceania) are outside of the tropics. Sea navigable regions are generally richer than land-locked nations. Those that are both tropical and land-locked-including Bolivia, Chad, Niger, Mali, Burkina Faso, Uganda, Rwanda, Burundi, Central African Republic, Zimbabwe, Zambia, Lesotho and Laos are among the very poorest in the world (Sachs 1999).

At the core of this long-term growth was the continued development of technology, a process that has benefitted the temperate-zone countries much more than the tropics. Production technology in the tropics has lagged behind temperate-zone technology in the two critical areas of agriculture and health. The difficulty of mobilizing energy resources in tropical economies has also contributed to widening the income gap between climate zones. The problems of applying temperate-zone technological advances to the tropical setting have amplified these factors. Agricultural, health, and some manufacturing-related technologies that could diffuse within ecological zones could not diffuse across them.

In the Temperate-zone the productivity of the major crops like rice, maize and wheat is considerably higher than in the tropics. Sachs (1995) estimated that the productivity per hectare of grain produced was approximately 50 % higher in temperate-zone countries. The explanation lies in soil formation and erosion, pests, water availability, environmental, technological and economic factors. Poor nutrition, resulting from low agricultural productivity, then leads to poor health. Sachs argues that economic development in tropical eco-zones requires a concerted international effort: agricultural technologies must be specific to the needs of tropical agriculture (Sachs 1999). For instance, between 1961 and 1991 the so-called 'Green Revolution', exponentially increased the yield of maize, wheat and rice in developing countries, demonstrating that it is possible to increase food production in the tropics with technological know-how. Unfortunately, the intensive agricultural practices implemented in the past century, were not always environmentally friendly. Nevertheless, it is possible to increase food production in the tropics in a sustainable manner. Food production also varies in the tropics. For instance, in Africa, the annual increase (1.3%) in yield per hectare of maize, wheat and rice is less than a one third of that achieved (4.5%) in Asia (Persley 2002).

1.4 Tropical Crops

The tropics are either the center of origin or of domestication of many of the most important food crops currently cultivated in the world: maize, rice, potato, sweet potato, cassava, cocoa, sorghum, millet, tomato, peppers, many cucurbits, peanut, rubber, tobacco, cotton, lima bean, common beans, oil palm, coconut, sugarcane, coffee, cocoa, and many fruit crops, such as banana, pineapple, mango, sweet pepino, passion fruit, guava, avocado and papaya. However, a myriad of other food crops were also domesticated and consumed by the early civilizations that developed in the tropics, particularly in Latin America.

1.5 Plant Virus Diseases in the Tropics

Plant viruses greatly affect food production in the tropics. Virus genera such as the *Begomovirus*, *Potyvirus*, *Tospovirus*, and *Cucumovirus* affect crops that feed the greatest number of people in tropical countries, often causing 100% yield losses and widespread famine, as is the case with several *Begomoviruses* transmitted by whiteflies in Africa, Asia and Latin America and the Caribbean. The third chapter of this book will cover the extent of yield losses in different crops grown in the tropics.

Table 1.2 Virus diseases of Tropical Countries

Central/East Africa	North/Central/South America	South East Asia
African cassava mosaic virus	Abutilon infectious variegation virus	*Alfalfa mosaic virus*
African cereal streak virus	*Andean potato latent virus*	*Banana bract mosaic virus*
Alfalfa mosaic virus	*Arracacha virus A*	*Banana bunchy top virus*
Banana bunchy top virus	*Banana streak virus*	*Banana streak Mysore virus*
Banana dieback virus	*Barley yellow dwarf virus*	*Banana streak OL virus*
Banana streak virus	*Bean calico mosaic virus*	*Barley stripe mosaic virus*
Barley stripe mosaic virus	*Bean common mosaic necrosis virus*	*Barley yellow dwarf virus*
Barley yellow dwarf virus	*Bean dwarf mosaic virus*	*Bean common mosaic virus*
Bean calico mosaic virus	*Bean golden mosaic virus*	*Bhendi yellow vein mosaic virus*
Bean common mosaic virus	*Bean golden yellow mosaic virus*	Bittergourd yellow mosaic virus
Bean yellow dwarf virus	Bean leaf crumple virus	*Cacao swollen shoot virus*
Brome mosaic virus	*Bean rugose mosaic virus*	Capsicum chlorosis virus
Cassava brown streak virus	Bean yellow stipple virus	Cassava Colombian symptomless virus
Cassava common mosaic virus	Bidens mosaic virus	*Cassava common mosaic virus*
Cassava Ivorian bacilliform virus	Cacao swollen shoot virus	*Cassava green mottle virus*
Cassava kumi virus	*Cassava American latent virus*	Chick pea chlorotic dwarf virus
Cassava 'Q' virus	Cassava Caribbean mosaic virus	*Chilli leafcurl virus*
Cereal chlorotic mottle virus	Cassava Colombian symptomless virus	Chrysanthemum stem necrosis virus
Chick pea chlorotic dwarf virus	*Cassava common mosaic virus*	Citrus infectious variegation virus
Citrus tristeza virus	Cassava frogskin virus	*Citrus mosaic virus*
Cocoa swollen shoot virus	Cassava Ivorian bacilliform virus	*Citrus psorosis virus*
Cotton leafcurl virus	Cassava latent rhabdo virus	*Citrus tristeza virus*
Cotton leaf mottle virus	*Cassava vein mosaic virus*	*Cotton leaf crumple virus*
Cowpea aphid borne mosaic virus	*Cassava virus X*	*Cotton leafcurl virus*
Cowpea golden mosaic virus	*Chinodel tomato virus*	*Cowpea golden mosaic virus*
Cowpea mild mottle virus	Chrysanthemum stem necrosis virus	*Cowpea mild mottle virus*
Cucumber mosaic virus	*Citrus tristeza virus*	Cucumber chlorotic spot virus
East African cassava mosaic virus	Clitoria falcate mosaic virus	*Cucumber green mottle mosaic virus*
Groundnut ringspot virus	Corn lethal necrosis virus	*Cucumber mosaic virus*
Groundnut rosette virus	Cotton antho cyanosis virus	*Dolichos yellow mosaic virus*
Impatiens necrotic spot virus	*Cotton leafcrumple virus*	Eastern wheat striate virus
Iris yellow spot virus	*Cowpea aphid borne mosaic virus*	*Groundnut eye spot virus*
Limabean golden mosaic virus	*Cowpea mild mottle virus*	*Groundnut ringspot virus*
Macroptilium yellow mosaic virus	*Cowpea mosaic virus*	*Hibiscus chlorotic ring spot virus*
Maize dwarf mosaic virus	*Cowpea severe mosaic virus*	*Horsegram yellow mosaic virus*
Maize line virus	*Cucumber mosaic virus*	*Impatiens necrotic spot virus*
Maize mottle/chlorotic stunt virus	*Dasheen mosaic virus*	*Indian cassava mosaic virus*
Maize mottle virus		*Indonesian soybean dwarf virus*
Maize pellucid ringspot virus		
Maize rayado virus		
Maize rough dwarf virus		

(continued)

Table 1.2 (continued)

Central/East Africa	North/Central/South America	South East Asia
Maize streak virus	*Eggplant mosaic virus*	Iris yellow spot virus
Maize stripe virus	Elephant grass mosaic virus	Kokke kondu carla virus
Moroccan Watermelon mosaic virus	*Groundnut ringspot virus*	Limabean golden mosaic virus
	Impatiens necrotic spot virus	*Maize dwarf mosaic virus*
Okra leafcurl virus	Iris yellow spot virus	*Maize streak virus*
Okra mosaic virus	*Lettuce mosaic virus*	Melon yellow spot virus
Papaya leafcurl virus	Lima bean golden mosaic virus	*Mungbean yellow mosaic virus*
Papaya mosaic virus	Macroptilium yellow mosaic virus	*Mungbean yellow mosaic*
Papaya ringspot virus	*Maize chlorotic mottle virus*	*India virus*
Pea leaf roll virus	*Maize dwarf mosaic virus*	Okra leafcurl virus
Peanut clump virus	*Maize rayado finovirus*	*Pangola stunt virus*
Peanut mottle virus	*Maize streak virus*	*Papaya leafcurl virus*
Peanut stunt virus	*Maize stripe virus*	*Papaya ringspot virus*
Peanut yellow mottle virus	*Mal de Rio cuarto virus*	Peanut bud necrosis virus
Pepper leafcurl virus	*Melon chlorotic leafcurl virus*	*Peanut chlorotic streak virus*
Pepper mildmottle virus	*Melon chlorotic mosaic virus*	Peanut green mosaic virus
Pepper veinal mottle virus	Melon severe mosaic virus	*Peanut mottle virus*
Potato leafroll virus	*Merremia mosaic virus*	Peanut stripe virus
Potato virus S	Mirafiori varicosavirus	Peanut yellow spot virus
Potato virus X	*Pangola stunt virus*	Physalis silver mottle virus
Potato virus Y	*Papaya mosaic virus*	Pigeonpea sterility mosaic virus
Rice stripe necrosis virus	*Papaya ringspot virus*	*Plum pox virus*
Rice yellow mottle virus	Peanut chlorotic fanspot virus	Potato apical leafcurl virus
Rhynchosia golden mosaic virus	*Peanut mottle virus*	*Potato leafroll virus*
Soil-borne wheat mosaic virus	*Pepper golden mosaic virus*	*Potato virus S*
Sorghum mosaic virus	*Pepper Hausteco yellow vein virus*	*Potato virus X*
South African cassava mosaic virus	Pepper mild tigre virus	*Potato virus Y*
Soybean golden yellow mosaic virus	Pepper yellow vein huasteco virus	*Rice black streaked dwarf virus*
	Plum pox virus	Rice chlorotic streak virus
Sugarcane bacilliform virus	*Potato black ringspot virus*	*Rice grassy stunt virus*
Sugarcane chlorotic streak virus	*Potato leafroll virus*	Rice mosaic virus
Sugarcane mosaic virus	*Potato virus T*	*Rice ragged stunt virus*
Sugarcane yellow leaf virus	*Potato virus Y*	*Rice stripe virus*
Sunflower yellow blotch virus	*Potato yellow mosaic virus*	Rice transitory yellowing virus
Sunflower yellow ringspot virus	*Potato yellow vein virus*	*Rice tungro virus*
Sweet potato chlorotic fleck virus	*Rice hoja blanca virus*	*Sorghum mosaic virus*
Sweet potato chlorotic stunt virus	Rice stripe necrosis virus	*Soybean crinkle leaf virus*
Sweet potato leaf curl virus	Rhynchosia golden mosaic virus	*Soybean mosaic virus*
Sweetpotato feathery mottle virus	Solanum apical leafcurling virus	*Squash leafcurl china virus*
Tobacco bushy top virus	*Sorghum mosaic virus*	*Srilankan cassava mosaic virus*
Tobacco leaf curl virus	*Sowbane mosaic virus*	*Sugarcane bacilliform virus*
Tobacco mosaic virus	Soybean golden mosaic virus	Sugarcane fiji disease virus
Tobacco ringspot virus'	*Soybean mosaic virus*	*Sugarcane mosaic virus*
Tobacco vein mottle virus	Soybean yellow shoot virus	Sugarcane streak mosaic virus
Tomato dwarf leafcurl virus	*Squash leafcurl virus*	*Sugarcane yellow leaf virus*
Tomato mosaic virus	Squash yellow mild mottle virus	*Sweet potato feathery mottle virus*
Tomato spotted wilt virus	*Sugarcane bacilliform virus*	*Sweet potato leafcurl virus*
Tomato vein-yellowing virus	*Sugarcane mosaic virus*	Tea phloem necrosis virus
Tomato yellow leafcurl virus	*Sugarcane yellow leaf virus*	*Tobacco leafcurl virus*
Turnip mosaic virus	*Sunflower chlorotic mottle virus*	*Tobacco mosaic virus*
Watermelon chlorotic stunt virus	*Sweet potato chlorotic stunt virus*	*Tobacco streak virus*
Wheat dwarf virus	*Sweet potato feathery mottle virus*	*Tobacco vein banding mosaic virus*
Wheat spindle streak mosaic virus	*Tobacco leaf curl virus*	*Tomato leafcurl New Delhi virus*

(continued)