


Diseases and Disorders of Cotton

A Field Guide for symptom-based identification and management

S.K. Sain, D. Monga, M. Sabesh,
Y.G. Prasad, A. H. Prakash, and R. K. Singh



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Author's Note

Cotton is an important cash crop for the sustainable economy and provides a direct livelihood to millions of farmers in tropical to sub-tropical regions, worldwide. India is producing around 61.57 lakh metric tons of cotton lint during 2021-22 and is the largest cotton producer in the world followed by China and the USA. In India, four cotton species are grown commercially in the north, central and south zones. The production area and productivity of cotton have considerably increased after the introduction of Bt-cotton in India but concurrently the disease scenario has also shown some changes as compared to old cotton cultivars. Over the last two decades, there is a shift in the prevalence and relative importance of diseases affecting cotton production and productivity in India. The shift may be due to climate change and the changeover from the cultivation of diploid desi cotton (*G. arboreum* and *G. herbaceum*) to tetraploid upland cotton (*G. hirsutum*), BG II hybrids. Since 2002, the susceptibility of Bt cultivars to many new diseases, which did not prevail earlier, is being observed. Cotton crop suffers from several diseases but the increasing pattern of target leaf spots, TSV, boll rots, bacterial leaf blight, *alternaria* leaf spot, and grey mildew, is observed and may become an emerging threat to cotton cultivation. Due to continuous cropping and decreasing soil fertility several nutritional deficiencies are also being observed. Moreover, constant vigilance on the occurrence of quarantine-important diseases in cotton-growing areas of the country is very important.

The book "Diseases and Disorders of Cotto" A Field Guide for symptom-based identification and management" is designed to help agricultural scientists, extension personnel, students, and cotton farmers identify the common diseases, disorders, and biosecurity threats of cotton in India. We have attempted to describe the most important characteristic features of the symptoms of about 22 diseases, 2 disorders, and 13 nutritional deficiencies; however, we recognize that local/regional/varietal variations may occur which have not been explained. In addition to this, the coincidence of two or more diseases/disorders on the same plant or plant part may confuse the identification process. Therefore, it is recommended that infected samples should be examined properly by experienced scientists and extension workers to confirm the identification of pathogens/species/strains of diseases, causes of disorders, and nutritional deficiencies in the designated laboratories. Moreover, the location-specific management practices developed and recommended under AICRP on cotton and by CIB&RC are also elucidated in this book which can be applied subsequently upon the proper identification of diseases and disorders. We hope that the information will be used by all the cotton stakeholders for the proper diagnosis and effective management of diseases and disorders for enhanced productivity and reduced unnecessary inputs.

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Foreword

Cotton (*Gossypium* spp.) known as "White Gold" is one of the most important cash crops in India. More than 80% of the cotton produced in the country was consumed domestically while export surplus was about 77 lakh bales in 2020-21. India meets it raw material requirements for the textile industry, food, feed and cottonseed oil. Cotton production plays a vital role in the agricultural and industrial economy, and the livelihood of the Indian farming community.

World over, cotton crop suffers from several insect pests, diseases and abiotic stresses. Crop loss up to 30% is estimated due to occurrence of biotic stresses. It is estimated that about 6% of the World's pesticides are used on cotton. Due to a large global acreage of about 33 million ha and intense use of agro-chemicals, cotton is attributed to contribute signicantly to the global green house gas emissions. In the last decade, yield of cotton was stagnant in India, where cotton is grown under rainfed conditons and is subjected to adverse weather, increased incidence of insect pests, and diseases. In the next decade, growth potential of cotton in the country can come from increased use of smart mechanisation, varietal development, and pest/ disease management practices. Climate change/variability coupled with narrowing down of genetic diversity of popular cotton genotypes is probably responsible for changing pattern in pest and disease dyanamics and severity. Several minor and sporadic diseases and crop disorders have emerged and pose a threat to cotton production and productivity. There is also a potential threat to the biosecurity from serious diseases that are prevalent outside but currently absent in India. Constant vigil is required in cotton growing areas in the country to prevent introduction of such looming threats.

ICAR-All India Cooridnated Research Project (AICRP) on cotton along with technical backstopping of ICAR-Central Institute for Cotton Research (CICR) and its field network of 21 AICRP centres across 10 state agricultural universities (SAUs) has a strong component of pest and disease survey, surveillance, screening of genotypes and evaluation of pest management options in multi-location trials in diverse cotton growing areas of the country. This publication on "**Diseases and Disorders of Cotton: A Field Guide for symptom-based identification and management**" is an outcome of the rich and varied experience of researchers over the years. I am confident that this manual will be useful in providing comprehensive information to scientists, extension personnel, students, and cotton growers, on symptom-based identification of cotton diseases, disorders and their management. I compliment all the researchers for their technical inputs and authors for bringing out this valuable publication.

(T.R. Sharma)

1. Introduction

Worldwide, cotton (*Gossypium* spp.) known as "White Gold" is one of the important cash crops in tropical to sub-tropical regions. It provides more than 65% of raw materials for the textile industry, food, feed, cottonseed oil, and protein, and plays an important role in the agricultural and industrial economy. India produced around 61.57 lakh metric tons of cotton and is the highest cotton producer in the world followed by China, USA, and Brazil. Insects, mites, pathogens, weeds, nematodes, rodents, and birds constitute the pest complex of cotton. Of the biotic stresses, insect pests cause by far, the highest economic losses. The cotton plant is the host of 1326 species of insects. In India too, there are over 166 insects recorded as pests on cotton crops and a few of them like bollworms, sucking pests and mealybugs are economically important. From immemorial time, agriculture has been fronting damage happenings to abundant insect pests, and diseases which results in an essential reduction in crop yield. The cotton insect-pest scenario has also shown a continuous change during the past sixty years. The climatic change scenario has played a significant role in altering the cotton pest problems. Several minor and infrequent insect pests and diseases are emerging and posing threat to cotton production and productivity. The Indian Government permitted commercial cultivation of Bt- cotton for the central and south zone in 2002 and for the north zone in 2005, which played a vital role in the management of bollworms.

The cotton disease scenario has also shown a continuous change in the past. When mainly indigenous diploid cotton was being grown in the fifties, the *Fusarium* wilt, root rot, seedling blight, anthracnose, and grey mildew were the major problems. With the large-scale cultivation of tetraploid upland cotton (*G. hirsutum*), bacterial blight became the major problem to which indigenous cotton was highly resistant. *Fusarium* wilt has become less important as upland cotton (Bt hybrids) is now being grown in above 90 percent area and is immune to the Indian race of the pathogen. *Verticillium* wilt which appeared in Tamil Nadu remained restricted mainly to the south zone only. The grey mildew, once a serious problem for diploid cotton especially in central India with the continued cultivation and imposed selection pressure got adapted to tetraploid cotton and their hybrids as well. Presently, it is a major problem in central and south India in Bt-cotton hybrids. *Alternaria* blight and *Myrothecium* leaf spots are prevalent almost everywhere but are severe in the states of Karnataka and Madhya Pradesh, respectively. Other diseases such as *Cercospora* and *Helminthosporium* leaf spots are sporadic only. Rust, although a minor disease may become a problem in southern states of India shortly. In north India, the cotton leaf curl virus disease transmitted by whitefly (*Bemisia tabaci*) has become a major threat to cotton cultivation since 1993. Due to the climatic change, several minor insect pests, and diseases are emerging and posing threat to cotton production and productivity. After the introduction of Bt-cotton hybrids, the disease scenario has also shown some change. Bt hybrids have manifested more susceptibility to bacterial blight and *Alternaria* leaf spots as compared to their non-Bt counterparts. The incidence of cotton leaf curl virus disease has shown changes in its virulence due to frequent recombination among the strains. The *Tobacco Streak Virus* (TSV) is reported to be an emerging disease in Andhra Pradesh, Tamil Nadu, and Maharashtra. Sporadic and low incidence is also reported in the north cotton-growing zone of India. The target leaf spot caused by *Corynespora cassicola* is observed in all three zones with an increasing trend in certain areas of central and southern zones.

All around the world, chemical pesticides are expansively used to manage diseases, they greatly contributed to boosting cotton productivity and farmer income over the years. Nevertheless, there is an amplified societal burden to substitute chemical pesticides progressively with biopesticides which are harmless to humans and non-target organisms. Over the last few years, biopesticides have attracted global attention as a safer pest control strategy for incorporation into IPM programs. Several efforts have been made to minimize crop losses due to diseases of cotton with a focus on eco-friendly and sustainable control. However, proper field identification plays a vital role in decision-making for the selection of suitable chemical or bio-pesticides, and their timely application will certainly provide economic benefit to the growers.

This guide provides comprehensive information for cotton growers, extension staff, students, and scientists on symptom-based identification of cotton diseases, disorders, and nutritional deficiencies for providing management decisions. Thus, proper identification can help choose the correct management strategy either for the current year or the subsequent years. The simple low-cost integrated pest management (IPM) techniques outlined in this guide provide satisfactory sustainable management of cotton diseases and nutritional deficiencies and can help cotton growers decrease their reliance on chemical-only management practices.

2. Prevalence and Distribution of Cotton Diseases in India

Among several cotton diseases, the national and regional economically important diseases based on their prevalence, occurrence and incidence are described below. These diseases are seed-borne, soil-borne, foliar and emerging diseases caused by bacterial, fungal and viral pathogens (Table 1). Foliar leaf spots (bacterial and fungal), boll rot and cotton leaf curl virus disease have been considered important diseases in Bt cotton and categorized into different cotton growing zones. *Corynespora* leaf spot, Grey mildew, and internal boll rot are emerging diseases in central and south cotton-growing zones. *Tobacco Streak Virus* (TSV) is an emerging disease in Andhra Pradesh, Tamil Nadu and Maharashtra. Also, some viral diseases which are of quarantine importance for India are described (Table 1).

Table 1. Important disease problems of cotton in India and their prevalence.

Name of the disease	Regions of prevalence
Bacterial disease	
1. Bacterial blight	All zones
2. Internal boll rots (*Pantoea* spp.)	All zones
Fungal diseases	
3. Alternaria leaf spot	All zones
4. Myrothecium Leaf Spot	All zones
5. Root rot	All zones
6. Fusarium wilt	All zones in diploid cotton
7. Verticillium wilt	South zone
8. Target leaf spot	All zones
9. Grey mildew	Central & South Zones
10. Leaf rust	South Zone
11. Helminthosporim leaf spot	All zones in traces
12. Anthracnose	All zones in traces
13. Boll rot (outer)	All zones

Viral diseases	
14. Cotton leaf curl disease (CLCuD)	North zone
15. Tobacco Streak Virus (TSV)	All zones
16. Cotton Blue Disease	USA (California, Arizona, Texas), Mexico. Only one report in Maharashtra
17. Cotton leaf roll dwarf virus	Only reported from Nagpur, Maharashtra in India.
18. Cotton virescence	Only in Western Africa

3. Diagnosis Procedures

A stepwise process is required for symptom-based diagnoses of diseases, nutritional deficiencies, and physiological disorder problems in the cotton fields to decide on the development of good management tactics. This requires an understanding of how disease, nutritional deficiency, and physiological disorder-damaged crops look like, how the damage is done and what is the damage pattern on the plant as well as in the fields. A farmer must consider several factors including host plant type, damage symptoms, the presence of the disease (symptoms or signs), disorders caused by nutrition deficiencies, and physiological changes.

To be an expert, get out in the field and look for symptoms, signs, stunting, wilting, discolorations, misshapen plants, and their roots. In the case of fungal and bacterial diseases, the progressive symptom will appear on plants and in the field with signs of their growth (during most favorable conditions). The viral diseases also produce progressive symptoms without any signs, though there may be the presence of a viral disease vector. In the case of wilting, foliage symptoms like yellowing of plants, leaf scorching, and root/stem rot may appear. If irrigation-related problems and wilting symptoms appear on the plant, inspect the plant root system including the external and internal stem parts (vascular system, xylem vessels) for the presence or absence of causal organism/damage, etc.

Generally, symptoms of nutritional deficiency and physiological disorders (herbicide, chemical & salt injury) on plants and fields appear uniformly without any signs. The nutritional deficiency shows uniform color change/necrosis of plant leaves, on leaf margin or veins or interveinal parts, distorted, abnormal uppermost leaves, aborted flowers, boll shedding, etc. Nutritional disorders show their symptoms on lower (N, P, K, Mg), middle (Mn, Cu, Zn, Mo), and upper leaves (B, Ca, S, Fe). There may be some confusing symptoms of nutritional deficiency and disease infection in leaves and flowers.

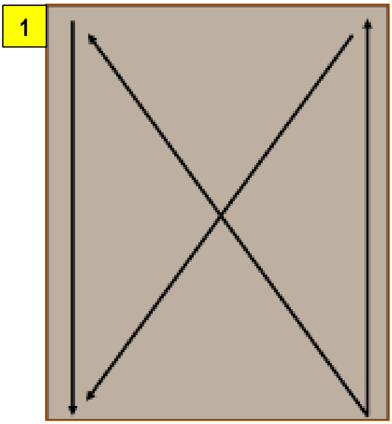
In case of physiological disorders/damage symptoms, herbicidal/ chemical toxicity uniform types of symptoms will be observed on leaves, stems, stem-bark, flower parts, etc. in a defined area uniformly. If needed a bit of expert advice (scientists, plant health Doctors) must be taken for confirmation and suspected samples can be tested under laboratory conditions (ICAR institutes, SAUs Departments, Plant Health Clinics).

4. Scouting Procedures

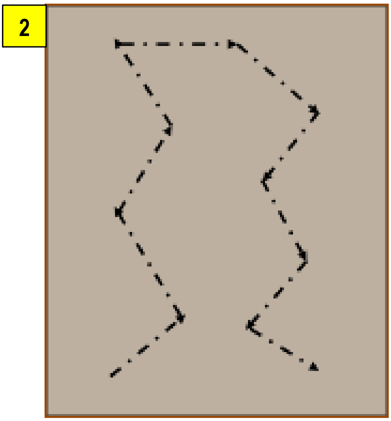
Regular surveillance and scouting are excellent processes to survey and monitor your field crops. It serves as insurance to prevent the destruction of your plants/crop and allows you, the grower, to timely initiate need-based disease management practices before significant crop losses occur. It is essential to adopt a proactive integrated pest management (IPM) approach. A periodic and systematic survey is necessary and should be followed at regular intervals. Inspect every plant starting from seed germination, and carefully look at all plant parts, particularly the lower, middle, and upper strata of the plant and leaf margins. You may consider using a hand lens with at least 10 x or 20 x magnifications. In larger plantings (about 0.4 ha/ or one acre), carefully inspect at least 10 randomly selected, widely scattered plants. For disease, severity estimation, observe at least 5 leaves on each randomly selected plant (2 bottoms, 2 middle, and one top leaf). If damage has occurred in certain sections of the field, concentrate your efforts there and in adjacent areas. In the case of root rot/wilt diseases, incidence/severity is observed based on the individual plant (wilting/mortality). However, for fungal/bacterial foliar and viral diseases, the incidence is based on the individual plant, and the severity is based on a severity grading/rating. To obtain reliable results from scouting, take the samples from several locations throughout the field, not only from one side or the edge of the field. Several sample scouting patterns are shown on the next page.

You should be aware that disease and phycological disorders often differ depending on the part of the plant you are looking at and the pattern of symptoms. For example, generally fungal and bacterial disease symptoms start from lower leaves, while viral disease symptoms preferably appear on upper or younger leaves. The physiological disorder symptoms may appear on any part of the plant depending on the contact with herbicides/chemicals. Nutritional deficiency symptoms may appear on lower (N, P, K, Mg), middle (Mn, Cu, Zn, Mo), and upper leaves (B, Ca, S, Fe). Once the cotton crop has germinated, inspect the crop at least once every seven days. Note that diseases and disorders are not always confined to the aboveground portions of the plant. Damage can and does occur at the roots, stems, and other plant parts below ground. Also, some nutritional deficiency symptoms may be similar to the disease symptoms and need careful and comparative examination (specific symptom). Do not forget to collect information about the field/season/ weather like field history, cultivation practices, previous/ adjacent crops, weeds, the chemical used, etc. All these should be considered and surveyed especially when you find some typical symptoms or complexes.

Fig. 1-4. Survey pattern for scouting and disease monitoring in the fields

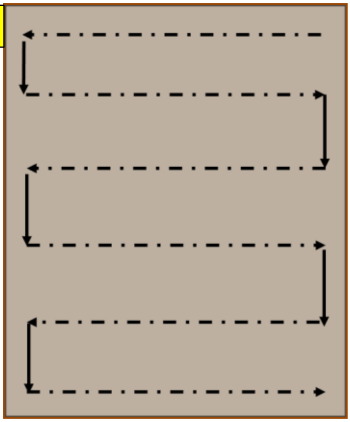


Cross pattern



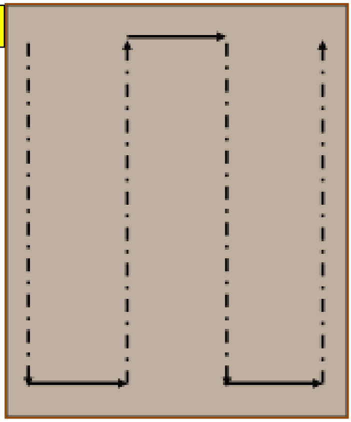
Zig-Zag pattern

3



Parallel pattern

4



Straight pattern

How to use this Guide

1. Inspect your crop closely and critically, and decide what type of damage has been done or what symptoms are present on plant/plant parts.
2. Try to locate the symptoms, signs, and symptom progression pattern. Examine it carefully. Look at several specimens to ensure a correct diagnosis.
3. Go to the section in this Field Guide dealing with fungal, and bacterial diseases, physiological disorders, or nutritional deficiency. The diagnosis will be facilitated by descriptions and pictures of the symptoms, signs, and damage. Once you have determined the causal agent, recommendations for management can be available through your local or regional extension personnel or institutes of ICAR or SAUs.

4. Some typical characteristic symptoms of an individual disease/disorder will help in the correct identification for which Go to the “disease symptom identification of individual diseases of this Field Guide.
5. If you are still unsure of the causal agent, collect several samples (leaves in brown paper, roots in plastic bags, soil samples, whole plant, etc.) and bring them to your local agricultural authority for identification. Make sure you collect specimens of the plant parts in the early stages, not at the later dry stages.

5. Viral and Phytoplasma diseases

5.1. *Cotton Leaf Curl Virus Disease* (CLCuD)

Cotton leaf curl virus disease (CLCuD) was reported for the first time from Nigeria on *Gossypium peruvianim* and *G. vitifolia* in 1912 by Farquharson which is identified as *Cotton leaf curl Gezira virus* (CLCuGV). It was noticed on *G. hirsutum* in Oyo, Nigeria with characteristic symptoms of downward curling of leaves and changes in leaf texture and colour (Golding, 1930) in Sudan in 1924, and subsequently, in 1926 the disease broke out in cotton fields of Northern Africa and Tanzania (Kirkpatrick, 1931; Bailey, 1934). At present, it is widespread throughout the cotton belt in sub–Saharan Africa/Sahel region (Brown, 2020). It started affecting the cotton crop (*G. hirsutum*) in Pakistan in 1967 (Hussain and Ali, 1975) and India (*G. barbadense*) in 1989 (Varma *et al.,* 1993). Later in 1993, it was observed on *G. hirsutum* at farmers' fields in the Sriganganagar district of Rajasthan state of India (Ajmera, 1994). CLCuD has become a major threat to cotton production causing enormous losses to cotton crops in most of the cotton-growing countries including the Indian subcontinent. The disease is spread to the entire north zone in an area of around 1.9 million hectares and is restricted to only the northern cotton-growing zone of the country.

Where to observe/look

The disease symptoms occur on new leaves on top of the plant and branches. Initial symptoms of the disease appear as small and large vein thickening and darkening which can be observed from under the side of the leaves.

Symptoms description

The disease is spread by the whitefly, *Bemisia tabaci* a vector of the virus and symptoms can appear at the seedling stage (~30 days after sowing) and thereafter at any stage. The CLCuD-affected cotton plants show characteristic symptoms of thickening and darkening of veins when seen against sunlight called small vein thickening type (SVT) followed by distinct upward/downward curling. Leaves of affected plants also show thickened dark green veins as compared to normal translucent veins of healthy plants. Some of the leaves develop secondary leaf-like structures originating from nectaries called enations. Development of enations may vary with the germplasm/cultivar and the severity. Similar symptoms are also observed on bracts. The diseased plants remain stunted and give a dwarf appearance or stunted growth of plants with reduced internodal length.

Fig. 5-10. CLCuD symptoms on the underside (SVT type) and upper side (depression above small veins) of the leaves (*Gossypium hirsutum*)

SVT Symptoms

6

Severe Vein Thickening

7

Healthy leaf

Diseased leaf

Downward curling

Upward curling

Fig. 11-13. CLCuD symptoms on the upper and lower side of leaves, squares, and bracts (*Gossypium hirsutum*)

Downward curling

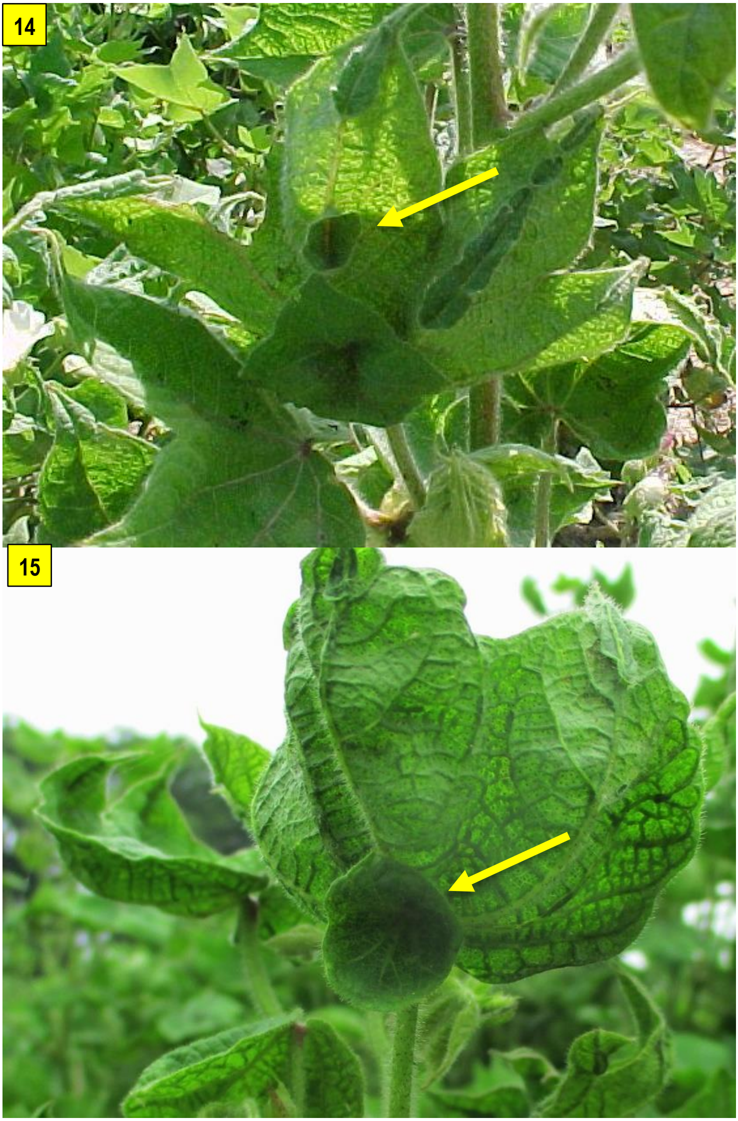
12

Upward curling

13

Vein thickening on squares, and bracts

Fig. 14-17. Leaf enations and severely infected cotton plants (*Gossypium hirsutum & G. barbadense*)



Leaf enations

Stunted *G. hirsutum* plants

Stunted *G. barbadense* plants

Whitefly: Whitefly - *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is a vector of CLCuD. It is a highly polyphagous, pest and reduces the yield by direct feeding and the development of black sooty mold due to the secretion of honeydew on leaves. Sooty mold significantly reduces the photosynthetic capabilities of crop plants, causes leaf shading, and results in an economic loss.

Fig. 18-21. Whitefly and sooty mold symptoms on leaves, and plant (*Gossypium hirsutum*)

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Whitefly

Whitefly & CLCuD - infested plants

Plants infested with sooty mold

Causal organism: Cotton leaf curl virus disease (CLCuD) is induced by complexes of cotton infecting begomoviruses (family *Geminiviridae*) having monopartite genome with circular ssDNA intimately associated with satellite molecules viz. alpha satellite and beta satellite. CLCuD has many weed, ornamental and vegetable hosts (~26 genera) which help perpetuate the virus from one season to another season and one plant to another plants.

Economic losses: The incidence of diseases is increasing and this has become an alarming problem for almost all Bt and non-Bt cotton hybrids in the north zone. The percent disease incidence (PDI) increases slowly during June and reaches up to 80% during August and September (Monga et al., 1998). Recent estimates revealed that the average yield loss corresponding to disease rating scales 1,2, 3, 4, 5, and 6 of cotton leaf curl virus disease (CLCuD) was recorded to be 15, 28, 38.6, 49.1, 59.1 and 72.1%, respectively in Bt cotton hybrids under field conditions during 2012-2017 in Haryana and Punjab (Sain et al., 2020). If the disease appears up to 80 DAS compared to 110, 140 DAS the reduction range in SCY (4.6-62.4%), fiber length (23.9-29.9%), strength (21.4-30.1%) and uniformity (62.5-83%) were recorded to be higher in susceptible hybrids (Monga and Sain 2021).

5.2. *Tobacco Streak Virus* (TSV)

Tobacco streak virus (TSV) is the type species of the genus *Ilarvirus*, of the family *Bromoviridae* which includes viruses having tripartite quasiisometric particles of size 27 to 35 nm (Fauquet *et al.,* 2005). TSV can infect more than 200 plant species belonging to 30 dicotyledonous and monocotyledonous plant families (Fulton, 1985) and its occurrence is reported in over 26 countries worldwide (EPPO, 2005). In India, Ahmed et al. (2003) studied the natural occurrence of TSV in cotton in Pakistan. Though the virus is widespread around the world, it is not known to cause destructive epidemics in India (Prasada Rao et al. 2000, Sharman et al., 2008). However, in the recent past, the necrosis disease caused by TSV was frequently recorded in the cotton-growing regions of India (Rageshwari et al. 2016, Vinodkumar et al. 2017). Reports of TSV with chlorotic and necrotic lesions on leaves accomplished with leaf purpling, necrotic buds, and drying of young bolls in the cotton fields are available (Prasada Rao et al. (2009).

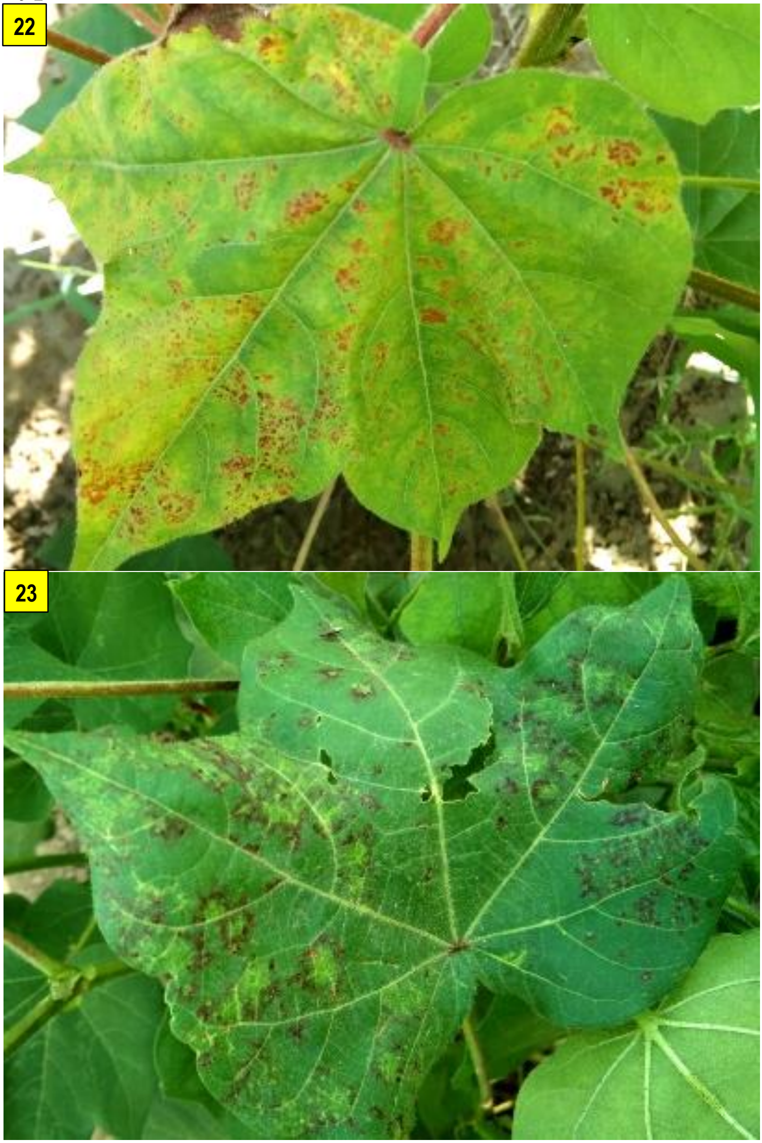
Where to observe/look

The disease symptoms occur on the newer leaves and tips of the plant/branches. Necrotic symptom starts from the top to bottom and depends on the abundance of infected pollens of parthenium and its populations, thrips multiplication, and its movement on the crops. Two to three months old plants can express symptoms.

Symptoms description

The symptoms of TSV infection on cotton plants (*G. hirsutum* and *G. barbadense*) resemble almost similar to physiological or nutritional disorders and herbicide phytotoxicity which is difficult to distinguish. Commonly chlorosis of young leaves at the tip, discoloration, bronzing, necrosis, veinal chlorosis curling of leaves, and necrotic streaks on petioles, stem, and flowers, and dwarfing or stunting of plants are observed if infection occurs at an early stage. Square drying and dropping are also observed under severe infection conditions, which depend on the abundance of infected pollen, parthenium population, thrips multiplication, and their movement. Infection at the later plant growth stage results in mild chlorotic symptoms, with little effect on plant growth and crop yield. TSV symptoms can show three distinct stages: 1: the acute or necrotic stage – local lesions appear as rings, solid necrotic spots, or diamond-shaped patterns. Sometimes the symptoms may disappear at a later stage. 2: the early recovery stage – new leaves develop which appear normal except for chlorotic veins and 3: the chronic or late recovery stage – the leaf is thicker than normal with a smoother texture and the tubular corolla splits with the bracts become separated, especially the upper half. Symptoms are strongly influenced by temperature. At mild temperatures (around 20°C), only small necrotic spots develop. The symptoms are more severe and appear as large necrotic arcs, broken rings, lines, and dots around the necrotic secondary veins when the temperature is above 30°C.

Fig. 22-25. TSV symptoms on leaves, squares, and plants (*Gossypium hirsutum*)



Chlorosis and necrosis on leaves

Square drying on the plants

Fig. 26-28. TSV symptoms on leaves, squares, and plants (*Gossypium barbadense*)

Stunted plant growth


Stunted plant growth and square drying

Causal organism: *Tobacco streak virus* (TSV) is the type species of the genus *Ilarvirus*, of the family *Bromoviridae* which includes viruses having tripartite quasiisometric particles of size 27 to 35 nm. TSV is transmitted through pollen assisted by thrips (Thysanoptera: Thripidae) and experimentally by mechanical sap inoculation, grafting, and dodder (*Cuscuta campestris*), but not by contact or soil (Fulton, 1985). In several weed hosts, such as parthenium, TSV causes asymptomatic infection.

Economic losses: Infection at the early or mid-growth stage of the plant may result in a severe reduction in yield. The premature death of the plant is the main reason for enormous yield losses during epidemics. In Tamil Nadu, 12.6 to 38.8% of disease occurrence in *G. hirsutum* and *G. barbadense* was recorded in 2010. A 35.9 to 50% incidence was observed in Coimbatore and Anthiyur districts, respectively (Rageshwari et al. 2017).

5.3. *Cotton Leaf Roll Dwarf Virus* (CLRDV): Cotton Blue Disease

Biosecurity Threat

The cotton blue disease is caused by *Cotton Leaf Roll Dwarf Virus* (CLRDV), a positive-sense, single-stranded RNA virus of Genus *Polerovirus* (Family: Luteoviridae) and transmitted by Aphid (*Aphis gossypii*) in a circulative-persistent manner. In India, only one report from Maharashtra during 2011 is available (Mukherjee, et al., 2012). CLRDV is very close to the chickpea stunt disease-associated virus (CpSDaV). It can be transmitted from cotton to chickpea. Studies indicate that CpSDaV and CLRDV in India are possibly two different strains of the same virus (Mukherjee et al., 2012, 2016). CLRDV, which is prevalent in Argentina and Brazil, was also detected in the USA in 2017 from two Alabama counties and affected chickpeas in Uzbekistan in 2012. One year later, the virus spread to 21 Alabama counties as well as cotton fields in Florida, Georgia, Mississippi, and Texas states of USA. Yield losses of up to 80% from susceptible cultivars have been reported in South America. Constant vigilance on the occurrence of this disease in cotton-growing areas of the country is very important.

Where to observe/look

The disease symptoms occur on the newer leaves and tips of the plant/branches. Symptoms start from top to bottom depending on the abundance of aphids, their populations, and their movement on the crops. Two to three months old plants can express symptoms.

Symptom description

Cotton plants affected by this disease show stunting, leaf rolling, intense green foliage, vein yellowing, brittleness of leaves, and reduced flower and boll size sometimes resulting in sterility of plants (Fig 5). CLRDV, which is prevalent in Argentina and Brazil, was also detected in the USA in 2017 from two Alabama counties. One year later, the virus spread to 21 Alabama counties as well as cotton fields in Florida, Georgia, Mississippi and Texas. Yield losses of up to 80% from susceptible cultivars have been reported in South America. Constant vigilance on the occurrence of this disease in cotton-growing areas of the country is very important.

Fig.29-30. Symptoms of Cotton Leaf Roll Dwarf Virus disease

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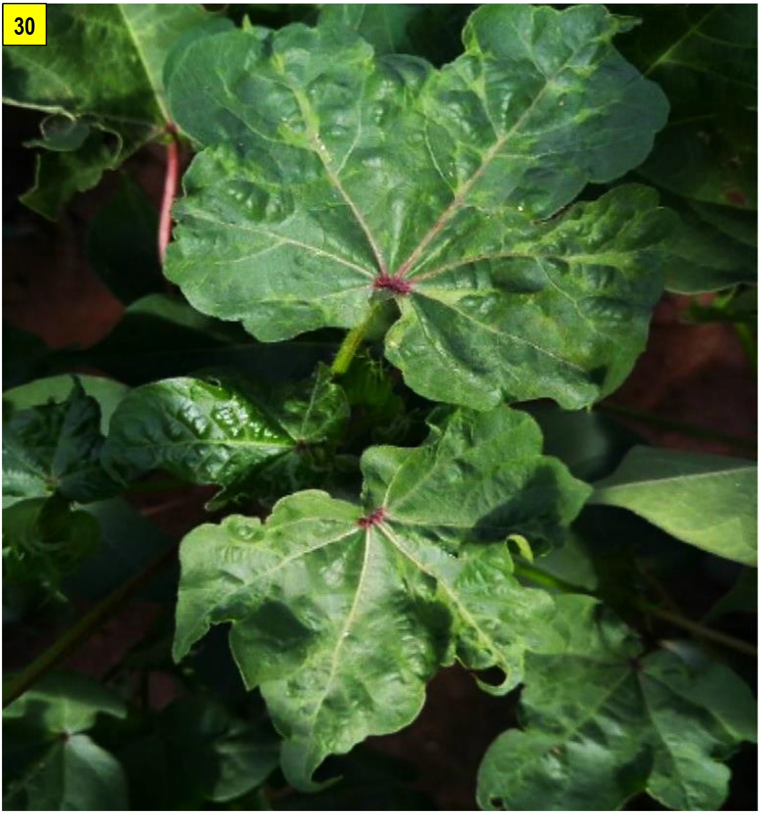


(Photo - Dr. Sudeep Bag, University of Georgia, Tifton)

Causal organism: The cotton blue disease caused by Cotton Leaf Roll Dwarf Virus (CLRDV). This positive-sense single-stranded RNA virus genus Polerovirus (Family: Luteoviridae) is transmitted by Aphid (*Aphis gossypii*) in a circulative persistent manner.

Economic losses: Yield losses of up to 80% from susceptible cultivars have been reported in South America.

5.4 *Cotton Leaf Crumple Virus* (CLCrV)

Biosecurity Threat

Cotton Leaf Crumple Virus disease (CLCrVD) has been known to occur in the southwestern United States since 1950. CLCrVD mainly occurs in California, Arizona, Texas (USA), and Mexico. Mali (1977) reported the occurrence of the disease in the Marathwada region of Maharashtra in India. However, no further confirmation about its occurrence and spread has been noticed. It is a widespread disease of cotton *G. hirsutum* in the Sonoran Desert of Arizona and Sonora, Mexico, southern California, the Rio Grande Valley of Texas, and Guatemala (Brown 1992). Constant vigilance on the occurrence of this disease in cotton-growing areas of the country is very important.

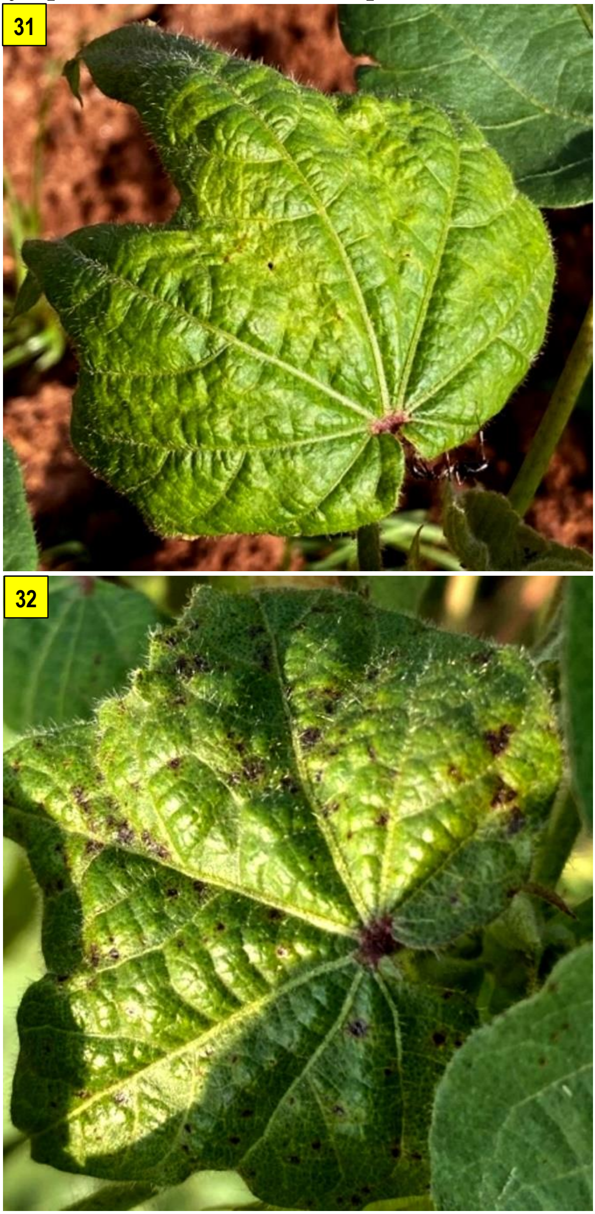
Where to observe/look

The disease symptoms occur on the newer leaves and middle age leaves. Two to three months old plants can express the symptoms.

Symptom description

Usually, the CLCrV-infected plants remain stunted with leaf crumpling, and downward curling accompanied by interveinal hypertrophy and foliar mosaic. Characteristic symptoms include foliar discoloration and venial hypertrophy leading to puckering, crumpling, downward leaf curling, and shortening of internodes along with stunting of the host. The symptoms are almost similar to CLCuD except for small vein darkening and vein thickening. Sometimes necrotic and mosaic-like patterns can also be seen on leaves.

Fig.31-32. Symptoms of Cotton leaf crumple virus (CLCrV) disease



(Photo - Dr. K. R. Kranthi)

Causal organism: Cotton Leaf Crumple Virus (CLCrV) is a bipartite DNA genome (DNA-A and DNA-B) of begomovirus (Geminivirus) and is transmitted by whitefly *Bemisia tabaci*.

Economic losses: Severe outbreaks of CLCrVD may be exacerbated by ratooning; a practice in which cotton is pruned and allowed to regrow the following year.

5.5 *Cotton Virescence - Phytoplasma*

Biosecurity Threat

Among arthropod-borne diseases, cotton virescence associated with phytoplasmas has been recorded from Burkina Faso, Ghana, Ivory Coast, and southwest Mali. Cotton and luffa plants with little leaf symptoms were observed in February 2010 in New Delhi, India. Sequence comparisons showed homology with the members of '*Candidatus Phytoplasma asteris*', group 16SrI (Kumar et al 2010). However, no records of the disease in cotton-growing areas of the country were observed. Moreover, the nature of similarity between this reported phytoplasma disease in India and the cotton virescence disease reported elsewhere is still to be ascertained. A strict quarantine vigilance and constant watch on its host plants & vectors are very important.

Where to observe/look

The disease symptoms occur on the top of the plant and its branches, especially on newer leaves and flower bracts/squares. Flowering, vegetative and fruiting stages of plants can express symptoms.

Symptom description

Virescence-infected plants exhibit symptoms that vary according to growth stage and time of infection. Infection at an early stage of growth results in cessation of internode elongation, reduction in leaf size, and stunting (about two-thirds of normal plant height). The entire inflorescence is converted into phyllody or malformation, like leaves are twisted, rolled with abnormal colour, leaves closely arranged on the top of the stem, with very short internodes (Fig 4). The stem shows stunting or resetting or witches' broom symptoms. The whole plant shows dwarfing, resetting, or elongation with early senescence. Infections that occurred later in the season caused characteristic symptoms, such as witches' broom. Roots become hairy.

Fig. 33-36. Virecsence symptoms at Various growth stages;

Malformation of floral parts into leaves

Plants showing virescence symptoms - yellowing, reddening, and stunting.

(Photo - Dr. K. R. Kranthi)

Causal organism: Cotton virescence associated with phytoplasmas. The brown leafhopper/ jassids *Orosius cellulosus* (Lindberg), breeding mainly on *Sida cordifolia* L. and *Mitracarpus scaber* Zucc. have been identified as the vector of the cotton virescence phytoplasma and two species of the genus *Sida*, family Malvaceae, act as phytoplasma reservoirs (Laboucheix et al., 1973).

Economic losses: So far, cotton virescence has been found to cause losses only in Western Africa but this disease represents a threat to other cotton-growing areas around the world since weeds of the genus *Sida*, potential reservoirs, are widespread and leafhoppers of the genus *Orosius* are present throughout Asia (from Middle to the Far East), Australia and Pacific Region. The incidence of the disease in Mali cotton-growing areas fluctuates, but in some fields, up to 50% of the plants were infected (Marzachi et al 2009).

6. Soil borne diseases
6.1. Root rot

Root rot of cotton is a worldwide occurrence and has been a major cause of loss in many countries. Different fungi as well as nematodes cause injury to the cotton roots. In India, root rot is caused by *Rhizoctonia bataticola* = *Macrophomina phaseolina* and *Rhizoctonia solani*. Sometimes, it is also called charcoal rot or collar rot and is prevalent in sandy soils, alluvial soils and also in the heavy clays constituting the black cotton soils. *Sclerotium delphinii* also causes seed, and seedling rot and is also reported to cause root rot in cotton.

Where to observe/look

The disease symptoms occur on the lower part of the stem and roots which leads to the wilting of plant foliage from top to bottom. Root rot caused by *M. phaseolina* appears either in the seedling stage (60 DAS) or after wood formation. While *R. solani* may occur at 30 DAS and become severe at 90-120 DAS. Check for disease patterns in the field (random, aggregated, repeated), as the disease occurs in circular patches in the fields, which expand year after year. Also, check the presence of fungal growth (mycelia, sclerotia) at the crown region.

Symptoms Description

Initially, a yellow patch appears on the lower part of the stem which later turns black leading to the drying of seedlings. Affected seedlings and plants show wilting foliage symptoms and can easily be pulled out of the ground due to the rotting of secondary roots. The leaves of the plant remain attached to the branches/stem. Tips of roots are mostly discolored, and yellow, and become sticky. Under favourable conditions, small black dot-like sclerotia may be seen on the wood beneath the bark and between the shredded bands of bark. The affected plant can easily be distinguished by the discolored stele of the main root and pith of the stem. In severe cases, there is the dissolution of the stem and root tissues and minute sclerotia can be found on it. The most identical symptom is dry or wet dark rot of the lower stem followed by shredding of bark and sudden wilting of plants with leaves remaining attached to plants. In the case of *Sclerotium* root/crown rot, the crown region of the stem shows white thread-like fungal growth and becomes wet. Brownish black mustard seed-like sclerotia can be seen on the crown region of the stem at the later stage. The disease caused by root rot pathogens occurs in circular patches in the affected field.

Fig. 37-42. Root rot symptoms on plant, leaves and roots (*Gossypium arboreum*)

Wilting and drying of the plants and root rot and bark shredding

Fig. 41-44. Root rot symptoms on plant, leaves and roots (*Gossypium hirsutum*)

Wilting and drying of the plants and root rot and bark shredding

Causal organism: Root rot is caused by *Rhizoctonia solani* Kuhn.; *R. bataticola* (Taub) Butler (pycnidial stage *Macrophomina phaseolina*); or *Sclerotium rolfsii* Sacc. The disease caused by soil-borne pathogens occurs in circular patches in the affected field. The pathogen can affect the plant at the seedling stage or after wood formation.

Economic loss: The root rot disease is serious in northern India but is also reported in Bihar, Gujrat, Andhra Pradesh and Tamil Nadu (Srinivasan, 1994). The disease affects both the *G. hirsutum* (American cotton) and *G. arboreum* (Desi) cotton species in almost all the cotton-growing areas, being more serious in desi cotton (Monga and Raj, 1994a).

6.2. *Fusarium* wilt

Fusarium wilt occurs only in diploid cotton (*Gossypium arboreum, G. herbaceum*) and is caused by the fungal pathogen *Fusarium oxysporum* f.sp *vasinfectum* (Atk.) which is both seed and soilborne. The pathogen survives on seed and infected plant debris in the soil by producing sclerotized, thick-walled resting bodies (chlamydospores).

Where to observe/look

The disease symptoms occur on roots which lead to the wilting of plant foliage from top to bottom. It appears in any crop growth stage but is seen generally between 30 to 120 DAS. Make a cross-section of the stem near the root zone and observe the colour change of the mainstem (especially the xylem), pathogen colonization, and growth in the plant vascular system. The pathogen develops into the roots and grows systemically into the vascular tissues and proliferates within the xylem vessels eventually spreading throughout the plant. Check for disease patterns in the field, as the disease occurs in patches in the fields, which expand year after year.

Symptoms description

Symptoms of this wilt may appear at any stage of crop development (generally from 30 to 120 DAS), depending on inoculum density, temperature, and host susceptibility. At very high inoculum density or the very beginning of infection, plants may be killed at the seedling stage itself. Usually, the first symptoms in the field appear 30-60 days after planting generally, on the onset of flowering. The pathogen colonizes in plant roots and grows systemically into the vascular tissues and proliferates within the xylem vessels eventually spreading throughout the plant. It grows out of the vascular tissues and after the death of the host, sporulates on crop residues. The disease can be recognized at the seedling stage with symptoms first appearing on the cotyledons as the darkening of veins, followed by peripheral chlorosis and necrosis before they drop. In older plants, the infection occurs as yellowing at the margin of one or more of the lower leaves. As the disease progresses within the plant more leaves develop chlorosis, which characteristically appears in patches between the main veins, the rest of the leaf remains green. Under optimal conditions, all the leaves of affected plants succumb and shed before the stem dries out.

Fig. 45-48. Wilt symptoms on the plant foliage and roots (*Gossypium arboreum*)

Wilting and drying of the plants

Infected patch in the field and xylem tissue rotting

Causal organism: Wilt caused by *Fusarium oxysporum* f.sp *vasinfectum* (Atk.) Snyder and Hansen which is both seed and soilborne fungal pathogen for diploid cotton. The disease affects only diploid cotton (*G. arboreum, G. herbaceum*) in India as only race 4 is known to occur in India.

Economic loss: The wilt disease caused by *Fusarium oxysporum f sp. vasinfectum* appears at any stage of plant development and the loss may vary from field to field and variety to variety from 5 to 40%.

6.3. *Verticillium* wilt

Verticillium wilt, caused by *Verticillium dahliae* Kleb*.,* is a widespread disease that occurs in most cotton-cultivating areas. *V. dahliae* is a soil-borne pathogen that infects plants through the roots. The disease is known to occur mostly in southern India both in *G. hirsutum, G. barbadense, G herbaceum,* and *G. arboreum.*

Where to observe/look

The disease infection may appear at any stage of crop development which leads to the development of symptoms on leaves and stems. Generally, it appears at the square and boll formation stages. There may be similar symptoms like wilting. Hence, internal symptoms can be checked by cutting the stem (cross or diagonally) at the base of the plant just above the soil. Check for color changes and patterns in the xylem, phloem, and cortex tissues.

Symptoms Description

Symptoms of this wilt may appear at any stage of crop development, depending on inoculum density, temperature, and host susceptibility. Usually, the first symptoms in the field appear 90-100 days after planting generally, on the onset of squaring and boll formation stage. Although the pathogen is present throughout the crop cycle, the incidence remains highest during the flowering stage.

Generally, infected plants show drooping branches and leaves. Infested leaves exhibit interveinal chlorosis, followed by yellowing, leaves scorching, and death of the entire plant.

Sometimes leaves exhibit drying of leaf margins and areas between veins known as "Tiger stripe symptoms". Sometimes, infected cotton plants show stunting and wilting by some strains of *V. dahliae* and defoliation by other strains. Characteristic symptoms of *Verticillium* wilt include wilted plants, leaf mottle, necrosis, defoliation, and in some cases the death of plants. The diseases are distinguished by flecked brown or pink discoloration of vascular tissues starting from the main root up into the stem and causing the blockage. Affected plants remain barren showing pinkish discoloration in the stem and wood. It may produce smaller bolls. Severe cases of Verticillium wilt can be easily mistaken for Fusarium wilt, and there are instances where both diseases have been found in the same field. It is most severe during extended wet or overcast weather, waterlogging, and late-maturing crops. Pushing the last irrigation to add further yield to the crop can allow the crop to be exposed to cooler weather which is ideal for Verticillium.

Fig. 49-52. Wilt symptoms on the plant, leaves (*Gossypium arboreum*)

Interveinal chlorosis, yellowing and leaves scorching

Infected plant and field patch

Fig. 53-54. Wilt symptoms on plants, leaves, and roots (*Gossypium hirsutum*)

Leaves scorching and vascular discolouration

Causal organism: Wilt caused by *Verticellium dahliae* Kleb. is both seed and soilborne fungal pathogen. It infects the plants at the seedling stage and continuously grows with the plant growth.

Economic loss: The wilt disease caused by *Verticillium dahliae* appears at the late stage of plant development around 90-100 days when plants are at the flowering to boll setting stage. The plants may remain barren during extended wet or overcast weather, waterlogging, and late-maturing crops which allows the crop to be exposed to cooler weather. The loss may vary from field to field and variety to variety.

6.4. Texas wilt: *Fusarium* Wilt Race 4

Biosecurity Threat

Fusarium wilt of cotton (*Gossypium* spp.), caused by the soilborne fungus *Fusarium oxysporum* f. sp. *vasinfectum* (FOV), is a widespread and economically important disease. FOV is genetically diverse with numerous described races and genotypes, most of which cause disease only in the presence of plant-pathogenic nematodes. Among 8 FOV races, Race 4 was first described in India in 1960 only on *G. arboreum* (Armstrong, and Armstrong, 1960; Cianchetta et al 2015). FOV race 4 is extremely virulent and can cause severe, early-season damage in the absence of nematodes. FOV race 4 was first detected in California on *G. hirsutum,* and *G. barbadense* in 2001 and had not been confirmed elsewhere in the United States. FOV race 4 was observed on seedlings of Pima cotton (*G. barbadense*) in Texas in El Paso and Hudspeth Counties during 2016-17, on *G. hirsutum,* and *G. barbadense* in New Mexico during 2017-18, Kansas during 2021 and widespread in U.S.A. FOV was found to be highly virulent, with the ability to kill the seedlings and cause severe plant stunting. As, the FOV race 4, which is present is different in terms of the race reported in California and Texas, strict quarantine vigilance and constant watch on the movement of cotton seeds and material should be kept.

Where to observe/look

The disease infection may appear at any stage of crop development which leads to the development of symptoms on seedlings including leaves and stems. There may be similar symptoms like wilting, stem and root rot. Hence, internal symptoms can be checked by cutting the stem (cross or diagonally) at the base of the plant just above the soil. Also, while importing the seed and soil material the samples/pack should be evaluated following the standard quarantine procedures.

Symptoms Description

The disease affects the crop at all stages. The earliest symptoms of wilting can appear on the seedlings in the cotyledons. Seedling damping-off caused by FOV4 can resemble disease caused by other common fungal pathogens, such as *Fusarium oxysporum* f. sp. *vasinfectum* (FOV), and *Rhizoctonia solani*. It may take several years to see disease field symptoms after FOV-4 is introduced into a field. The typical symptoms of FOV include leaf wilt, chlorosis and vascular discoloration. Bare spots occur randomly throughout the field, indicating areas where seedlings are killed earlier in the season. Over several years, the size of these bare spots increases, because of the movement of infested seeds or soil due to tillage or furrow irrigation. When infected plants are at the initial flowering stage, black streaking can appear at the center of the root which is limited to the roots. As the fungus grows, more of the root becomes decayed and, eventually, the plants wilt and die. Susceptible Upland varieties can have root rot without visible above-ground symptoms, in contrast to susceptible Pima varieties, which tend to show above-ground symptoms when root rot is present.

Causal organism: Texas wilt is caused by *Fusarium oxysporum* f. sp. *vasinfectum* (FOV) race-4 (FOV4). It is both soilborne and seed-borne. The fungus produces spores in the plant, which persist in the soil in the crop residue after harvest. The spores spread within a field when implements or water (for example, furrow irrigation) move the infested soil. The fungus can be transferred to other fields via implements that carry infested soil.

The fungus does not kill the seed and survives on acid delinting and seed-treatment fungicides. As a result, contaminated seeds can disseminate FOV-4 great distances and into previously non-infested fields.

Economic loss: Among 8 FOV races, Race 4 is extremely virulent and can cause severe, early-season damage in the absence of nematodes in *G. hirsutum,* and *G. barbadense* cultivars. FOV was found to be highly virulent, with the ability to kill the seedlings and cause severe stunting greater than 80%.

7. Bacterial Diseases

7.1. Bacterial leaf blight (Angular Leaf Spot, Black Arm)

The bacterial blight caused by *Xanthomonas citri* pv. *malvacearum* (Smith) Vauterin, Hoste, Kersters & Swings *(Xcm)* is a major disease of cotton. The disease used to be serious during pre-Bt era, then it decreased after the development of resistant hybrids/varieties. However, currently, there is a recent resurgence in additional states and it is observed regularly in central and south India. Four phases of the disease (seedling phase, angular leaf spot, vein blight phase, black arm phase, and boll rot phase) are recognized.

Where to observe/look

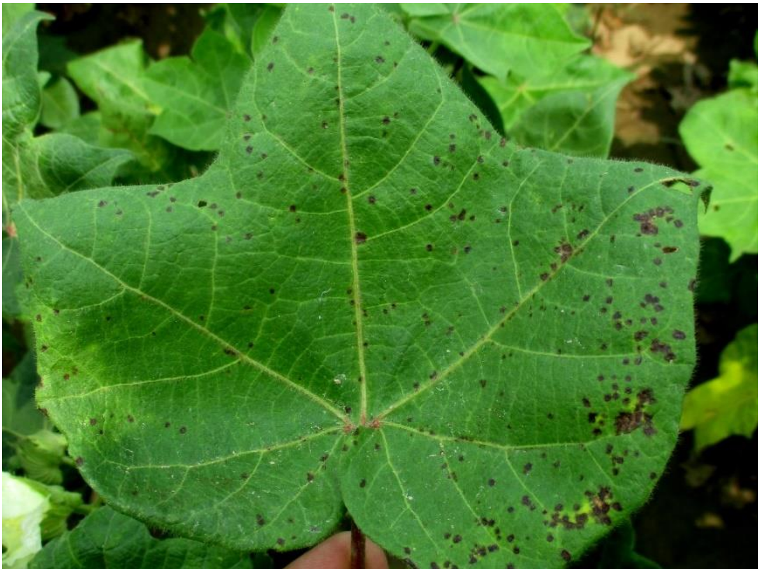
The disease occurs at the seedling to boll development stages. Look for the watersoaked, angular leaf spot on all above-ground parts starting from lower leaves to stem. Observe the underside of the leaf for water-soaking around the lesions. Symptoms appear on the leaves, flower bracts, bolls, branches, and stems which lead to the development of blighted and black arm symptoms. Systemic infections show the main veins as black streaks. The disease appears about 45 days after sowing to 105 DAS.

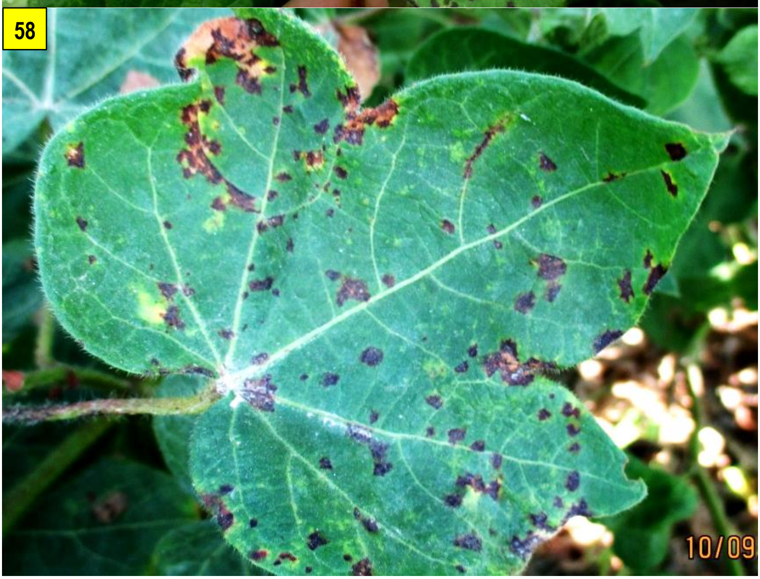
Symptoms Description

Four phases of the disease are recognized. The initial symptoms are tiny round to elongate lesions on cotyledons (seedling phase), initially deep green and water-soaked lesions/spots and later progressing into angular shapes due to veins limiting bacterial movement. Lesions appear on the upper side of the leaf and turn brown as they expand. Lesions are angular and typically dark brown (darker than many other pathogens) and there can be a

Fig. 55-58. Bacterial leaf blight symptoms-water soaked and angular leaf spots on leaves (*Gossypium hirsutum*)

Water-soaked lesions on upper and lower surface





Dark brown necrotic spots

"shot-hole" appearance when necrotic tissue falls away. On the underside of the leaf, there will be water-soaking around the lesions. Defoliation may occur due to severe infection. Lesions on hypocotyl are black, elongated cankers that often girdle and kill the seedlings. The foliar phase of the bacterial blight (angular leaf spot and vein blight phase, may appear at any time during the season as water-soaked lesions on leaves, bracts that are angular in outline. The infected spots tend to be restricted from spreading by the network of fine leaf veins. As the older spots dry, their colour darkens to brown. The systemic infection shows the main veins as black streaks and is known as 'Vein Blight'. Ultimately the severely affected leaves fall due to premature formation of the abscission zone at the base of the petiole. Later the infection also extends to the stem causing elongated grayish-to-black lesions (Black arm phase). On the bolls, the infection starts as small round water-soaked spots which later turn sunken, and brown (Boll rot phase). Secondary organisms then also enter the bolls and cause extensive boll rotting.

Fig. 59-60. Bacterial leaf blight symptoms-vein blight on leaves (*Gossypium hirsutum*)

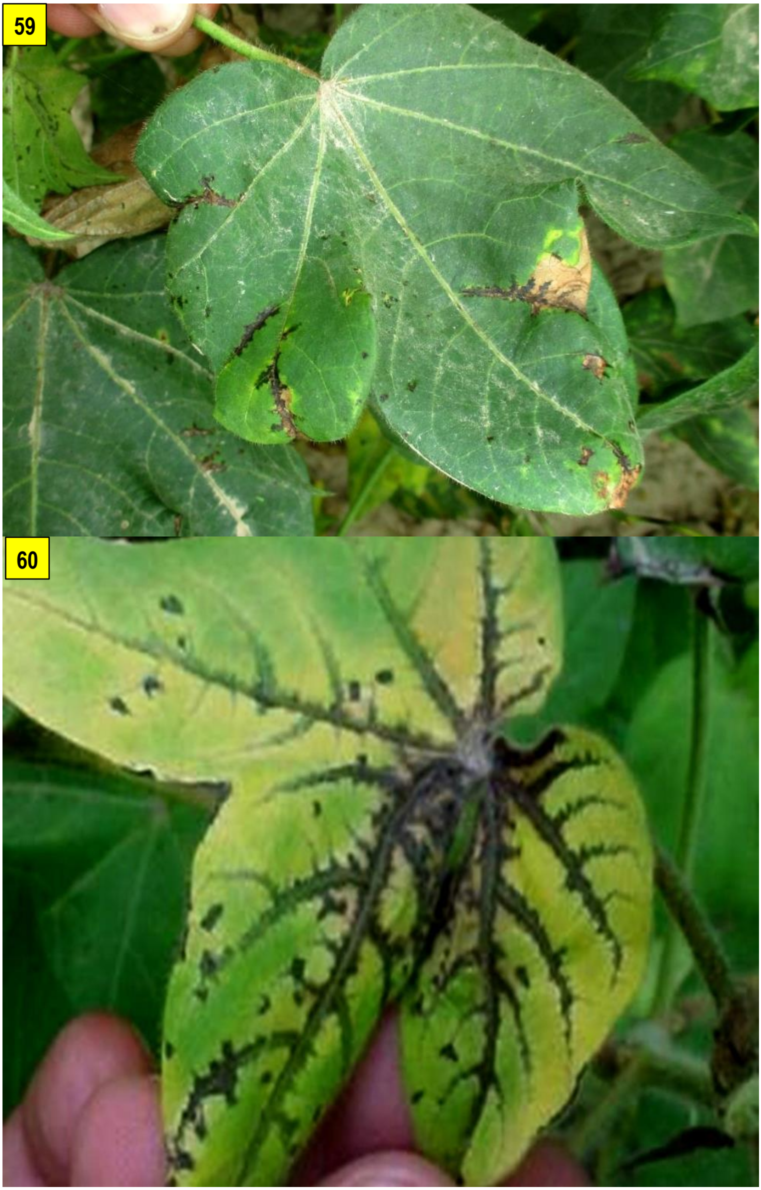


Fig. 61-63. Bacterial leaf blight symptoms on bracts and bolls (*Gossypium hirsutum*)

Causal organism: Bacterial leaf blight is caused by *Xanthomonas citri* pv. *malvacearum.* Several races of Xcm are reported to cause mild to severe symptoms being the Race-18 most virulent.

Economic loss: Yield loss can be severe, up to 20%, depending on variety and pathogen race. The potential yield loss due to bacterial leaf blight was estimated to be 22% with a maximum disease index of 28.8% at Dharwad, Guntur, Surat & Akola (Monga et al 2013).

7.2. Bronze Wilt

Biosecurity Threat

Bronze wilts a mysterious cotton disease also referred to as copper top, red wilt, sudden wilt, or phloem wilt was reported earlier in the Midsouth and Southeast of the U.S.A. during the hot summers of 1995, 1996, and 1998. The bronze wilt is characterized by bronze or red discoloration and wilting of leaves.

The disease occurs on short-season varieties of Upland and Pima cotton and is reported to flourish when daytime temperatures are above 32 °C for 2 to 3 weeks. Devastating losses from bronze wilt occurred in 1998 in the upper Mississippi, Georgia, Arizona and California.

Where to observe/look

The disease occurs at any stage but especially during the boll development stage. Look for the copper top, red wilt, sudden wilt, and phloem wilt symptoms on the plant and plant parts. Also, observe the fruit shed, and necrosis of leaves. Symptoms appear on the leaves, flower bracts, bolls, branches and stems which leads to the development of bronze wilt symptoms. Check for wilting if the upper taproot and lower stem appear healthy. It often appears first and most severely on plants at the ends of rows or along the field margins, or in single, isolated, or random plants. Generally, the symptoms of bronze wilt may resemble those of Fusarium and Verticillium wilts; Macrophomina root rots; damage from root-knot, reniform, stunt, or lance nematodes; potassium, sulfur and phosphorus deficiencies; drought; and extended periods of high temperatures. Brown scars on taproots from the death of secondary roots should be observed.

Symptoms Description

Bronze wilt on upland or Pima cotton is identified as the sporadic occurrence of plants across the field. Affected plants show rapid wilting, the collapse of the youngest leaves in the terminal of the plant, "bronzing" of the leaves, increase in leaf temperature (relative to "normal" adjacent plants), reddening of the stem, and fruit shed. Commonly, occur during fruit development and may become progressively more severe as bolls mature. More typical onset of symptoms occur after plants begin to bloom, followed by wilting, bronzing, and fruit shed symptoms. A series of symptoms occur at different growth stages. Bronze wilt can be distinguished from other diseases by the condition of the lower stem and upper taproot and the spatial pattern of diseased plants in the field. At the early stage, symptoms are mild and bronze leaf tint, lower leaf angle (wilting), and higher leaf temperature in the upper canopy than in normal plants are observed. At mid-stage, symptoms are moderate, early symptoms and reddening of the upper canopy (stem or leaf) and abnormal shedding of fruit can be seen. At the late stage, symptoms are more severe including the above symptoms, plus necrosis of stem tissue or whole plants. Severely affected plants show fruit shed when the symptoms begin during the fruiting period. Some plants may become necrotic and die, particularly if symptoms begin when cotton is at the early stage (8 to 12 nodes).

Causal organism: The exact cause of the bronze wilt is not certain and has to be investigated. Both biotic and abiotic factors have been proposed and referred to as possible causative agents. Brown scars on taproots from the death of secondary roots are reported in Texas, USA to be infected with a unique strain of *Agrobacterium tumefaciens*. As the bacterium is ubiquitous and can be found in the roots and seeds of nearly all cotton plants regardless of symptoms. Additionally, temperatures above 32 °C for 2 to 3 weeks; high light intensity; high rates of nitrogen fertilizer; deficiencies of phosphorus, sulfur and/or potassium; and high soil pH (above 7) are found to be congenial for bronze wilt. Drought followed by rain or irrigation may also accentuate symptoms. Depending on varieties, high moisture early in the growing season, high temperatures and drought particularly in the short-season are found most severe.

Fig. 64-65. Symptoms of bronze wilt on above-ground parts (*Gossypium hirsutum*)

Economic loss: Losses from bronze wilt are difficult to estimate, however, devastating losses from bronze wilt occurred in 1998 in the upper Mississippi River Delta and in the Gulf Coast States. In 1998, cotton losses in Georgia were valued at nearly $25 million. Even Pima varieties of cotton grown in Arizona and California showed yield losses that year.

8. Fungal Foliar Diseases

8.1. *Alternaria* leaf spot or blight

Alternaria leaf spot or blight is one of the most common cotton diseases considered to be of minor importance. *Alternaria* leaf spot is associated with late-season cotton development and does not cause considerable yield loss. But it becomes most severe when cotton plants undergo insufficient potassium availability, either due to inadequate fertilization or drought. However, the widespread occurrence is being reported throughout India and sometimes assumes serious proportions. It was reported earlier to be serious on tree cotton and various varieties of *G. hirsutum*, the other cultivated species of *Gossypium* being resistant. In recent years, infection in all four cultivated species has been observed. The incidence of the disease is erratic in occurrence causing severe defoliation in one or more years and then suddenly ceasing to be of major importance the next year. Natural infection of seeds or seed inoculation results in disease on cotyledons. It occurs in Gujarat, Tamil Nadu, Odisha, and Rajasthan on a mild to severe scale on *G. hirsutum, G. barbadense,* and the interspecific hybrids. Recently, *Alternaria* blight showed an increasing trend in South, and Central India depending on varieties and field conditions.

Where to observe/look

The disease symptoms occur on the leaves, bracts, branches and stems which leads to the development of blighted symptoms. It appears at the boll formation stages. Check for dark brown to black spots with concentric rings starting from the lower to upper leaves. Alternaria leaf spot lesions with concentric rings may appear similar to "Target leaf Spot"; however, spots from Alternaria leaf spots are wider and will occur throughout the canopy and are also associated with reddening and yellowing leaves.

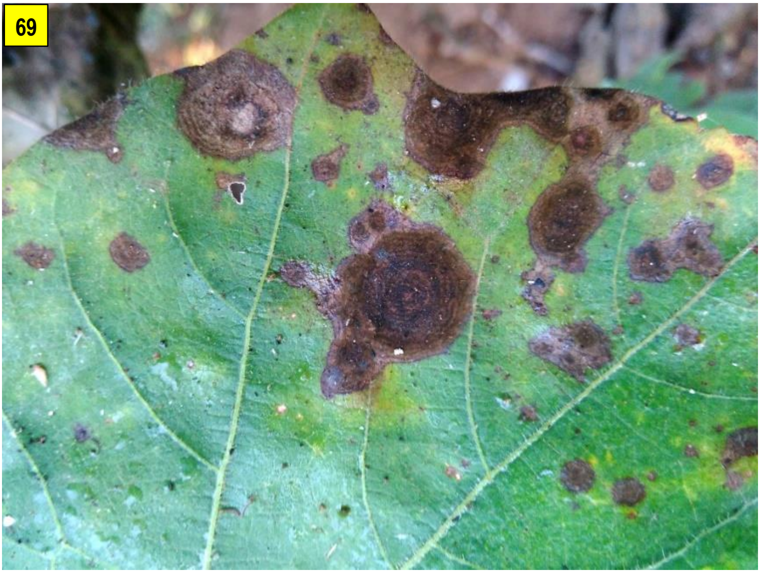
Symptoms Description

The earliest symptom of the disease is the appearance of spots on the cotyledons of the seedlings. Large numbers of spots coalesce together causing cotyledons to shed. Later, symptoms of the disease appear initially on leaves as small dull and dark brown, circular or irregularly shaped spots, varying in diameter from 0.5 to 10 mm on the upper surface of the leaf having concentric rings. Generally, spots form on senescing leaves that are brown with purple margins. As lesions expand they typically exhibit concentric zonation and the necrotic tissue will overlap with other lesions. As the disease progresses the lesions will become gray and dry with some of the necrotic tissue falling out giving it a "shot-holed" appearance. The spots get coalesced and form a big patch and such leaves look burnt or blighted, which results in defoliation. A few spots are also noticed on the petiole, stem, and bolls.

Causal organism: Alternaria blight caused by *Alternaria* spp. including *A. macrospora Zimm. A. alternata* (Fr.) Keissler

Economic losses: Alternaria is one of the most common diseases and is associated with late-season cotton development. (Note: Alternaria and Stemphylium Leaf Spots are similar and become most severe when cotton plants have insufficient potassium, either from inadequate fertilization or during periods of drought). Yield loss is not considered a problem if symptoms and defoliation occur late in the season. However, it showed an increasing trend from 2008-09 to 2010-11) in LRA 5166 at Rahuri (28.7 to 36.6 PDI) and in the case of Bt hybrid RCH 2 i.e., from PDI 21.3 to 39.5 at Dharwad (Monga et al.,2011). During 2006-2008 the potential yield loss due to ALB was estimated to be 26.6% with a maximum disease index 31.6% at Rahuri, Guntur, and Dharwad (Monga et al 2013).

Fig. 66-71. *Alternaria* blight on leaves (*Gossypium hirsutum*)



Leaf spot with concentric zonation and necrotic tissue

70

71

Leaf blight symptoms due to severe infection

8.2. *Cercospora* leaf spot or blight

Cercospora leaf spot is noticed in many cotton-growing areas of India. It occurs only sporadically and has not been reported as a serious hazard to cotton crops. It usually affects the older leaves but may spread over the whole plant in favorable weather under wet soil conditions when plants are unthrifty. Young plants are affected only if plant growth is impeded by unfavorable conditions.

Symptoms Description

The earliest symptom of the disease is the appearance of reddish spots on the cotyledons of the seedlings. Reddish lesions will also occur during the early crop stages. As the disease progresses, the lesions enlarge and turn white to light brown in the center. The lesions are circular and vary in size. The margin is formed of a distinct, dark brown or blackish rim which in young spots may be reddish at first. Concentric zones are often present with red color at the margins. In favorable conditions, the spots can enlarge to 10 mm in diameter. Large numbers of spots coalesce together following the drying of tissues causing cotyledons to shed.

On plants symptoms of the disease appear initially on leaves as small dull and dark brown, circular or irregularly shaped spots, varying in diameter from 0.5 to 10 mm on the upper surface of the leaf having light colour concentric rings. In the advanced stage, the spots dry with a grey center which cracks and some of them drop down giving the target board appearance. Adjacent spots may coalesce causing the withering of large patches of the leaf. In old spots, the center may crack and break away, leaving a ragged margin. Badly affected leaves turn pale, wither and drop. A few spots are also noticed on the petiole, stem, and bolls.

In the field, it is often difficult to differentiate Cercospora leaf spots from other foliar diseases like Alternaria, Corynespora, and Myrothecium leaf spots. The spots appear concentric, like those of Target Spot, and the general distribution of spots on the plant may be the same as Stemphylium and Alternaria Leaf Spots. Correct diagnosis often requires viewing the long, thin whip-like, septate spores. Caution should be taken as *C. cassiicola* spores can appear similar to Target Spot, but typically are broader and may have a basal scar.

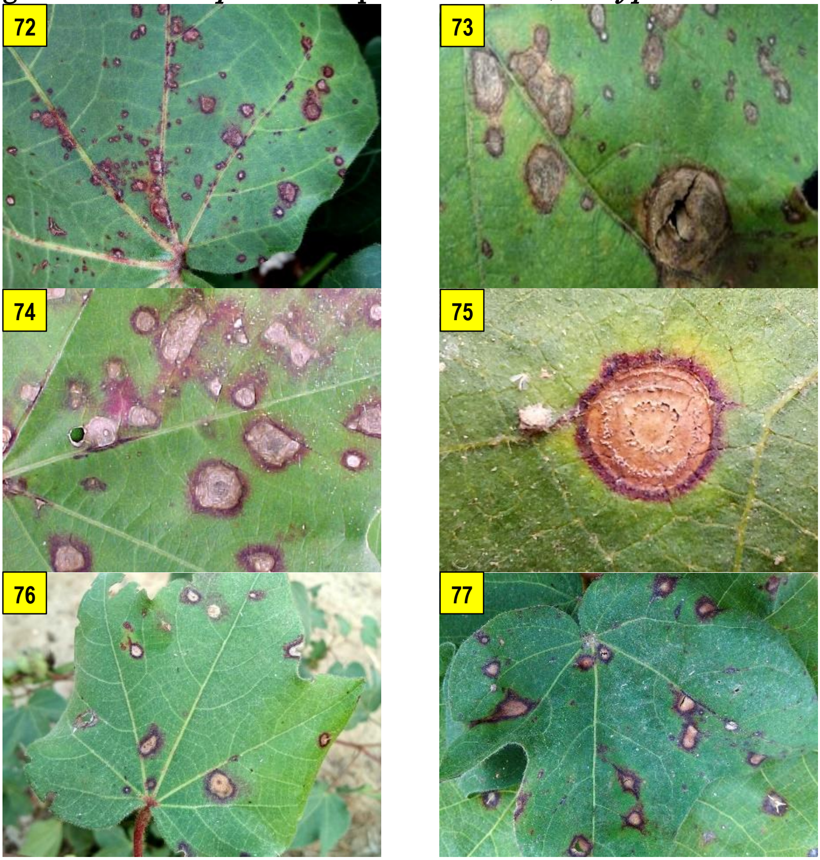
Where to observe/look

The disease symptoms occur on the leaves, bracts, branches, and stems. It appears at vegetative to boll development stages. Check for dull and dark brown, circular or irregularly shaped spots with a grey center and dark brown to purple margin starting from the lower to upper leaves. On old leaf spot lesions, small black dot-like perithecia may appear. Leaf spots are almost similar to Target leaf Spot, and Myrothecium leaf spots and will occur throughout the canopy and are also associated with reddening and yellowing leaves.

Causal organism: *Cercospora* leaf spot is caused by *Cercospora gossypina* Cke. and its perfect state is *Mycosphaerella gossypina* (Cke.) Atk.

Economic losses: *Cercospora* leaf spot is considered a minor disease and is not considered to be a cause of yield loss.

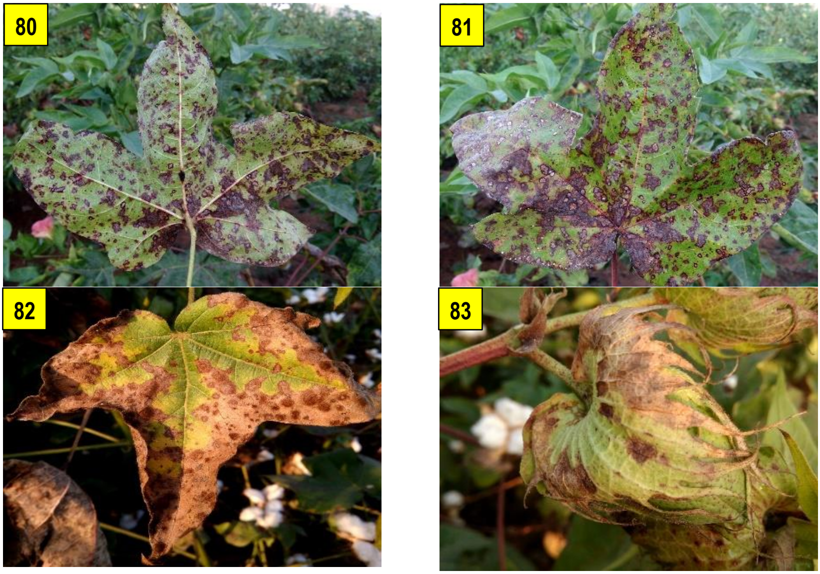
Fig. 72-79. *Cercospora* leaf spot on leaves (*Gossypium hirsutum*)



Progressive spots on leaves

Severely infected plants

Fig. 80-83. Cercospora leaf spot on leaves and bracts（*Gossypium barbadense*）



8.3. *Corynespora* leaf spot or target leaf spot

Target spot or target leaf spot or leaf fall caused by the ubiquitous fungus *Corynespora cassiicola* (Berk. & Curt.) Wei. found in the tropics and subtropics and is widely diverse in substrate utilization and host association. More than 530 plant species from 380 genera, including monocots, dicots, ferns, and one cycad, have been reported to support the growth of *C. cassiicola* (Dixon et al. 2009; Farr & Rossman 2011). Target spot is an emerging disease on cotton and other crops like cucumber, sweet potato, soybean, tomato, chilli, rubber plant, sesame, okra, sweet basil, etc. *C. cassiicola* is considered to be an aggressive, facultative parasite that sporulates readily on plant debris. There have been widespread reports of target leaf spot (CoLS) on cotton across multiple cotton cultivars along the cotton-growing regions of India and ToLS was reported in the North Maharashtra region (Dhule, Jalgaon, and Nandurbar Districts) in the year 2012- 2014, Nagpur district and Guntur (Andhra Pradesh) during 2017 (Shirsath et al. 2016; AICRP on cotton 2017; Salunkhe et al. 2019). Frequent rain events in the south and central cotton growing zone including Andhra Pradesh, Gujarat, and Maharashtra in the last few years provided ideal conditions for disease development. CoLS is likely to be present in other cotton-producing states of India and on other cotton varieties and Bt hybrids depending upon their susceptibility. When the disease occurs early in the season (at bloom), it may cause significant yield loss.

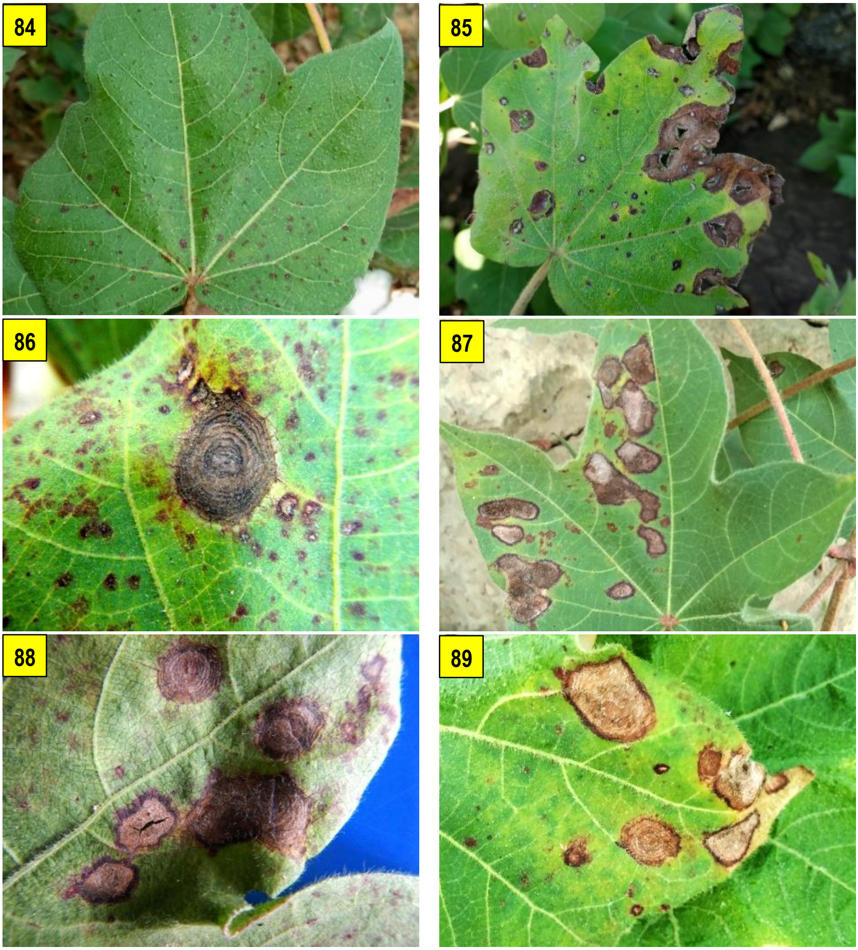
Symptom description

On cotton leaves, symptoms begin as small brown to brick-red circular to irregular shaped spots which then lead to the formation of large spots sometimes approaching 2 cm (~1 inch) in diameter, exhibiting a series of concentric rings. (1/4 to 1 inch in diam.) with the typical target pattern. The lesions due to infection of the pathogen are necrotic and show peculiar "target spot" symptoms, with some depression at the center of the lesion. Infection commonly occurs in the lower canopy and causes premature defoliation when disease severity is high with several lesions (20+ spots/leaf) per leaf. Initially, leaves show dark red spots as small circular to irregular spots, varying between 2 mm and 10 mm in size.

The CoLS can be quickly differentiated from the Stemphylium leaf spot by location in the canopy. Unlike Stemphylium and Alternaria leaf spots, the spots are typically not bordered by a dark band. Leaf spots and premature defoliation are generally confined to the interior canopy (unlike that found in Stemphylium and Alternaria diseases.) Lesions may occur in the upper canopy, but defoliation of the upper 20% has not been observed. Also, defoliation from CoLS typically begins at the bottom of the plant and progresses upwards.

The symptoms of the target spot start appearing as early as 60-70 DAS. It produces spores which are spread through wind and rain splash. In the case of severe infection, the lesions on leaves get coalesce and the infected leaves show severe necrosis leading to premature senescence and dropping of the leaf (Figure 1.7). At the latter stage, the target spot observed on the bract of the squares and in severe infection square and flowers dropping causes poor boll setting.

Fig. 84-90. Target leaf spot on leaves (*Gossypium hirsutum*)



Different stages of leaf spot symptoms

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Leaf spot infected plant

Where to observe/look

The disease symptoms occur on the leaves and bracts. Check for dark brown to brick-red spots with concentric rings starting from the lower, middle to upper leaves. CoLS lesions with concentric rings may appear similar to Alternaria and Stemphylium; however, unlike Stemphylium and Alternaria leaf spots, the ToLS spots are typically not bordered by a dark band. Lesions may occur in the upper canopy. Defoliation from CoLS typically begins at the bottom of the plant and progresses upwards. Defoliation is generally confined to the interior canopy, but defoliation of upper 20% has not been observed.

Causal organism: Target spot is caused by the ubiquitous fungus *Corynespora cassiicola* (Berk. & Curt.) Wei. found in the tropics and subtropics and is widely diverse in substrate utilization and host association. The pathogen is soil and partially seed-borne and overwinters in infected plant debris. The climate has an important influence on this disease as well; a hot and humid climate will encourage the disease. The main factors responsible for early disease onset are frequent showers/irrigation, dense crop canopy creating microclimate, and high humidity leading to rapid premature defoliation.

Economic losses: *C. cassicola* was reported in the North Maharashtra region (Dhule, Jalgaon and Nandurbar Districts) with 30-40% incidence in Nagpur district and Guntur (Andhra Pradesh) (Shirsath et al. 2016; AICRP on cotton 2017; Salunkhe et al. 2019). Yield losses have been reported (5-40% in the southern United States) when the disease occurs early in the season (at bloom) causing a significant amount of defoliation (10-50%) (Hagan 2014). Hence, it is unlikely to cause any significant yield loss when the disease develops on cotton that is close to picking.

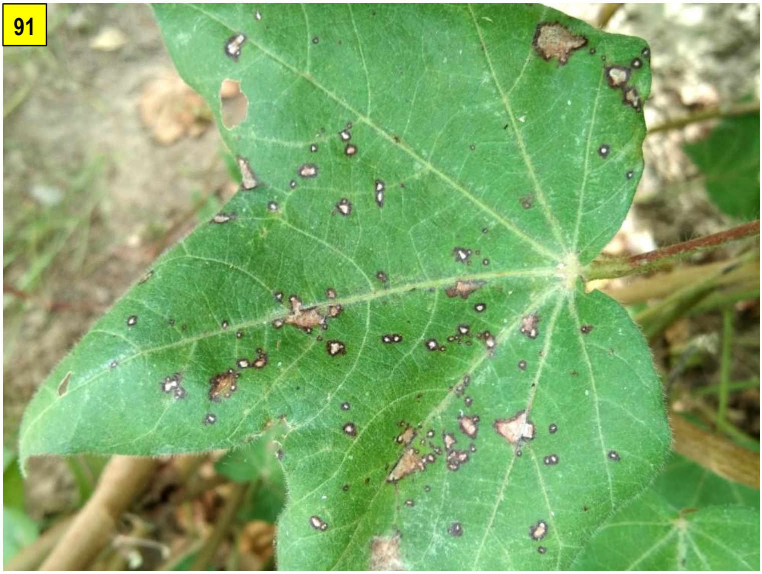
8.4. *Myrothecium* leaf spot

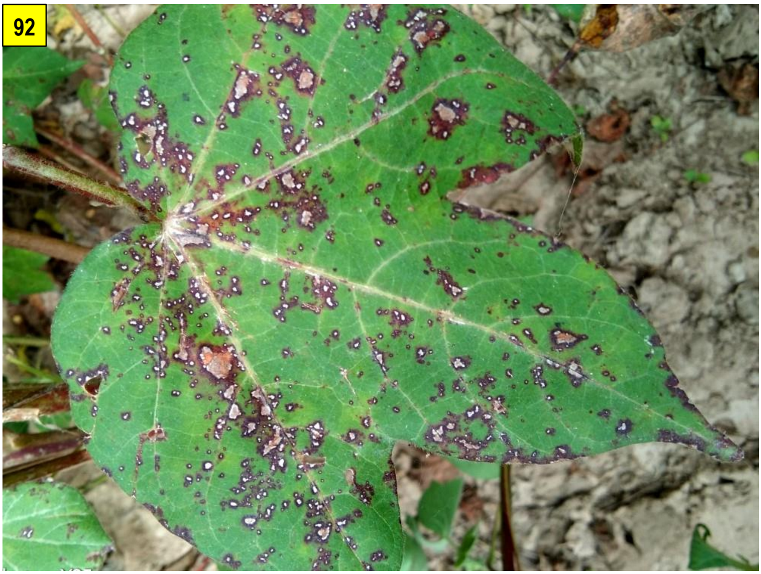
Myrothecium leaf spot in North Zone was observed in the late 1950s and early 1960s. The pathogen appears to have been carried to South India on seeds of hybrid H4 from Gujarat around 1971. The disease assumes a serious form in seasons of prolonged rainfall and humidity and is hardly noticeable during relatively dry periods. *Myrothecium* leaf spot disease occurs all over India. During recent years, the maximum incidence has been reported from Khandwa, Madhya Pradesh (AICRP on Cotton Reports).

Disease symptoms

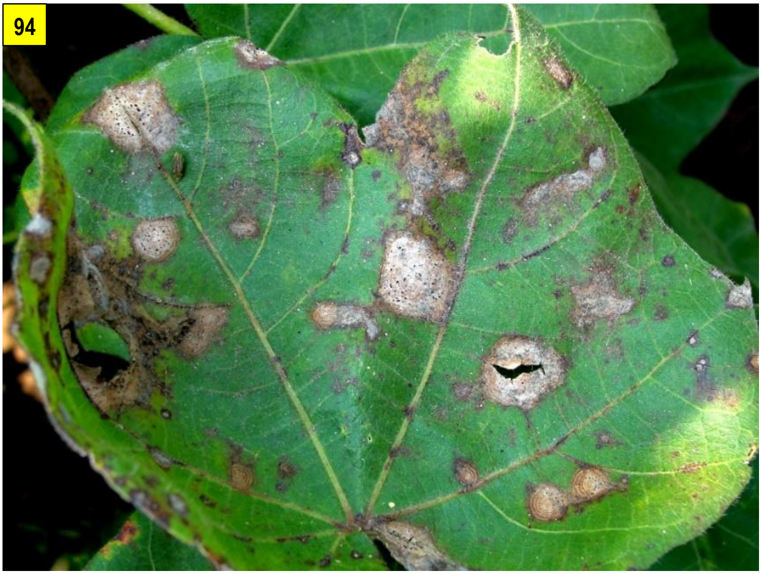
Myrothecium disease produces light brown to light ash colour small, circular to oval shape spots of 2-10 mm in diameter with dark brown/violet to the reddish-brown margin. In severe cases, the lesions/spots coalesce to form large patches. Later the bigger spots may show a shot hole and infected leaves may fall off. In favorable weather conditions, conspicuous rings of pinhead size and black sporodochia can be seen on the spots. The characteristic symptoms caused by *Myrothecium roridum* are the appearance of fungal fruiting bodies (sporodochia) which are produced in concentric rings and protrude from the lower as well as the upper surface of leaves. Under severe conditions, the lint gets strained to yellow or light brown. It causes heavy defoliation and occasionally attacks stems and branches, and may result in a serious blight. Sometimes the bolls are also damaged in some cultivars of *G. hirsutum* and *G. barbadense* are more severely attacked than other species. Boll lesions can lead to damage to the lint which may become brittle and discolored.

Fig. 91-94. *Myrothecium* leaf spot symptoms on plant, leaves (*Gossypium hirsutum*)






93


94

Where to observe/look

Check for light brown to light ash colour spots with dark brown/violet to the reddish-brown margin on the leaves. Also, check for the appearance of fungal fruiting bodies (sporodochia) in concentric rings in the spots on the upper surface of leaves. The center may drop leaving a shot hole.

Causal organism: Myrothecium leaf spot is caused by *Myrothecium roridum* Tode. It occurs in several types of soils with a wide pH range, sewerage irrigated fields, running water, and decaying plants. The pathogen is seed-borne and reduces the germination of cotton seeds. As the only pathogenic species of the genus, it infects a wide range of hosts including tomato, cotton, coffee, Antirrhinum, Viola, *Vigna sinensis, Cyamopsis tetragonoloba*, and *Ceiba pentandra.*

Economic Losses: Myrothecium leaf spot disease became an important problem in Madhya Pradesh. During 2007-2010 the potential yield loss due to Myrothecium leaf spot was estimated to be 29.2 % with the maximum disease index 22.5 % at Khandwa (Monga et al 2013). During recent years, the maximum incidence has been reported from Khandwa, Madhya Pradesh (AICRP Reports). Losses have been estimated at 15% by Taneja (1989) with 37 % disease intensity.

8.5. *Colletorichum* leaf spot or anthracnose

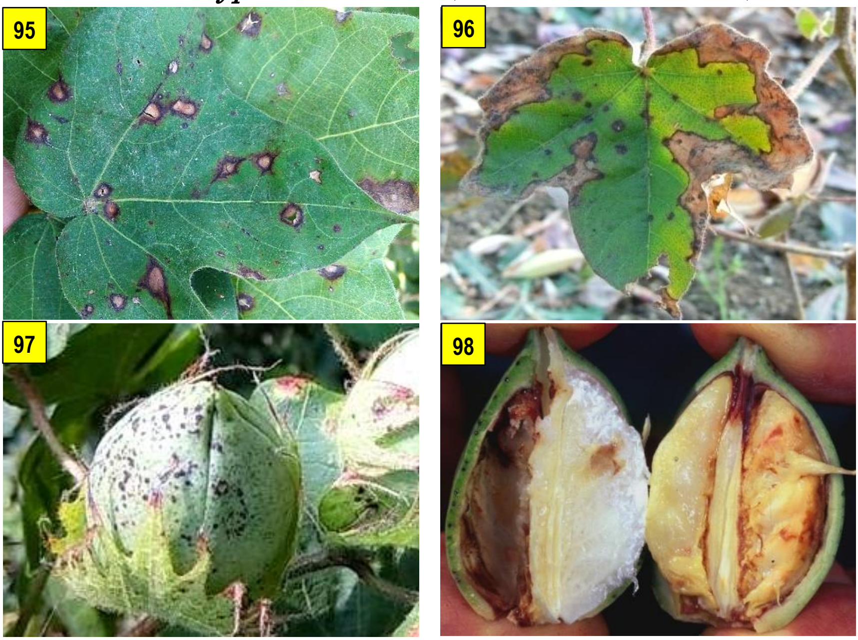
Colletotrichum leaf spot known as anthracnose of cotton was considered to be destructive particularly at seedling early stages and later at the boll development stages of the cotton. Earlier, it was prevalent in all the cotton-producing zones. But later it is being observed in Madhya Pradesh, Maharashtra, Tamil Nadu, etc., and was considered important in Tamil Nadu and Madhya Pradesh at one time but losses have decreased to negligible proportions. At present, the disease is occasionally noticed in southern and central parts of India.

Symptoms description

The disease affects every part of the plant at almost all stages. Symptoms may appear 20 days after sowing to the boll maturation stage (severe at the seedling stage). At the seedling stage, reddish brown or dark brown lesions appear just below the ground level which may cause seedling collapse even before the stem is girdled. Older seedlings exhibit yellowed leaves and retarded growth without collapse. On the cotyledons, small spots appear with irregular, necrotic margins and in moist conditions, cotyledons may completely be destroyed. This form of attack emanates from the infestation of seeds.

On the true leaves, initially small circular, sunken reddish to brown spots appear on the leaves, especially on the margin or near tips. These spots are reddish turning dark with a deep brown margin and 5-10 mm in diameter. Under severe infection, the necrotic lesion area increases and often causes defoliation. Black dots (*acervuli* of the pathogen) may be observed on these spots particularly on the lower leaves under humid microclimate, especially under irrigated conditions. On older plants, the symptoms may be observed on the stem as cankers spots- small, reddish, or brown with a depression in the center, later turning black. In moist weather, salmon-colored conidial masses may appear on the spots. Reddish-brown to purplish-brown spots and depression in the center develop on bolls (at the tip of the boll). Later central part may turn black with a reddish margin. In humid weather, slimy, salmon-pink conidial masses appear on the spots and later dry to form a crust. In the infected bolls, the lint remains compact, discolored, or stained with pinkish-brown color due to covering with mucilaginous, pink spore masses.

Fig. 95-98. Colletotrichum leaf spot symptoms on plant leaves and bolls of *Gossypium hirsutum* (external and internal)



Where to observe/look

All plant parts should be observed. Check for reddish-brown or dark-brown lesions just below the ground level. Check the small circular, sunken reddish to brown spots on leaves, especially on the margin or near tips and stem for cankers spots- small, reddish, or brown with a depression in the center, later turning black. Black dots may be observed on these spots. Check the internal part (lint discoloration) of the bolls if spots are observed on the bolls.

Causal Organism: The causal organism of the anthracnose disease is *Colletotrichum gossypii* Southw (perfect stage-*Glomerella gossypii*), *Colletotrichum capsici* (Syd.) Butl. & Bisby.

Economic Losses: Earlier, it was considered important in Tamil Nadu and Madhya Pradesh at one time but losses have decreased to negligible proportions. At present, the disease is occasionally noticed in southern and central parts of India.

8.6. *Helminthosporium* leaf spot

This disease is common in many cotton cultivation countries of the world. It is occasionally has been observed in many cotton-growing areas in India, especially in the Dharwad region of Karnataka.

Symptom description

Initially, numerous, circular, light brown spots occur usually on the lower leaves, 0.5-2.5 mm in diameter may occur. Later spots may turn ashy in the centre, with a dark, purple ring around them. Tissue in the centre of the spots often dropdown leaving holes. There is early defoliation when the disease is severe. Although lesions have not been observed on the bolls under natural conditions, however, similar spots develop sometimes on bracts.

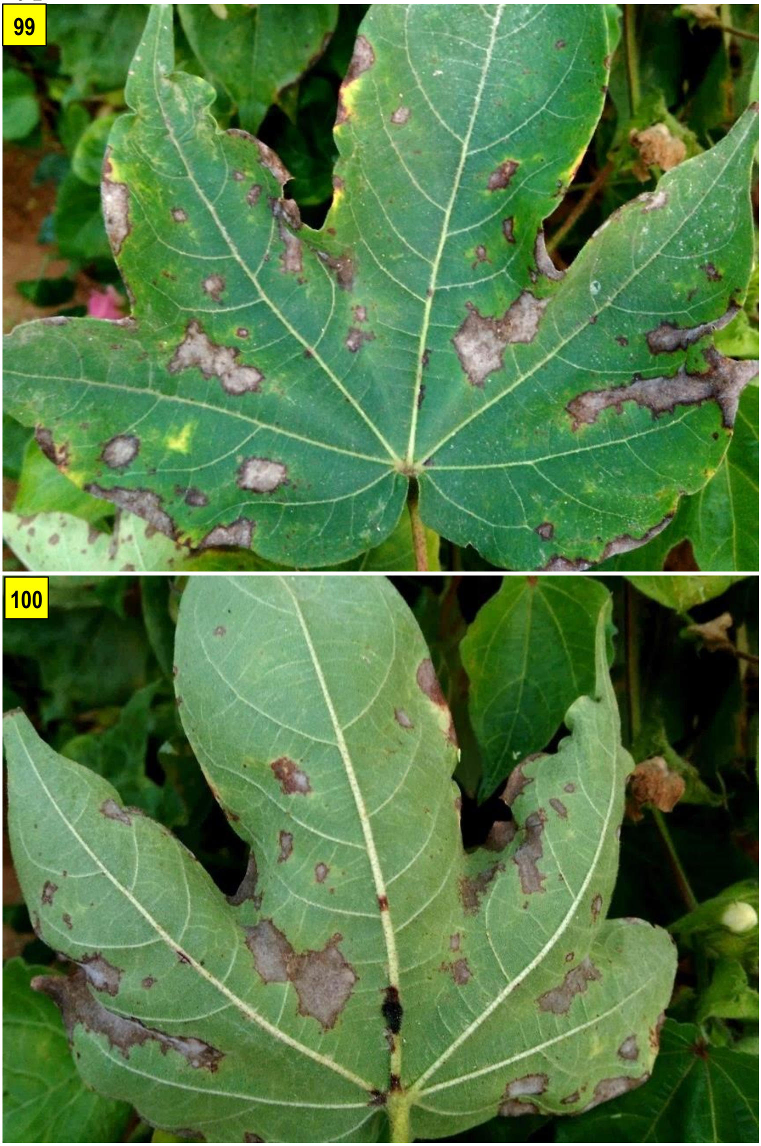
Where to observe/look

Check for circular, light brown spots 0.5-2.5 mm in diameter on the lower leaves. Later spots may turn ashy in the center, with a dark, purple ring around them.

Causal organism: The leaf spot disease is caused by *Helminthosporium gossypii* Tucker. All four cultivated species of *Gossypium* including the tree cotton are susceptible to this pathogen. The pathogen overwinters on diseased plant debris, particularly the dead leaves during the off-season.

Economic Losses: Leaf spot disease caused by *Helminthosporium gossypii* does not cause any noticeable loss in yield and is considered to be a minor disease.

Fig. 99-100. Helminthosporium leaf spot symptoms on leaves (*Gossypium hirsutum*)



8.7. Ascochyta Blight (Wet Weather Blight)

The Aschochyta blight occurs widely, and is also known as 'wet weather blight', 'Wet weather Canker' and 'ashen spot'. It causes a seedling disease which may lead to serious loss of plant stand. It has been observed on *G. arboreum*, *G. hirsutum,* especially during the continuous rainy period in Maharashtra, Gujarat, Tamil Nadu and Karnataka.

Symptom description

Disease symptomatic lesions appear on cotyledons, leaves, stems, and bolls. Plants are most susceptible during the early stage i.e. 3-8 weeks old. Lesions on the cotyledons and leaves approach 2 mm (<0.1 in) in diameter. Lesion are white to light brown and circular which enlarges and coalesces into irregular necrotic spots. Margins of necrotic regions on leaves and cotyledons will have a narrow, dark border. Spots may have a target-like appearance. However, early-season infection in the season, and small black fruiting structures are observed in the lesions. Elongated canker spots with reddish-purple to black or ash gray are observed on the stem which may lead to cause the death of vital parts. Small, black fruiting structures are likely to be embedded in symptomatic tissue. The partial defoliation of older plants may be observed. Rough, circular lesions may be observed on the bolls following boll rotting.

Where to observe/look

The disease symptoms occur on the leaves. Initial symptom development starts on lower leaves and progresses upwards if wet weather prevents it. It can appear at the seedling to vegetative stages (20-60 DAS). The disease can easily be confused with other fungal leaf blight at an early stage, hence carefully examining the leaf spots for lesions/margins and fungal growth on the spots should be observed. Check for light brown and circular spots or shot holes with a narrow, dark border. Also, check for small black fruiting structures on the older lesions.

Fig. 101-103. Ascochyta wet blight symptoms on leaves and infected plants (*Gossypium hirsutum*)

(Photo: D. Davara)

Causal organism: Wet weather blight disease caused by *Ascochyta gossypii* Woron (perfect stage *Phoma exigua)*. Pathogen has a wide host range that serves as a collateral host for the pathogen.

Economic loss: Wet weather blight has been in most of the major cotton-growing regions. However, yield loss is rarely reported. It may possible that under favourable conditions i.e. prolonged rains it may hinder the plant stand. Light infection may allow plants to recover at a later stage.

8.8. *Ramularia* Grey mildew

The names grey mildew, areolate mildew, false mildew (Faux Mildiou), white mildew (Moho Blanco), and Dahiya (curd disease) all refer to an affliction mainly of the leaves of cotton. In India, it is known in Madhya Pradesh, Bihar, Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu. The disease was found principally to affect the Asiatic cotton (*G. arboreum* and *G. herbaceum*) in India in the earlier decades while American cotton was free. Grey mildew showed increased incidence from 2008-2011. Later in India, it was considered of minor importance as it occurred only in some low-lying moist situations and caused little economic loss. But recently the incidence of grey mildew is assumed to be serious in the central and southern zone. Many hybrids/varieties of *G. arboreum, G. herbaceum,* and *G. hirsutum* are susceptible to grey mildew.

Symptom description

The disease is prevalent in the central and southern zone of India. The disease symptoms appear on the leaves which start from the lower canopy to the middle canopy at vegetative to boll formation stages (60-120 DAS). The disease appears on the lower canopy usually when the plants are reaching maturity. The characteristic symptom appears as irregular, angular, pale, translucent spots measuring 1-10 mm wide (usually 3-4 mm) and restricted by major leaf veinlets (called 'areolae'), which are slightly chlorotic on the upper leaf surface. A frosty or mildew growth consisting of conidiophores of the fungus appears first on the undersurface and subsequently on the upper surface of affected leaves. As the infection progresses leaves become yellowish-brown and lesions may become necrotic and resemble bacterial blight. In severe cases, premature defoliation will occur.

Lesions occur on the bracts subtending the bolls. they also appear on the cotyledons but no sporulation occurs on these structures unless they are placed in a moist chamber.

Where to observe/look

The disease symptoms occur on the leaves which start from lower to middle leaves It appears at vegetative to boll formation stages (60-120 DAS) generally at the maturing stage. The disease can easily be confused with bacterial leaf blight at an early stage, hence carefully examine the leaf spot for dirty-white fungal growth on the spots (grey mildew) or water-soaked lesions (for bacterial leaf blight). No other cotton disease commonly observed will have white, powdery growth on the underside of the leaf.

Fig. 104-107. Grey mildew symptoms on upper and lower leaf surface during severe condition (*Gossypium hirsutum*)

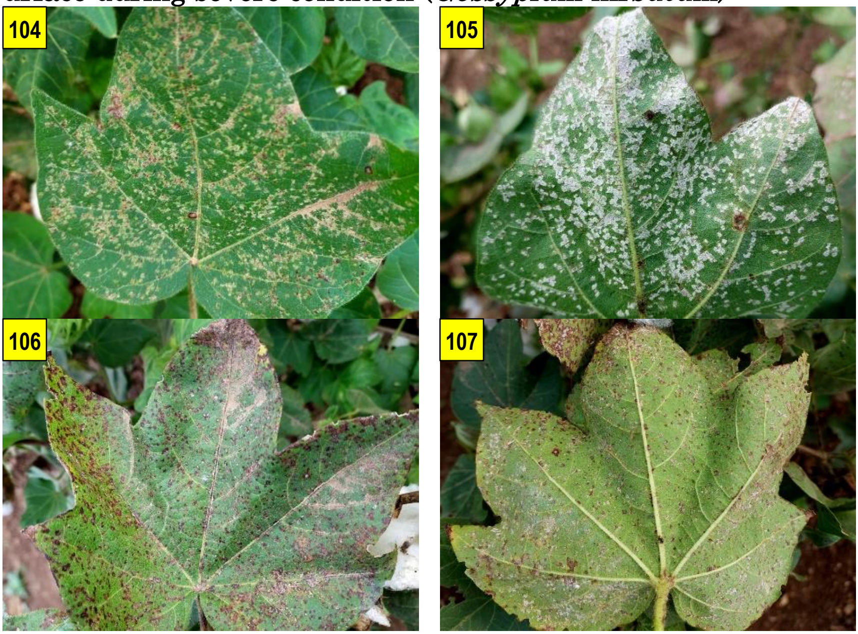
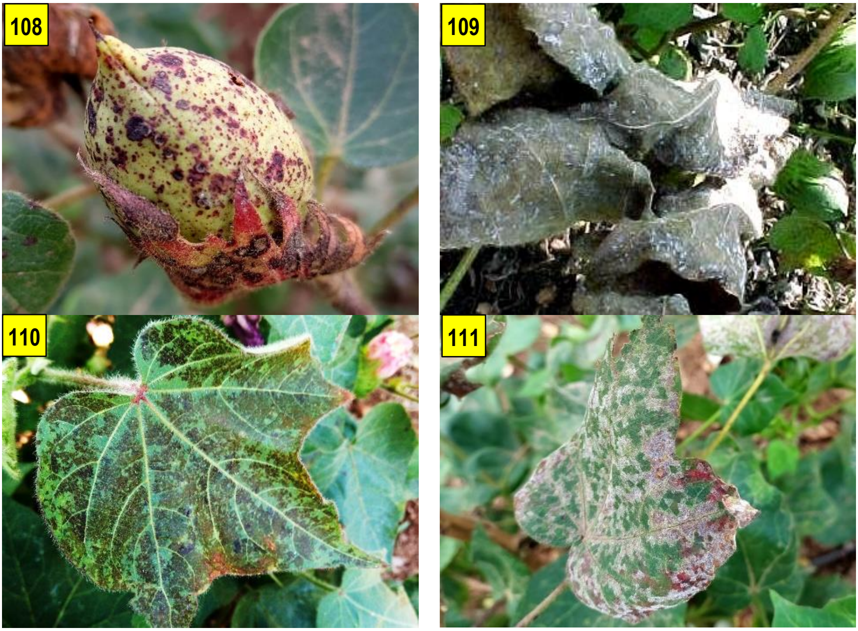


Fig. 108-111. Grey mildew symptoms on leaves, boll during the severe condition (*Gossypium hirsutum*)



Causal organism: The disease is caused by *Ramularia areola* Atk. and survives on infected dead leaves. It also overwinters on perennial cotton, volunteer plants and overlapping crops (genus Gossypium).

Economic losses: The majority of released Bt hybrids fall in the moderately susceptible to highly susceptible category (Hosagoudar et al. 2008). Grey mildew showed an increasing trend from 2008 to 2011 with PDI from 11.5 to 32.2 %, respectively (Monga et al. 2011). During 2009-2011 the potential yield loss due to grey mildew was estimated to be 25.6-46.6% at Dharwad, Guntur, and Nanded (Monga et al 2013).

8.9. *Phakospora* Leaf Rust

The rust is caused by *Phakospora gossypii* (Arth) Hirat. F. occurs sporadically in Tamil Nadu, Gujarat, Andhra Pradesh and Karnataka. It was considered to be of minor importance however it was reported to have depressed yields by as much as 24% in Coimbatore during 1963. Cotton leaf rust has become an important problem in the southern zone. It appears late in the season often after the onset of senescence when it may be beneficial in augmenting leaf fall before harvest. Though, its early appearance occasionally causes considerable loss by decreasing the photosynthetic area and heavy defoliation. The pathogen initially affects the older leaves and then spreads to the younger ones. Only the uredial stage of rust occurs in India.

Symptom description

The disease symptoms occur on the leaves which start from the lower to middle leaves. It appears at flowering to boll formation stages (120-180 DAS). Especially in the dry season during December-March. Rusty light to brown spots appears on older leaves which leads to premature defoliation. Uredial sori appear on the leaves as small (1-3 mm) pinkish-brown spots which may coalesce to form larger patches. Yellowish-brown uredia form on both the surfaces of leaves (Fig.1&2). Primary uredia on the upper surface, are deeply immersed in the tissues while shallowly seated secondary uredia are on the lower surface of the leaf. The shape of the uredia is oval to circular on the pedicels and branches. The urediospores are exposed to the rupture of the epidermis. Though the disease occurs during the later part of the crop season, it may cause losses in late sown as well as a prolonged irrigated crop. The disease is favoured by cooler temperatures.

Where to observe/look

The disease symptoms occur on the leaves which start from the lower to middle leaves. It appears at flowering to boll formation stages (120-180 DAS). Look for the light to brown rusty spots on older leaves and premature defoliation. Also, check for yellowish-brown uredia on both sides of spots on the leaves.

Causal Organism: Rust is caused by *Phakospora gossypii* (Arth.) Hirat. F. The disease generally appears in the dry season. In South India, it appears during the month of December-March.

Economic Losses: Since the last few years, the disease has become important due to its early appearance, and significant losses in seed cotton yield have been reported. However, this degree of damage is not of frequent occurrence. The severe incidence of rust leaf spots was noted from 2009 to 2012 in northern Karnataka, especially during the reproductive phase of crop growth. During 2009-2012 the potential yield loss was estimated to be 21.7% with a maximum disease index of 32.8% at Dharwad (Monga et al 2013). The PDI ranged from 29.1 to 39.8% on different varieties/hybrids at Dharwad and 35.0 to 37.0% at Guntur (AICCIP Report, 2014-15). The avoidable loss was estimated to be 21.7% in Bunny Bt while the loss was 34.05% in RCH 2 BG II in Andhra Pradesh (Monga *et al* 2013, Bhattiprolu, 2015).

Fig 112-116: Rust symptoms on cotton leaves (lower and upper surface) and plant


114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(Photo: Dr. SL Bhattiprolu)

9. Boll rots

9.1 External boll rot

"Boll rot" is a common term that is used to describe the rotting of cotton bolls due to insect-pest damage, several external, and internal pathogens and saprophytic organisms. It is considered a boll rot complex due to the involvement of several causal organisms depending upon location, and epidemiological factors. Monocropping of the crop and varieties, climate changes resulting in the higher incidence of boll rot pathogens complex in cotton. About 170 organisms are reported to be associated with the boll rot complex which directly impacts the production and the quality of the cotton lint. The cotton boll rot disease complex comprises cotton diseases that cause damage to the developing bolls. Several plant pathogenic fungi, bacteria and saprophytic microorganisms are associated with internal and external boll rot. Broadly the causal organisms are categorized into three groups-(a) cotton pathogens causing infection of developing bolls (b) pathogens, saprophytes causing infection in the intact bolls after physical or insect damage, and (c) infection of the bolls after bolls are damaged by insects and suture are broken.

External boll rot: Generally, this external boll rot complex occurs during the boll maturity and bursting stages. It is caused by several fungal and bacterial pathogens, and saprophytic fungi depending upon climatic conditions and insect-pest infestation (Allen and West 1986; Kirkpatrick and Rothrock 2001; Palmateer et al.2004; Mirzaee et al. 2013). Continuous cloudy weather, rain shower, warm weather and high relative humidity are conducive to external boll rots. Mostly, the growth of fungi and mycelia can be seen on infected bolls. Initially, the disease symptoms appear as small brown or/and black colored dots which later may enlarge and develop to cover the entire bolls. Further, the infection spreads to inner tissues and rotting of seeds and lint may occur.

Fig 117-122: External boll symptoms due to saprophytic fungal and bacterial pathogens

The infected boll opens prematurely and the quality of fiber gets affected. In the case of high relative humidity and warm weather, mycelial growth and fruiting bodies of fungi may be observed on infected bolls. Sometimes, the bolls may never burst open and fall off prematurely. In another case, the rotting of the pericarp occurs but internal tissues may remain disease-free.

Where to observe/look

The disease symptoms occur on the bolls which start from lower to middle bolls. It appears at boll formation stages (120-180 DAS). Look for the rotting or discolouration of bolls or water soaked or brown to black spots on bolls. Also, check for fungal growth on the bolls. Several fungal growth and fruiting structures may be observed on the bolls.

Causal organisms: External boll rot complex is caused by several fungal and bacterial pathogens, and saprophytic fungi including *Colletotrichum gossypii* var*. cephalosporioides, C. gossypii, Fusarium* sp*., Ramularia areola, Lasiodiplodia theobromae, Myrothecium roridum, Alternaria macrospora, Phoma exigua, Phomopsis* spp*., Phytophthora* spp*., Rhizoctonia* spp*., C. cassicola, Rhizopus* spp., *Aspergillus* spp., *Mucor* sp., *Cercospora* sp., and Diplodia sp. *Curvularia* sp. *Cladosporium* sp. *Helminthosporium* sp., *X. c.* pv. *malvacearum,* etc.

9.2. Internal boll rot

It can be caused single or a combination of bacteria and fungi. Bacterial seed and boll rot was first recorded in South Carolina, USA in 1999. The disease causes 10–15% yield loss in the USA and 20% in Chinese cotton fields of Xinjiang Province in 2006. It is also reported in Pakistan and India. In India, *Erwinia aroideae* was associated with boll rot of green bolls in cotton (Chinthagunta 2008). *Pantoea ananatis* causes disease symptoms in a wide range of economically important crops including plantation crops. Early disease diagnosis is very complicated; the boll seems to be healthy as no symptoms appear on the outer surface of the boll. The disease can only be observed when bolls are cross-sectioned or opened. The immature diseased locule is attributed to as "hard lock" having rotted seeds with brown dense lint. Infected bolls are partially opened, either drop or do not open properly. The putative internal boll rots of green bolls are incited by opportunistic, facultative anaerobic bacterial phytopathogens of the family Enterobacteriaceae and some endophytic fungi. After flowering, disease organisms may invade the developing ovary (boll) via wounds associated with insect feeding, especially stink bugs and drizzling rains (Madrano et al. 2007; Esquivel et al. 2010; Brewer et al. 2012; Ehetisham-ul-Haq et al. 2014). However, the developing boll is susceptible to these piercing/sucking insects for only about the first 3 weeks. The immature seeds, fibers and lint in locules of immature unopened green bolls initially appear discolored, light yellow, pink-red to brown coloured with a slimy presence. The infected seeds may be swollen and rotted. Occasionally, minute black spots may be seen in some cases as an indicator of feeding signs of hoppers, bugs and other piercing-sucking insects transmitting bacteria to the carpel layer of developing bolls. Internal carpel wounds caused by the insect-pest help pathogen to cause rotting of the entire locule. The seed infection is generally restricted to one or two locules. In some cases, pathogens cause severe necrosis and rot of flowering buds, young bolls and seeds within older bolls and the whole locules of immature green bolls get diseased and headlocks may be formed (Dipak et al. 2020).

Where to observe/look

The disease symptoms occur on the bolls which may start from any place in the cotton plant, especially at the lower canopy. Critically look for the sucking-piercing insect damage on the

Fig 123-128: Internal boll symptoms bacterial and fungal pathogens

healthy bolls. Cross open the bolls and observes the locules and seeds with lint inside the boll. Rotting or discolouration of locules/seeds and lint inside bolls without any fungal growth may be observed. Check the seeds, fibers and lint in locules of immature unopened green bolls which may initially be light yellow, pink-red to brown coloured with slimy presence. Also, the whole locules of immature green bolls get diseased and headlocks may be formed.

Causal organism: Internal boll rot complex can be caused by a single or combination of bacteria and fungi including *Pantoea agglomerans*, *P. ananatis, P. dispersa*, *P. anthophila*, *Erwinia uredovora*, *X. c.* pv. *malvacearum*, *Nigrospora oryzae, Colletotrichum gossypii* etc.

Continuous rain showers, cloudy weather, high relative humidity, an infestation of piercing-sucking bugs/insect during buds and bolls development, and early crop sowing are some of the major factors which lead to internal boll rot infection. Generally, an external boll rot complex occurs when continuous cloudy weather, water stagnation and high humidity persists in the field. Hence, the incidence of this disease must be regularly monitored especially at early boll development stages. In the case of internal boll rot continuous rain showers, cloudy weather, high relative humidity, and an infestation of piercing-sucking bugs/insects during buds and bolls development may be checked.

Economic losses: It is estimated that cotton boll rot disease can cause losses in productivity up to 20-30% (Lamamoto, 2007). About 10–15% cotton (*Gossypium hirsutum*) yield loss was reported due to seed and boll rot disease in South Carolina of USA (Hudson 2000; Hollis 2001). Several factors like geographic locations, climatic conditions, presence of pathogens, and population of insect vectors are responsible for losses due to boll rot.

10. Physiological Disorders

10.1. Parawilt or sudden wilt complex

Parawilt or sudden wilt in cotton has been recorded in many cotton-growing states and to the newly released hybrids and varieties of cotton, and the scale of its destruction caused havoc among cotton growers across the country. Large-scale wilting is often observed in Bt fields in Central, South and North cotton-growing zones. In this physiological disorder, the soil–plant–atmosphere continuum is broken due to adverse environmental factors like flooding or soil saturation, which leads to poor root development and function.

Symptoms Description

The plant starts wilting from the top once the water stagnation takes place in the root zone. The wilting is more common and severe on clayey soils because they drain more slowly than sandy soils, but injury sometimes occurs even on sandy soils, if poorly drained. Within a few days all the leaves drop off while the bolls remain attached. If parawilt occurs just prior to the crop harvest, bolls may forcefully open but will not ripen fully, leading to poor quantity and unmarketable quality. At times wilt spreads like a wildfire and can cover the whole field within a few hours of its initiation. Poor root growth, coupled with sudden rain followed by water stagnation, high air temperature and bright sunshine are the major cause of sudden wilting and its occurrence is much more severe if the cotton has been growing rapidly. In another case, when the root development is very poor in the beginning or root growth is parallel or shallow, and the dry conditions coupled with the high vigour and heavy boll load, and or sudden and heavy irrigation/rainfall may result in sudden wilting in the plants.

Fig. 129-130. Parawilt due to water logging

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Fig. 131-132 Parawilt due to poor root growth, soil hard pan/compactness, nutritional deficiency and heavy boll load

Where to observe/look

The symptoms occur on the plant canopy. Critically look for the roots. Cross opens the roots and stem, which may be observed as healthy and without any fungal growth. Leaves start wilting from top to bottom within a few hours. If treatments in not applied within 24- 48 hours, all the leaves may drop off while the bolls remain attached and may open early.

Causal factors: Young plants are generally not affected and the symptoms typically occur from flowering onwards. Three factors have been implicated with the cause of the disorder complex are 1) soil saturation/ water logging, 2) rapid growth rate of plants at the grand growth stage show higher metabolic activity, transpiration at a faster rate and increased stomatal conductance and photosynthesis, 3) bright sunshine and hot air temperature which induces high stomatal conductance, transpiration and photosynthesis. Root respiration increases with increasing temperature, causing an increase in O2 requirement and limited O2 available in waterlogged soil, which is faster in plants with rapid growth. The lack of oxygen leads to the death of roots and root hairs, and thus restricts the uptake and transport of water through the roots.

In the case of clay/sandy clay soil conditions, the soil–plant–atmosphere continuum is broken due to adverse environmental factors like early irrigation/ soil saturation, soil hard pan/compactness, low organic carbon, and continuous cropping system, leading to poor root growth, and nutritional deficiency and heavy boll load result in sudden wilt. In such field conditions, sudden wilt was found to be more prominent in early maturing and high-yielding Bt hybrids

10.2. Red leaf or Leaf reddening complex

Red leaf complex of cotton, commonly known as *lal patti* in India. It is also known as Bronze wilt, "copper top," "sudden wilt" and "phloem wilt" in the U.S. and "red leaf," "red wilt" and "anthocyanosis" in other countries, is a physiological disorder induced by different abiotic stresses. Recently, this has emerged as a serious problem in various cotton-growing regions of Indian subcontinents.

Symptoms description

Leaf reddening symptoms appear during boll development and may become severe at boll maturity. Initial symptoms appear on the fully expanded leaves and the area between the veins in the upper part of the leaf becomes raised. The leaf margin becomes yellow and turns into red pigmentation covering the whole leaf. Reddening may progress to other leaves and the stem. Later this may lead to poor plant growth and result in the shedding of the leaf and bolls.

Where to observe/look

The disease symptoms occur on the above ground. Critically observe the leaf, stem and boll for leaf reddening and its progress.

Causal factors: Though the exact cause is not yet fully understood. The abiotic factor like nitrogen deficiency, water stagnation and high soil moisture, magnesium deficiency and cloudy weather and low night temperature are proposed to be the abiotic factors responsible for this complex. Factors such as drought followed by rain/irrigation, high wind velocity, high solar radiation, soil with poor capacity to supply nitrogen and phosphorus.

Fig. 133-134. Common symptom of leaf reddening on the leaves and whole plant

11. Management of Diseases

Common plant health management practices

- Regular monitoring of weeds and other alternate hosts to observe the incidence of diseases, pests and CLCuD vectors for effective diseases and insect-pests management.
- Maintain the field, field bunds, and irrigation channel clean and weed-free, as the weeds compete with the cotton crop for nutrition and harbor sucking pests, especially whitefly and act as the source of CLCuD inoculum.
- Destroy volunteer/ ratoon/infected cotton plants and weed hosts on or near irrigation channels/canals/bunds and in fallow lands.
- Adopt crop rotation to break the life cycle and reduce soil-borne diseases inoculum and enhance soil fertility, health.
- Avoid growing whitefly and CLCuD host crops near cotton crops: Do not cultivate crops like cucurbits, bhindi, moong, arhar, castor, dhaincha, and kinnow orchard etc. in and around cotton or *vice versa* to minimize build-up and spread of pests and diseases in cotton.
- Avoid cultivating non-recommended and undescriptive hybrids/ varieties as they may be highly susceptible to insect-pests and disease specially CLCuD and sucking insect-pests.
- Avoid early and late sowing: Untimely sown crop attracts insect- pests, especially late sown crop is prone to CLCuD and other diseases and insect-pests
- First irrigation should be applied 6-7 weeks after sowing and irrigation should be stopped at the end of September based on crop requirements.
- Field soil samples must be tested from approved laboratories for genuine crop fertilizer application requirements.
- Do not let the crop suffer from nutrition deficiency: Use balanced fertilizer and avoid excess nitrogen application. Apply fertilizers as per the recommendations and soil test report. The excessive use of nitrogenous fertilizers should be

avoided to minimize the incidence of pests and diseases. Apply 3-5 sprays of 2% potassium nitrate (13:0:45) solution starting from flower initiation at weekly intervals.

- Need-based micronutrients should also be applied like Zinc, Magnesium, Manganese and Boron.
- Azotobacter and PSB (phosphate solubilizing bacteria) @ 25 g each / kg seed should be used for nutrient fixation.

Common disease management practices

- Grow only recommended Bt Hybrids/ varieties resistant/tolerant to CLCuD
- To minimize seed and soil-borne diseases, seed treatment with Carboxin 75%WP @2.5g/kg or Thiram 75%WP @ 2.5-3g/Kg or Thiram 37.5+Carboxin 37.5% DS @ 3.5 g / kg seed or Tetraconazole 11.6% w/w (12.5% w/v) SL @ 2 ml /kg seed or Fluxapyroxad 333 g/LFS @ 1.5 ml/Kg or *Trichoderma harzianum* or *T. viride* @4 g/ kg or *Pseudomonas fluorescence* @ 10 g/kg seed before sowing.
- Soil application of *Trichoderma* spp. and or *Pseudomonas fluorescence* @ 2.5 kg/ha by mixing in 250 kg of vermicompost/well-decomposed FYM is good for seed and soil-borne disease management.
- To reduce CLCuD incidence, weed sanitation, cultivation of Desi cotton/sorghum/Perl millet/maize as border rows, and optimal use of nitrogenous fertilizers are advocated as per crop conditions and soil test reports.
- In the case of fields with a history of sudden wilt and other soil-borne disease problems, adopt crop rotation, deep ploughing, incorporation of crop residue, green manuring, well-decomposed FYM/compost and seed and soil treatment with biopesticides and or biofertilizers/bioagents as mentioned above are useful to manage parawilt/sudden wilt.
- Do not plant the seeds originating from the region with seed and or soil-borne disease and without effective seed treatment, especially for control of FOV.

- Growers with infested fields should not save and replant their own seed.
- Farm equipment those have been used in infested fields, must be cleaned using a pressure washer and detergent or soap to clean soil and plant material. before moving it to other fields

Specific disease management practices

The region-specific and crop stage-wise management practices including the IDM packages developed under AICRP on cotton are as follow:

Table 2: Disease Management Practices

North Zone	
	▪ **IDM for CLCuD:** 3-5 foliar spray of Salicylic acid (200 ppm) or butter milk5% or Cow urine +Calcium nitrate (6.6%+0.5%) or mustard oil (3.0%) at the fortnightly interval starting from 30 days after sowing.
Early season (Seedling Stage)	
Root rot, wilt	• Spot application of Carbendazim @ 2.0 g/L of water or *Trichoderma harzianum* or *T. viride* @6 g/L in the affected patches.
CLCuD	• 1-2 Foliar spray of Nimbecidine 300ppm @ 1L /acre + 0.1% washing powder followed by diafenthiauron (200 gm/acre)/ buprofezin (320 ml/acre) for adults and spiromesifen (200 ml/acre)/ pyriproxifen (400-500 ml/acre) for nymphs, and Ethion (800 ml/acre) at later stage through CLCuD vector management.
Mid-season (Flowering Stage)	
Root rot, wilt	• Spot application of Carbendazim @ 2.0 g/L of water or *Trichoderma harzianum* or *Trichoderma viride* @ 6 g/L in the affected patches.
CLCuD	• 1-2 Foliar spray of Nimbecidine 300ppm @ 1L /acre + 0.1% washing powder followed by diafenthiauron (200 gm/acre)/ buprofezin (320 ml/acre) for adults and spiromesifen (200 ml/acre)/ pyriproxifen (400-500 ml/acre) for nymphs, and Ethion (800 ml/acre) at a later stage

Sooty mold	• Prophylactic sprays of Flonicamid @ 0.4g/L or propiconazole @1ml/L or mancozeb @ 2g/L or COC @ 2.5 g/L
Late season (Boll development)	
Alternaria & Cercospora leaf spot and other fungal leaf spots	• Kresoxim-methyl 44.3%SC@ 1ml/L or Azoxystrobin 18.2% + difenoconazole 11.4% SC@ 1ml/L or propiconazole @1ml/L or pyraclostrobin 20%SC @ 1ml/ L or Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L SC @ 0.6 g/L or Propineb 70%WP @2.5-3 g/L
Root rot, wilt	• Spot application of Carbendazim @ 2.0 g/L or *Trichoderma harzianum* or *Trichoderma viride* @6 g/L in the affected patches.
Sudden wilt/parawilt	• Avoid water stagnation in the crop • Foliar spray of Cobalt chloride @10 ppm or sodium benzoate@ 50ppm and/or drenching of copper oxychloride 25g+200g Urea / 10 L immediately after the appearance of the wilting symptoms on the affected plants.
Boll rot	• Copper oxychloride 50 %WP @2.5g or Copper sulphate 47.15%+Mancozeb 30% WDG @5 g/L of water
Sooty mold	• Prophylactic sprays of Flonicamid @ 0.4g/L or propiconazole @1ml/L or mancozeb @ 2g/L or COC @ 2.5 g/L
Leaf reddening	• Foliar spray of 1% MgSO4, 2%, Urea 0.5%, Zinc Sulphate and 0.2 % Boron, twice at 15 days intervals on 90 days old crop followed by spray of 2% DAP.
Central Zone	
	• **IDM for Rahuri Maharashtra:** Seed Treatment (ST) - *Pseudomonas fluorescens* (PF TNAU1) @ 10g/Kg of seed, Soil Application (SA) of *T. viride* @ 2.5 KG/ha (TV- TNAU1) in 250 KG of Compost or FYM, FS with Ergon (Kresoxim methyl) @ 1ml/L @ 60 DAS and Taqat (Captan + Hexaconazole) @ 1.5 g/L @ 90 and 120 DAS for fungal diseases
	• **IDM for Akola Maharashtra:** ST - *Pseudomonas fluorescens* (PF CICR) @ 10 g/ kg of seed + SA of

	Trichoderma viride @ 2.5 kg/ ha (TV- TNAU1) in 250 kg of Compost or FYM and foliar spray (FS) with Kresoxim methyl @ 1 ml/L followed by Captan + Hexaconazole @ 1.5 g/L for fungal diseases/ALS or COC (0.3 %) for BLB
	• **IDM for Nanded Maharashtra:** ST – *P. fluorescens* (PF CICR) @ 10 g/ kg of seed + SA of *T. viride* @ 2.5 kg/ ha TV- TNAU1 in 250 kg of Compost or FYM and FS with Kresoxim methyl @ 1 ml/L followed by Captan + Hexaconazole @ 1.5 g/L for fungal diseases or COC (0.3 %) for BLB.
	• **IDM for Junagarh Gujarat:** ST: *P. fluorescens* (PF-JAU) @10g/kg seed; SA: of *T. harzianum* (TH-JAU) @2.5 kg/ha in 250 kg of FYM; FS: with *P. fluorescens* (PF-JAU) *1*% for ALS and COC (0.2%) for BLB on need basis.) **Or** • ST with *P. fluorescens* (PF-CICR) @ 10g/kg seed; SA of *T. viride* (TV-TNAU) @2.5Kg/ha in 250kg of FYM; FS with Ergon@ 1ml/lit followed by Taqat @1.5 g/L for fungal diseases or COC (0.3%) for BLB), Module-5 (ST: *P. fluorescens* (PF-CICR) @10g/kg seed; SA of *T. viride* (TV-TNAU) @2.5Kg/ha; FS with Propiconazole 0.1% and COC (0.3%) for BLB or Carbendazim 0.1% for GM on need basis) **Or** • ST with Carboxin 37.5 % + Thiram 37.5 % DS @3.5 g/ kg of seed; FS with Captan70% + Hexaconazole 5 % WP 2.0 g/L, COC (0.2%) and Carbendazim12%+ Mancozeb 63% WP 2.5 g/L on need basis
	• **IDM for Surat Gujarat:** ST- *P. fluorescens* (PF-CICR) @ 10 g/ kg of seed + SA of *T. viride* @ 2.5 kg/ ha (TV- TNAU1) in 250 kg of Compost or FYM and FS with Kresoxim methyl @ 1 ml/L followed by Captan + Hexaconazole @ 1.5 g/L for fungal diseases or COC (0.3 %) for BLB. **Or**

	• ST – *P. fluorescens* (PF-CICR) @ 10g / kg of seed + SA of *Trichoderma viride* @ 2.5 kg/ ha (TV-TNAU1), FS with Propiconazole 0.1 % for fungal diseases and COC (0.3 %) for BLB or Carbendazim 0.1 % for grey mildew on need basis. **Or** • ST – *P. fluorescens* (PF-CICR) @ 10 g/ kg of seed + SA – *P. fluorescens* (PF-CICR @ 2.5 kg/ ha in 250 kg of Compost or FYM and foliar spray with *P. fluorescens* 1 %
Early season (Seedling Stage)	
Root rot	• Spot application of Carbendazim @ 2 g/L of water or *Trichoderma harzianum* or *Trichoderma viride* @6 g/L in the affected patches.
BLB	• FS of copper oxychloride 250 g/acre
TSV	• FS of spinetoram 11.7 SC @ 170 ml/acre or profenophos 50EC @ 500 ml/acre or diafenthiuron 50WP @ 200 g/acre
Mid-season (Flowering Stage)	
Root rot	• Spot application of Carbendazim @ 2.0 g per lit of water or *Trichoderma harzianum* or *Trichoderma viride* @6 g/L in root rot-affected patches.
BLB	• FS of copper oxychloride 250 g/acre
GM	• FS of Propineb 70%WP@ 2.5 g/L or Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L
Boll rot	• FS of Copper oxychloride 50 %WP @2.5g /L of water or Copper sulphate 47.15%+Mancozeb 30% WDG @5 g/L of water
ALB, CoLS, Boll rot	• FS of Fluxapyroxad 167g/l + pyraclostrobin 333g/l SC @ 0.6 g/L, or propiconazole @1ml/L or pyraclostrobin 20%SC @ 1ml/ L or Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L SC @ 0.6 g/L or Propineb 70%WP @2.5-3 g/L
ALB, CoLS, GM, Boll rot	• FS of Metiram 55%+ pyraclostrobin 5%WG @ 2g/L or Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L

TSV	• FS of spinetoram 11.7 SC @ 170 ml/acre or profenophos 50EC @ 500 ml/acre or diafenthiuron 50WP @ 200 g/acre
Parawilt	• Avoid water stagnation and drought stress in the crop at the boll development stage • FS of Cobalt chloride @10 ppm or sodium benzoate@ 50ppm and/or drenching of Copper oxychloride 25g+200g Urea / 10 L immediately after the appearance of the wilting symptoms on the affected plants.
Late season (Boll development)	
BLB	• FS of copper oxychloride 250g/acre
GM	• FS of Propineb 70%WP@ 2.5 g/L or Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L
Boll rot	• FS of Copper oxychloride 50 %WP @2.5g /L of water or Copper sulphate 47.15%+Mancozeb 30% WDG @5 g/L of water
ALB, CoLS, Boll rot	• FS of Fluxapyroxad 167g/L + pyraclostrobin 333g/L SC @ 0.6 g/L
ALB, CoLS, GM, Boll rot,	• FS of Metiram 55%+ pyraclostrobin 5%WG @ 2g/L or Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L
Leaf reddening	• FS of 1% MgSO4, 2% Urea 0.5%, Zinc Sulphate and 0.2 % Boron, twice at 15 days interval on 90 days old crop followed by FS of 2% DAP
South Zone	
	• **IDM for Coimbatore Tamil Nadu (Root rot & ALB)** ST – *Bacillus subtilis* (BSC5-TNAU1) + SA @ 2.5 Kg/ha + FS with *B. subtilis* @ 1% on 60, 90 and 120 DAS
	• **IDM for Guntur Andhra Pradesh:** ST- *P. fluorescens,* SA – *T. viride*, FS with kresoxim methyl @ 1ml/l at 60 DAS for fungal diseases and COC @ 0.3% for BLB at 90 DAS, FS with kresoxim methyl @ 1ml/L at 60 DAS and

	captan+hexaconazole (Taqat) 1g/L at 90 DAS for fungal diseases **Or** • ST- *P. fluorescens,* FS with Propiconazole 0.1% for Alternaria leaf spot at 60 DAS and COC @ 0.3% for BLB at 90 DAS; FS with carbendazim 0.1% for grey mildew at 60 DAS and propiconazole 0.1% at 90 DAS for leaf spots and rust.
	• **IDM for Dharwad Karnataka**: ST *P. fluorescens* (PF-CICR) @ 10g/kg of SSA *P. fluorescens* (PF-CICR) @ @ 2.5 kg/ha in 250 kg of Compost or FYM FS *P. fluorescens* @ 1%(PF-CICR) **Or** • ST *P. fluorescens* (UASD)10g/kg of seed /*P. fluorescens* (PF-CICR) @ 10g/kg of SSA, *T. viride* @ 2.5 kg/ha (TV-TNAU) in 250kg of Compost or FYM, FS of Ergon @ 1ml/lit followed by Taqat @ 1.5gL for fungal diseases or COC 0.3% for BLB
	• **IDM for Fungal and Bacterial leaf spots for Andhra Pradesh**: ST with *P. fluorescens* @ 10g/kg seed or carbendazim 2g/kg seed or thiram 3g or vitavax 2g; FS copper oxychloride 3g/l or mancozeb 3g/l or propiconazole 1ml/l or captan + hexaconazole 1g/L and copper oxychloride 3g/L for BLB starting from 50 days after sowing, 3-4 times, at fortnightly intervals.
Early season (Seedling Stage)	
Root rot	• Spot application of Carbendazim @ 2.0 g per lit of water or *Trichoderma harzianum* or *Trichoderma viride* @6 g/L may be done in root rot affected patches.
Verticillium Wilt	• ST *T. viride* @ 10g/kg seed or *P. fluorescens* @ 10g/kg seed or carbendazim 2g/kg seed or thiram 3g or vitavax 2g; SA *T. viride* or *P. fluorescens* @ 1kg/acre with 100kg FYM or vermicompost; balanced Nitrogen application, correcting micronutrient deficiencies; soil drenching at the base of infected plants with copper oxychloride 3g/L or carbendazim 1g/L.

Mid-season (Flowering Stage)	
Verticillium Wilt	• ST *T. viride* @ 10g/kg seed or *P. fluorescens* @ 10g/kg seed or carbendazim 2g/kg seed or thiram 3g or vitavax 2g; SA *T. viride* or *P. fluorescens* @ 1kg/acre with 100kg FYM or vermicompost; balanced Nitrogen application, correcting micronutrient deficiencies; soil drenching at the base of infected plants with copper oxychloride 3g/L or carbendazim 1g/L.
BLB	• Spray of copper oxychloride 250g/acre is advised.
GM	• FS of Propineb 70%WP@ 2.5 g/L or Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L
Boll rot	• FS of Copper oxychloride 50 %WP @2.5g /L or Copper sulphate 47.15%+Mancozeb 30% WDG @5 g/L of water
TSV	• FS of spinetoram 11.7 SC @ 170 ml/acre or profenophos 50EC @ 500 ml/acre or diafenthiuron 50WP @ 200 g/acre
ALB, CoLS, Boll rot	• FS of Fluxapyroxad 167g/L + pyraclostrobin 333g/L SC @ 0.6 g/L
ALB, CoLS, GM, Boll rot,	• FS of Metiram 55%+ pyraclostrobin 5%WG @ 2g/L or • FS of Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L
Late season (Boll development)	
BLB	• FS of copper oxychloride 250g/acre
GM	• FS of Propineb 70%WP@ 2.5 g/L or Sulphur 3g/L or carbendazim 1g/L, or Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L 3-4 times, at 10-15 days intervals
ALB	• FS of Propiconazole 25% EC @1 ml/L
Boll rot	• FS of Copper oxychloride 50 %WP @2.5g /L of water or Copper sulphate 47.15%+Mancozeb 30% WDG @5 g/L of water or carbendazim 1g/L

Sooty mold	• FS of Copper oxychloride 2.25g/L, propiconazole 1ml/L,
Rust	• FS of Sulphur 3g/L or propiconazole 1ml/L, starting from 75 days after sowing, 3-4 times, at fortnightly intervals
ALB, GM, Rust,	• FS of Kresoxim-methyl 44.3%@1ml/L,
ALB, CoLS, Rust, Boll rot	• FS of Fluxapyroxad 167g/L+Pyraclostrobin333g/L @ 0.6g/L
ALB, CoLS, GM, Boll rot,	• FS of Metiram 55%+ pyraclostrobin 5%WG @ 2g/L or • FS of Azoxystrobin 18.2% W/W + Difenoconazole 11.4 w/w SC @ 1 ml/L
Leaf reddening	• FS of 1% $MgSO_4$, 2%, Urea 0.5%, Zinc Sulphate and 0.2 % Boron, twice at 15 days interval on 90 days old crop followed by FS of 2% DAP

12. Nutritional deficiencies and their managements

Introduction

Soil nutrients are considered as essential during the critical crop reproductive phases. Deficiency in the nutrients must be supplemented with required nutrients for enhanced productivity. In the cotton plant growth cycle the following elements are identified as essential viz., Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Sulfur, Iron, Manganese, Zinc, Copper, Boron, Molybdenum, Chlorine, Cobalt, Selenium and Sodium. Most of the carbon as carbon dioxide enters the plant from the air; hydrogen and oxygen are taken up as water. The rest of the elements are taken up from the soil solution as mineral nutrients. The nutrients are classified into major or macro-nutrients and minor or micro-nutrients. The plant requires 1 to 150 g/kg of plant dry matter form major nutrients, and 0.1 to 100 mg/kg plant dry matter form minor nutrients. Chloride is essential in micro quantities but can accumulate in the plant in large quantities when present in high concentrations in the soil solution.

Cotton has indeterminate growth habits, where the vegetative and reproductive components grow simultaneously and tend to alter the physiology of the plant at different growth stages of the plant. This document is likely to highlight the physiological disorders which hinder cotton cultivation and progress.

12.1. Classification of Plant Nutrients

Table 3: Classification of Nutrients of Cotton

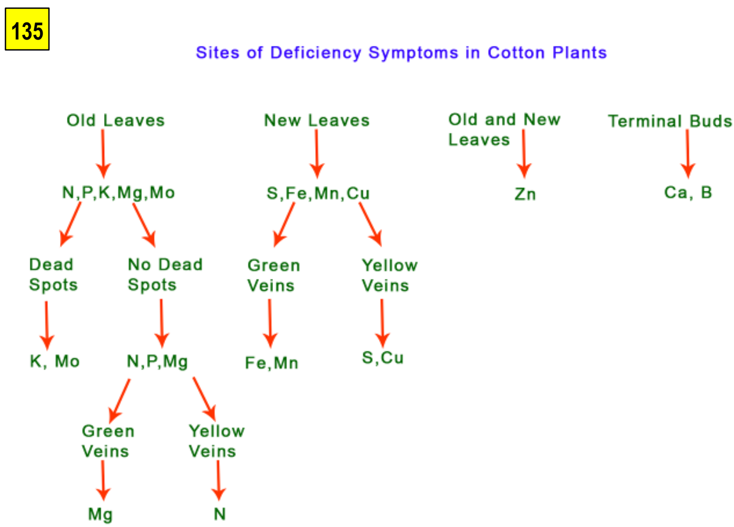
Major or Macro-Nutrients (6)	Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sulphur (S)
Minor or Micro-Nutrients (10)	Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl), Cobalt (Co), Selenium (Se) and Sodium (Na)

All the essential nutrients are required by plants in balanced proportions. Any deviation from this in terms of quantity and timing may result in nutritional disorders. Early detection of nutritional deficiency stress is important to save the plant. If the relief of stresses is not employed in time, stress might extend to the entire plant with loss of yield. Prolonged and continuous shortage of a nutrient might cause plant death. When two or more elements are deficient simultaneously, the composite picture of symptoms may resemble no single known deficiency. Nutrient deficiency symptoms are sometimes confused with among nutrients and other symptoms of damage caused by insect-pest, disease, salt stress, water stress, pollution, light and temperature injury and herbicide damage. For example, toxicity of Mo or Se is similar to P deficiency, Fe deficiency in mango is similar to chloride toxicity. The deficiency symptoms might be distinguished based on the plant part that shows deficiency symptoms, presence or absence of dead spots and an entire leaf or interveinal chlorosis.

Deficiency of soil mineral nutrients may be the consequence of low soil mineral contents, extreme temperatures, pH, drought and waterlogging conditions that alter the mineralization and hence availability to plants. Hence conditioning of soils to increase nutrient availability also plays an important role in achieving high nutrient uptake efficiency in plants. Generally, nutrient deficiency in the plant occurs when a nutrient is insufficient in the growth medium and/ or cannot be absorbed and assimilated by the plants due to unfavorable environmental conditions. Nutrient disorders limit crop production in all types of soil around the world.

ICAR-Central Institute for Cotton Research (CICR), Regional Station at Coimbatore found novel technology to identify the plant nutritional deficiency under hydroponic. Besides the experiments were conducted in sand and soil cultures both in closed and open conditions. The expression of nutritional deficiency in the cotton plant has been documented.

Fig 135. Sites of Deficiency Symptoms in Cotton



12.2. Visible Symptoms of Nutritional Deficiency

Nitrogen (N): Nitrogen deficiency is the most commonly observed nutrient deficiency in cotton crops. The characteristic deficiency symptom of nitrogen is the appearance of uniform yellowing of leaves including the veins, this being more pronounced on older leaves. The leaves become stiff and erect. The leaves detach easily under extreme deficiency conditions. If such condition of nitrogen stress does persist, the result is decreased foliage growth and shoot growth.

Excess leaching with heavy rainfall, low organic matter content of soils, burning of crop residue, denitrification (losses of N2 and N2O to the atmosphere induces nitrogen deficiency. Soil testing (depth of 30 cm) should be carried out in areas that have not received nitrogen fertilizer to determine the amount of nitrogen required for the succeeding cotton crop.

Fig 136 – 138 Nitrogen deficiency symptoms

136: Nitrogen deficient plant

137: Initial Stage Nitrogen deficient leaf

138: Advanced stage Nitrogen deficient leaf

Management of Nitrogen Deficiency: Grow leguminous crop as intercrop to correct edaphic conditions and to augment biological nitrogen fixation process or Top dressing with inorganic nitrogen fertilizer @10-20 kg N/ha or applying a 1% foliar spray of Urea or 2% Foliar spray of DAP.

Phosphorus (P): True phosphorus deficiency only occurs in less than 10 ppm of available phosphorus. In phosphorus deficiency, leaves remain small, erect, and unusually dark green. The underside develops a bronzy appearance. The root growth is also restricted under phosphorus stress. Anthocyanin pigment increases in leaves under phosphorus stress.

Acidic (high AI content), organic, leached and calcareous soils and a high rate of liming induce phosphorus deficiency. Soil tests (depth of 30 cm) should be carried out annually using either the lactate or bicarbonate test. Phosphorus deficiency is best corrected by soil-applied fertilizer (eg. Superphosphates or mono-ammonium phosphate).

Fig 139 – 141 Phosphorus deficiency symptoms

139: Phosphorus deficient plants

140: Initial stage Phosphorus deficient leaf

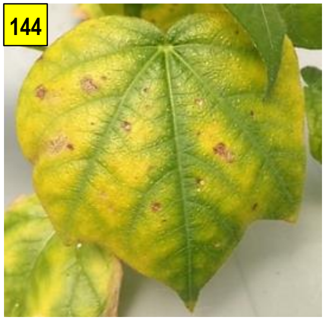
141: Advanced stage Phosphorus deficient leaf

Management of Phosphorous Deficiency: Correct soil pH by adding adjuvant or Apply p 205 @ 40-50 kg/ha as single or applying a 2% Foliar spray of DAP.

Potassium (K): Under potassium stress conditions, the yellowing of leaves starts from the tips or margins of leaves extending towards the center of the leaf base. The yellowing is interveinal and irregular in the leaves. These yellow parts become necrotic (dead spots) with leaf curling. There is a sharp difference between green, yellow and necrotic parts. Sandy, organic, leached and eroded soils; intensive cropping without fertilizer addition induces potassium deficiency.

Fig 142 – 144 Potassium deficiency symptoms

142: Potasium deficient plant



143: Initial stage Potassium deficient leaf

144: Advanced stage Potassium deficient leaf

Management of Potassium Deficiency: Apply K2O (Potassium peroxide) as potassium fertilizer @ 40-50 kg/ha or use foliar spray with potassium-bearing inorganic fertilizer or Apply potassium in 3 equal split doses at 30, 60 and 90 DAS through either muriate of potash or potassium sulphate at the rate indicated by soil test

Calcium (Ca): Calcium stress in plants results in chlorosis of young leaves along the veins, if deficiency persists longer, bleaching of the upper half leaf followed by leaf tip curling does occur. The growing bud leaf becomes chlorotic white with the base remaining green, the distortion of the tips of shoots i.e. dieback. Acidic, alkali or sodic soils induce calcium deficiency.

Fig 145 – 147 Calcium deficiency symptoms

145: Calcium deficient plant

146: Calcium deficient leaf (early stage)

147: Calcium deficient leaf (advanced stage)

Management of Calcium Deficiency: Deficiency of Ca can be corrected by application of gypsum @ 20-30 kg Ca.

Magnesium (Mg): Magnesium deficiency causes yellowing, but differs from that of nitrogen. The yellowing takes place in between veins of older leaves and veins remain green, this is followed by necrosis of tissues. Mg deficiency may be induced in cotton by high levels of ammonium in the nutrient solution. Low clay contents and sodic low Mg soils induce magnesium deficiency in cotton.

Fig 148 – 152 Magnesium deficiency symptoms

148: Magnesium deficient plant

149: Magnesium deficient leaf exposed to high temperature

150-152: Initial to advanced stage of Magnesium deficient leaf

Management of Magnesium Deficiency: Foliar application of MgSO. (3%) is essential for correcting the deficiency

Sulfur (S): Sulfur deficiency cause leaves to become yellowish and it appears similar to nitrogen deficiency, but the symptoms are first visible on younger leaves. The affected leaves are narrow and the veins are paler and chlorotic than the interveinal portion, especially towards the base with marginal necrosis. Low organic matter content of soils; continued use of N and P fertilizers containing no sulfur; burning of crop residue induces sulfur deficiency in cotton.

Fig 153 – 156 Sulfur deficiency symptoms

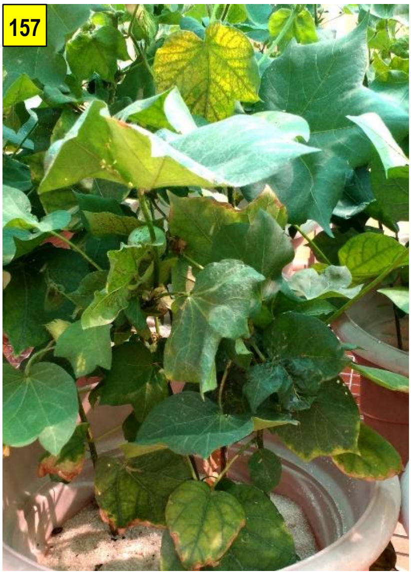
153: Sulphur deficient plant

154-156 Initial to advanced Sulphur deficient leaf

Management of Sulfur Deficiency: It is recommended to apply S @ 20-30 kg S/ha in the form of gypsum or applying a 1% Foliar spray of $MgSo_4$.

Iron (Fe): Iron deficiency normally only occurs after a waterlogging event. The young leaves develop a strong yellowing of the area between the veins (interveinal chlorosis) making the veins stand out green against a yellow background. Under severe deficiency, most parts of the leaf become white. Foliar iron application of $FeSO_4$ or iron chelate at 1 kg/ha will sometimes reverse the visual symptoms but will rarely increase lint yield. Calcareous soils, Soils with high P, Mn, Cu, or Zn and high rate of liming induce an iron deficiency in cotton.

Fig 157 – 159 Iron deficiency symptoms



157: Iron deficient plants

158: Initial stage Iron deficient leaf
159: Advanced stage Iron deficient leaf

Management of Iron Deficiency: Soil application of 15-20 kg $FeSO_4$/ha or spray of $FeSO_4$ (0.3-0.5%).

Zinc (Zn): Zinc deficiency is often observed in recently developed fields where there has been a cut of topsoil. The leaves become narrow and small, the lamina becomes, while veins remain green. Subsequently, dead spots develop all over the leaf including veins, tips and margins under severe deficiency, and shoot growth is reduced. Shoot elongation is reduced and a tuft or rosette of distinctly narrow leaves is produced at the shoot terminal. The symptoms are termed 'little leaf' or 'rosette'. Highly leached acidic soils, calcareous soils, and high levels of Ca, Mg and P in the soils induces Zinc deficiency in cotton.

Fig 160-162. Zinc deficiency symptoms

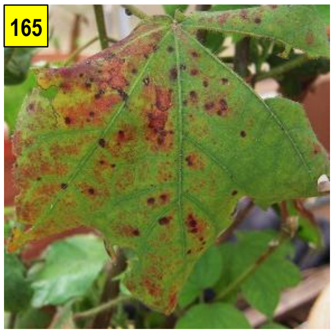
160: Zinc deficient plants

161: Initial stage Zinc deficient leaf
162: Advanced stage Zinc deficient leaf

Management of Zinc Deficiency: The deficiency is best treated by incorporation of 10-20 kg Zn as ZnO or ZnSO4 during soil preparation in the three months prior to sowing. Foliar applications of 200 g Zn as ZnSO4.7H2O may reduce the problem within the season (compound and rate).

Boron (B): The classical symptoms of boron deficiency include an irregular thickening of the petioles associated with dark areas of dead tissue, discoloration of the floral nectaries, irregular thickening of young shoots and parrot beak. Foliar boron applications are sometimes increasing boll retention, but there appears to be little justification for this practice. Heat stress can cause "parrot beak", a distortion of the boll, that has often been confused with boron deficiency. Death of terminal bud occurs in extreme cases. Sandy soils, naturally acidic leached soils, alkaline soils with free lime indices Boron deficiency in cotton.

Fig 163-165. Boron deficiency symptoms



163: Boron deficient plants

164: Initial stage Boron deficient leaf
165: Advanced stage Boron deficient leaf

Management of Boron Deficiency: Spray 0.1 % borox solution twice at 60 and 90th DAS

Manganese (Mn): The principal veins as well as smaller veins are green, the interveinal portion becomes chlorotic followed by necrosis and browning of interveinal tissue. The affected young leaves remain small and abscise before older leaves. Calcareous silt and clays, high organic matter and calcareous soils induce Manganese deficiency in cotton.

Fig 166-168. Manganese deficiency symptoms

166: Manganese deficient plants

167: Initial stage Manganese deficient leaf
168: Advanced stage Manganese deficient leaf

Management of Manganese Deficiency: Soil application of Mn SO4 (20 kg/ha) or spray (0.3-0.5%) would correct Mn deficiency

Molybdenum (Mo): The common symptoms of Mo deficiency in plants include a general yellowing, marginal and interveinal chlorosis, marginal necrosis, and rolling, scorching and downward curling of margins.

Fig 169-171. Molybdenum deficiency symptoms

169: Molybdenum deficient plants

170: Initial stage Molybdenum deficient leaf
171: Advanced stage Molybdenum deficient leaf

Management of Molybdenum Deficiency: Mo deficiency is very rare as most of the Indian cotton growing soils are alkaline. deficiency of micronutrients can be corrected by spraying the micronutrient salt (0.3-0.5%) mixed with 0.3% lime solution for quick recovery

Copper (Cu): In copper deficiency, visible foliar symptoms appear on young leaves as chlorosis changing to necrosis, rolling, wilting and twisting of leaves.

Fig 172-174. Copper deficiency symptoms

172: Copper deficient plants

173: Initial stage Copper deficient leaf
174: Advanced stage Copper deficient leaf

Management of Copper Deficiency: Spray of $CuSO_4$ (0.3 – 0.5%) or soil application of 10-20 kg $CuSO_4$/ha is recommended.

Chlorine (Cl): The symptoms of chlorine deficiency develop first on the older leaves. Discrete patches of pale green chlorotic tissue appear between the main vein near the tip of the leaf, downward cupping of some of the older leaves. The leaflets of the youngest leaves shrivel completely, and older leaflets develop a brown necrosis that starts near the tip and extend backward, particularly at the margins.

Fig 175-177. Chlorine deficiency symptoms

175: Chlorine deficient plants

176: Initial stage Chlorine deficient leaf
177: Advanced stage Chlorine deficient leaf

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About the book

The book Diseases and Disorders of Cotton - A Field Guide for symptom-based identification and management" is designed to help agricultural scientists, extension personnel, students, and cotton farmers identify the common diseases, disorders, and biosecurity threats of cotton in India. We have attempted to describe the most important characteristic features of the symptoms of about 22 diseases, 2 disorders, and 13 nutritional deficiencies; however, we recognize that local/regional/varietal variations may occur which have not been explained.In addition to this, the coincidence of two or more diseases/disorders on the same plant or plant part may confuse the identification process. Therefore, it is recommended that infected samples should be examined properly by experienced scientists and extension workers to confirm the identification of pathogens/species/strains of diseases, causes of disorders, and nutritional deficiencies in the designated laboratories.

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