



Virtual Reality (VR) Trainings: Game Changers in “Agricultural Technology Transfer”

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INTRODUCTION

The German Agency for International Cooperation or (GIZ) of the German Federal Government funded a project for the development of two Virtual Reality (VR) Training films by the International Cotton Advisory Committee (ICAC). The films were produced by One Hand Clapping Production Limited, UK. The VR movies were premiered in Cameroon and also shown in Senegal and Zambia. The VR technology has immense potential in facilitating the transfer of technology in agriculture, especially for women and resource-poor and low-literate farmers in least developed and developing countries.

PREMIER OF THE VR FILMS

The GIZ premiered the VR-3D training modules on 24 March 2022 in Garoua (Cameroon), using 70 Pico-G2 headsets to play them simultaneously for senior officials and extension workers of Sodecoton. The VR-3D films in French were also played simultaneously for more than 50 participants in Marua, (Cameroon) and Dakar (Senegal). The launch premier of the VR films was coordinated by Ms. Saskia Widenhorn, Project Manager, Sustainable Supply Chains, GIZ, Dr. Keshav Kranthi, Chief Scientist, ICAC and Dr Sandhya Kranthi, Projects Consultant, ICAC with assistance from Mr. Constantino Nguivoum Thea,

Conseiller Technique Coton and Mr. Bilal Mouliom, M&E Junior Advisor, as part of a ‘training the trainers’ initiative under the global project “Sustainability and Value Added in Agricultural Supply Chains” of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, undertaken on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).



Figure 2. Senior officials of Sodecoton viewing VR



Figure 1. The GIZ team loads VR films on headsets



Figure 3. Premier of the VR film in Garoua 24 March 2022



Figure 4. Premier of the VR film in Garoua 24 March 2022

The VR-3D films in English were shown to a large group of farmers and extension workers during a field day in Magoye (Zambia) on 5-6 April 2022. The VR film screening in English in Zambia was coordinated by Mr. Kai Hughes, Executive Director, ICAC, Dr. Keshav Kranthi, ICAC and Dr Sandhya Kranthi, ICAC, Mr Banda Sunduzwayo Executive Director, Cotton Board of Zambia, Mr. Dafulin Kaonga, Consultant, ITC and Mr. Martin Simasiku, Cotton Breeder, CDT. The Oculus-Quest-2 VR headsets in Zambia were sponsored by an EU-ITC funded project.



Figure 7. Trainees in Marua view the VR films



Figure 8. The trainers and trainees in Marua

Launching of the VR training films is a landmark event in the history of technology transfer, not just in cotton production but also in the field of agriculture itself.



Figure 5. The trainees with trainers in Garoua



Figure 6. Trainees in Marua view the VR films

THE VR TRAINING TOOL

As a first of its kind, the VR training tool opens a new avenue of transporting viewers into a virtual world where they experience a near-real presence in a virtual training environment. The two VR films transport viewers into the cotton fields of India and the United States of America and walk them through different stages of cotton, placing them close to a 3D action replay of insects and their predators in cotton fields and exposing them to various best practices that have the potential to increase their cotton yields. The response of participants was overwhelming and very appreciative.

The authors (Keshav Kranthi and Sandhya Kranthi) of this article were part of the team that launched the VR-3D in Cameroon. It was clear from the viewer responses that VR has immense potential in technology transfer and agricultural trainings especially for the benefit of extension workers and farmers, even in remotest of rural areas and for the least-literate farmers, including women who may not be able to travel and attend training programs in towns and cities. T

his article briefly describes the background story and technical elements of how the VR films were made and launched.

THE PIONEERS

The GIZ pioneered the project on “Seeing is Believing- Virtual Reality (VR) Trainings for Cotton Farming”, to develop two training film modules: one on integrated pest management and the other on global best practices for high yields.

The project was implemented by the International Cotton Advisory Committee (ICAC), Washington DC, USA from 2019 to 2022.

The ICAC contracted ‘One Hand Clapping (OHC) Productions Limited’ London, to produce the virtual reality film modules.

THE VR FILMING CREW

The ICAC team: Mr. Kai Hughes (Executive Director) and Ms. Lorena Ruiz (Economist) coordinated the project as producers; Dr Sandhya Kranthi (Projects consultant) and Dr Keshav Kranthi (Chief Scientist) wrote the script and organized the shoots in India and the United States. The OHC crew comprised of Mr. Sean Davison (Director and Editor), Mrs. Pamie Wikstrom (Producer) and Cinematographers, Mr. Sebastian Cramer, Mr. Ashley Meneely, Mr Aftab, Mr. Tony Cordeaux and Mr. Siddharth. An outstanding feature of the IPM module is a special section on ultra closeup 3D videos of insects shot on a special 3D rig invented and used by Mr. Sebastian Cramer, who won more than 30 Awards including Oscar-2008 Academy Award and Emmy Award.



Figure 9. GIZ sponsored the VR project



Figure 10. The ICAC implemented the project

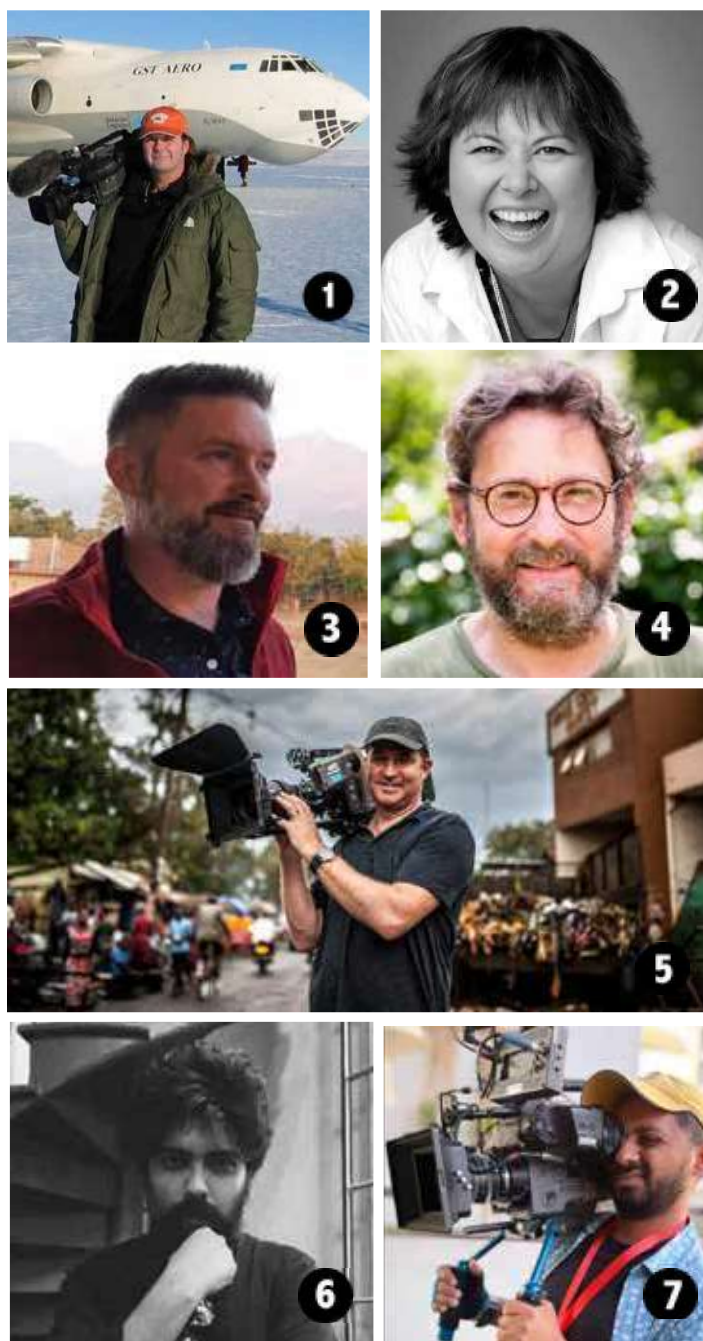


Figure 11. A women farmer views VR in Zambia

THE VR FILMING CREW

1. **Sean Davison** is a film maker for many international broadcasters including: National Geographic, Discovery, BBC, Smithsonian Channel, Disney and Netflix.
2. **Pamie Wikstrom** is a producer who specializes in advertising. She has produced over 100 commercials as varied as American Express, Candy Crush, Coca Cola etc.
3. **Tony Cordeaux** is Producer, Director, and Editor who runs the Goa Film Services that provides production services to international productions in India.
4. **Sebastian Cramer** is a specialist for stereoscopic imaging and 3D film projects. He also owns Screen Plane a company specialized in stereoscopic cameras.
5. **Ashley Meenley** is a freelance Director of Photography with experience across the world filming Broadcast and Branded content media production.
6. **Sidharth** is a multidisciplinary film maker with expertise in virtual reality applications and 360° filming.
7. **Aftab** is an award-winning cinematographer, adept at different styles and techniques, and is also a DGCA certified drone pilot in India.



Figure 14. Dr. Kranthis' collecting insects



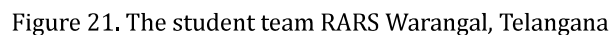
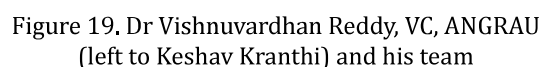
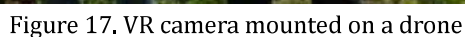
Figure 15. Sebastian setting up the 3D Macro rig to film insects



Figure 13. Ms. Christelle managing insect collections

The VR films were mainly shot in India and United States. The locations in India were BioRe and farmer fields in Khargone, Madhya Pradesh (September-October, 2019); South Indian Mills Association (SIMA) and farmer fields in Pollachi and Satyamangalam, Tamilnadu (February, 2020); Lam farm, Biofertiliser unit Amaravati, Nuziveedu farm and farmer fields in Guntur, Andhra Pradesh Agricultural University (ANGRAU), Lam Guntur, Vijayawada in Andhra Pradesh (September 2021); Regional Agricultural Research Station, Warangal and Prof. Jayashankar Telangana State Agricultural University (PJTSAU) Hyderabad in Telangana (October 2021). The locations also included Suffolk, United States (2021) and Zambia (2022).

The ICAC greatly acknowledges the support received from Dr. A. Vishnuvardhan Reddy, Dr. P. Ratna Prasad & Dr. G.M.V Prasada Rao, (ANGRAU); Dr. V. Praveen Rao, Dr. R. Uma Reddy & Dr. M. Upender (PJTSAU); Dr. M. Prabhakar Rao & Dr. B. Rosaiah (Nuziveedu Seeds); Dr. M. Ramasami & Dr. N. Kannan (Rasi Seeds); Dr. Selvarajan & Dr. Asha Rani (SIMA); Mr. Vivek Rawal, Mr. Yogendra & Mr. Ishwar Patidar (BioRe) and Dr Sagar Hanuman Singh (NIPHM).



THE VR TEASER MOVIE

OHC produced a teaser VR-movie on IPM which was premiered during the World Cotton Day celebrations in Geneva, on 7 October 2019. A further VR-IPM teaser was also developed and shown at the International Green Week in Berlin, Germany in January 2020. The global outbreak of COVID-19 in 2020 hindered shooting schedules and any possible progress in 2020 and until September 2021, when filming resumed. The two training modules were released in March 2022, premiered in Cameroon, and shown in Senegal and Zambia March-April 2022.

VR TECHNOLOGY

Virtual Reality technology creates an immersive simulated environment that enables the viewer to experience a 360o-3D vision of the filmed locations, actions and sequences. Viewers will be able to look around 360o to visualise everything around them in the virtual environment. VR technology can also generate a computer graphics simulated virtual and artificial environment created by artists and technicians. The VR movies are viewed through a pair of goggles in a head-mounted VR headset. Viewers exercise the option of managing the audio-video display settings and interaction with objects within their immersed surroundings using hand-held controllers. It is estimated that there are more than 200 companies across the world that provide VR related technologies and products. Prominent companies include Google, Microsoft, Apple, Facebook, Amazon, Sony, Samsung, Oculus, Pico, GoPro, Insta360, Vuze, Kandao, Matterport, Z Cam, Kodak, Ricoh, Cinegears, Spieltek, OMI, Orah, Elmo, Giroptic etc.

THE VR CAMERA

Virtual reality cameras have 2 to 12 fisheye lenses, each capable of recording images and videos in 180o at high resolutions up to 12K. The ICAC has an Insta360 Titan camera that has 8 lenses and a Qoocam Enterprise camera with two lenses. Both cameras can shoot VR videos at 8K resolution and have been used in filming in the US and India. The ICAC proposes to prepare at least a dozen, short training modules in VR before Dec 2022 to strengthen the VR curriculum for trainings.



Figure 23. The VR camera with Revashni and her sister.



Figure 24. Mr. Sean narrating the script to the actors



Figure 22. A VR camera in operation



Figure 25. Mr. Sean interacting with Revashni's family.

THE POWER OF VR TRAINING

Standalone trainer

Most standard conventional tools of training such as PowerPoint presentations, flipcharts, whiteboards, and audio-videos require trainers. A VR headset is an independent standalone device which can be used by trainees to learn directly from the training content presented in the VR-3D 360o videos, without the need for trainers to explain. VR movies provide a 360o viewing. They simulate a near-real experience of being at the location where the filming was done. The VR movies may have a trainer who explains the lessons, or the videos can be in the form of a story or a documentary that is self-explanatory. Thus, a VR headset can serve as a standalone expert-independent training tool. The recent VR headsets have a memory of 256GB and can store several training modules; each training module of 15 minutes could range from 2-4GB each.

Virtual travel

Trainings are most effective when conducted face-to-face with in-person interactions between trainers and trainees. VR trainings neither can replace face-to-face trainings, nor are they as effective as in-person trainings, but they are probably the next best substitutes for physical trainings. Virtual reality trainings come closest to face-to-face trainings where trainees get an opportunity to be present in a virtual training environment.

A VR module gives the advantage to enable trainees gain the experience of attending national or international training courses by participating in virtual training classes within the confines of their homes or offices or fields, by viewing VR movies that are filmed in different parts of a country or different countries of the world. Thus, trainees attend training programmes in different places or countries without having to take the trouble of having to travel to any of the locations where the training modules were filmed.

However, apart from the disadvantage of not being able to physically be present in the training course, trainees will not be able to ask questions or get further explanations from a VR training module unless attending coordinated events run by a trainer either in person or via Zoom or other media.

In-person trainings can be expensive because they need physical attendance of trainers and trainees which requires arrangements on travel, accommodation, and food. With VR headsets it is possible to train many persons remotely with minimum expenditure on logistic arrangements.

VR allows trainees to observe everything around them in a virtual field or a virtual class and be able to learn from a near-real environment. VR training modules are downloaded and stored in the VR headset and can be viewed anytime, anywhere and any number of times. The VR headset is an independent mobile gadget that need not be attached to a computer or any other device to be used, making it ideal for use in remote areas. The immersive learning experience with VR is far superior to all other audio-visual teaching tools.

Women empowerment through VR

In many parts of the world, women and less literate farmers are generally deprived of the opportunity to travel and attend in-person training programmes that are conducted within their region in towns and cities. Trainings are also conducted as farmer field schools in different villages or towns and women rarely get a chance to attend because of social and cultural reasons or family responsibilities. VR training modules provide access to virtual trainings for women at their doorstep by using a headset to view the training content and gain knowledge through immersive experiential learning. VR headsets also enable least literate farmers to participate in virtual training classes by viewing the VR training modules on headsets that can be taken to their villages.

Time-independent training

Agricultural training programmes are time sensitive. The cotton crop passes through different stages and each stage has its own very different challenges. The stage of the crop changes with age and so do the crop needs for water, nutrients, light. The crop ecology also changes with the crop age and stage. The ecological profile and intensity of insect pests, predators, parasitoids, and diseases change with weather and the crop stages. Therefore, the practical in-person training curriculum is different for different crop stages, especially since farmer field schools or trainings for extension staff are crop-stage dependent and are time sensitive. Generally, a series of 7-8 farmer field schools is conducted in a single season at different stages of the crop for the same set of trainees so that they learn and understand the importance of management interventions based on best practices and agro-ecosystem analysis that vary with the different stages of the crop. VR Training modules enable viewers to use the headsets anytime of the day and anytime of the year to experience VR movies that may have captured the entire cotton season all through its different stages and the challenges accompanying each crop stage.



Figure 26. The GIZ team uploads the VR films to headsets

THE ICAC VISION

The ICAC aims to provide information on best farm management practices to farmers, especially those from least developed countries in Africa and Asia, through VR technology so that smallholder farms achieve greater yields and improve farm income while producing better quality cotton more sustainably.

Better production practices will minimize environmental damage, reduce pesticide use, reduce greenhouse gas emissions, protect biodiversity and improve water use efficiency.

The ICAC aims to create instructional 2-D videos and VR movies using the latest technology in video-capture equipment. There are two sets of movies; one that caters to researchers and extension staff, and the other that is presented in a very simple format for farmers mostly in different local languages and dialects.

The ICAC has so far created two training modules in VR-3D, 14 training 2D videos in English and French and seven training manuals/pocketbooks. The training curriculum developed by the ICAC is oriented towards cotton, but several topics on soil health, weed management and nutrient management are common for other agricultural crops.

The ICAC has a dedicated technical information section to conduct analytical research and disseminate information on the global scientific advances made in best practices, cotton crop improvement, sustainable production practices, crop protection technologies, technology transfer methodologies and to coordinate interactions amongst global researchers.

The ICAC has an international mandate for cotton improvement, development and promotion. The staff members of the ICAC secretariat keep themselves abreast with the latest global technological advances, analyse scientific developments across the world and disseminate information on technical advances in research and development.

The technical experts at the ICAC have the experience of working with cotton farmers across the globe, conducting regional and global network meetings of cotton researchers and coordinating at least 26 research projects (14 regular projects and 12 “Fast Track” projects). The ICAC is currently handling three projects funded by the GIZ and one project funded by the ITC and European Union. The four projects focus on sustainable best practices in Africa and Asia.

The ICAC global expertise and technical knowledge on global best practices of cotton production can be converted into simple training modules using the Virtual Reality (VR) technology to enable virtual visits of resource-poor farmers into the best cotton fields in the world and virtually observe season-long global best practices within a few hours.

Thus, the virtual reality modules will obviate the need for resource-poor farmers to physically visit advanced countries and the need for extension specialists to conduct season-long trainings and undertake cumbersome multiple-visit educational programmes.

THE TWO VR TRAINING MODULES:

‘IPM’ AND ‘BEST PRACTICES FOR HIGH YIELDS’

Integrated Pest Management (IPM)

Virtual Reality movies provide the advantage of conducting training programmes on pest and disease management any time of the year by walking farmers into fields that are infested with insects and diseases to show them best eco-friendly management practices. Cotton is one of the crops that is infested with many species of insect pests and diseases apart from harbouring many naturally occurring beneficial insects within the cotton ecosystem that keep harmful insect pests under control. However, synthetic pesticides disrupt the natural ecology that generally results in pest resurgence and resistance, thereby necessitating repeated use of pesticides. Environmental impacts associated with the improper use of pesticides include contamination of drinking water, loss of biodiversity, long-term persistence in soils, loss of ecosystem services, reducing populations of pollinating insects and air pollution. Cotton farmers in the developing world generally apply pesticides with back-pack sprayers and often without adequate protective equipment, thus increasing exposure and harming human health.

The objective of the IPM module is to create and provide VR content on pests and diseases to equip the farmer with better and more realistic content to combat pests and disease effectively using integrated eco-friendly strategies. The IPM module features three films (14-16 minutes each) on insect pests, biological control and IPM strategies for efficient and effective insect pest management.

Best Practices for High Yields

Scientific advances have enabled the development of best practices that help farmers to increase yields and improve fibre quality. The ICAC has transcribed the global best practices into four simple practices that are adaptable to small-holder farms, especially in Africa and India. These practices have been captured in VR training modules to enable technology transfer for resource-poor small-holder, least literate farmers. Through the VR training modules, farmers will be informed and trained to gain better knowledge and practices to increase yields and quality. Examples of production from different countries and best practices will be presented.

Virtual reality (VR) can provide a great experience for farmers, who will be able to walk in the virtual cotton fields during different times of the season to experience a variety of farm operations and production practices especially in advanced countries where yields are high. Farmers will be able to understand the value of compact-short-statured plants, zero-monopodial type, short season (140-150 days), pest and disease management, quality fibre evaluation, and conservation-tillage practices that can help enhance their yields and income. The best practices module will guide trainees on crop production technologies that aim to optimize inputs (water and nutrients); to harness natural resources such as heat and light through proper agronomy and to use plant growth regulators to realize the best harvest index (higher lint yield v/s low plant biomass) while conserving soil health, biodiversity and ecosystems.

The Best Practices module features two films (14-16 minutes each) on plant mapping and best production practices, techniques to improve nutrient-use-efficiency and management of plant architecture and canopy to improve the source-sink relationship.

MODULE-1: INTEGRATED PEST MANAGEMENT (IPM)

PROLOGUE

Cotton is one of the world's most important crops. But across the world, cotton crops are badly damaged by insect pests. Many insects are present in the crop. Some are very harmful these are the bad bugs, and some are beneficial, these are the good bugs. The VR movie focuses on 3D visuals that help cotton farmers around the world to learn how to identify and manage the different bad bugs that damage the cotton crop by using the good bugs to keep their numbers under control. This means that farmers will be able to avoid using insecticides when they are not necessary.

The IPM story is narrated through the eyes of a small girl called Revashni who lives in a small farm in southern India. She tells the story of how her father, Amit, a cotton farmer works very hard in the hot sun every day. He used to be stressful most of the time because of the insect pests and diseases that were attacking his cotton crop. The poisonous insecticides that her father sprayed in the cotton fields to control insect pests were very dangerous to animals, birds, earthworms, soil health and also to human beings. Revashni was always sad to see their cows and chicken fall sick. The chemicals polluted air, contaminated water, food and the environment. Her father hated using harmful chemicals and had to wear a protective suit. She yearns to breath fresh air, drink clean water and live in a healthy environment.

Things changed for the family after her uncle Surya taught them the practical techniques of integrated pest management. Her uncle had been to a training camp conducted by cotton scientists. He now gets high yields on his farm and he uses very few chemical insecticides. The first lesson that her family learnt from her uncle was that all insects in their cotton fields are not bad and that there are many good bugs too which attack and eat the bad bugs. The second lesson: it is important to help the good bugs survive in the fields all through the season so that they control the bad bugs. The third lesson: with the use of IPM technologies that are eco-friendly and simple to use it is possible to support the good bugs but keep the bad bugs in check.

THE BAD BUGS

Cotton is home to at least 1326 species of insects (Hargreaves, 1948, Commonwealth Institute of Entomology, London). Most of the species recorded were just casual visitors to the crop, but certainly a few cannot survive without the crop. One example is the pink bollworm which feeds mainly on cotton and has very few alternate host crops. Many other species are polyphagous, meaning that they can feed on a wide range of crops and can live without cotton. Not all insects are equal in the risk that they pose to cotton cultivation. Beyond doubt some are more important than others. There are a few species of insects that are considered as major pests because they pose the greatest risk to crop production and have the propensity to cause significant economic losses in several countries across the world. There are a few minor pests which cause very less damage and that too only sporadically.

APHIDS

The aphid, *Aphis gossypii*, nymphs and adults, are soft bodied insects that suck plant sap from tender terminal portions of the plant. They feed on the undersurface of the leaf causing it to curl downwards. Young plants are most affected generally in a severe form under cloudy conditions. Aphids during the process of feeding secrete sugary substance called honey dew that encourages the formation of black sooty mold. Ants feed on the honey dew and in return protect aphids from predators. Predators such as *Chrysoperla* species, grubs of syrphid flies and ladybird beetles feed voraciously on aphids and insecticides may be discouraged for their management. Aphids transmit the sporadic viral disease called leaf roll dwarf virus.



Figure 27. Aphid damage



Figure 28. Aphids

JASSIDS

The leaf hopper (jassid), *Jacobiella facialis* is a major pest of cotton in many African countries. Jassids damage young plants mostly in glabrous (less hairy) susceptible varieties. Both nymphs and adults can be recognized by their characteristic sideward jumping movement on leaves. They suck sap from tender portions of the plant from the undersurface of the leaves causing the leaves to show symptoms of yellowing at the margins, downward curling and finally reddening of the leaf. Cultivation of jassid resistant varieties ensures an insecticide spray free window up to 60 DAS, which encourages the build-up of beneficial insect populations. Leaf hoppers transmit the phytoplasma disease called 'phyllody' or 'virescence' in Africa.



Figure 29. Jassid damage



Figure 30. Jassid nymph (left) and adults (right)

WHITEFLIES

Whiteflies *Bemisia tabaci*, are polyphagous insects and are vectors of the dreaded cotton leaf curl virus.

- Nymphs and adults suck sap from the tender portions of the plant, mostly from the lamina of young leaves.
- Typical symptoms in damaged plants are upward curling of leaves, chlorosis, development of sooty mold.
- Hot and humid conditions are favourable for high infestation.
- If the pest occurs at the time of boll opening, it can cause, stickiness, staining and poor spinnability of lint.



Figure 31. Whitefly damage



Figure 32. Whitefly adults (inset: whitefly pupa)

THRIPS

Thrips species, *Frankliniella occidentalis*, Thrips tabaci and Scirtothrips dorsalis have been reported to damage cotton in Africa. Thrips can harm plants but can also be beneficial when they feed on mite pests. Thrips are small slender insects that are about 1.5 mm long. They rasp the leaf lamina on the under-surface and cause silvery streaks. Affected leaves get distorted, malformed and turn crinkly. Older leaves turn red, brown, and shed. Thrips transmit the tobacco streak virus. Predatory thrips, that predate on spider eggs, can turn phytophagous if food is limited. Heavy rainfall or sprinkler irrigation also reduces thrips populations. Seed treatment with neonicotinoid insecticides protects against thrips damage.



Figure 33. Thrips damage



Figure 34. Thrips closeup

MITES

The two spotted spider mite, *Tetranychus urticae* is the most common species that damages cotton in Africa. Mites can be both, predatory on thrips and damage cotton as pests. Red spider mite nymphs and adults suck sap from the undersurface of tender leaves while forming fine webs. The leaf lamina starts reddening from its attachment to the petiole and extends to the entire lamina. Under dry hot conditions and severe prolonged infestations, the leaves become crisp, dry and are shed off. Wettable Sulphur or neem seed kernel extracts may be used to control mites. Predatory mites feed on thrips and eggs of bollworms.



Figure 35. Mites damage (insect: mite)

MIRID BUGS

The green plant bug, *Taylorilygus pallidulus* is the most common mirid bug in Africa. However, there are several species of mirid bugs in Africa belonging to the genus, *Campylomma* and *Hyalopeplus* that also cause damage to cotton. Nymphs and adults suck plant sap from the tender squares and bolls. Mirid bug damage results in square shedding. The typical damage symptoms are shedding of pinhead squares, branching of tender apical tips and damaged brown anthers in older squares. Mirid bug damage causes parrot beak in bolls, shriveled seed and stained and damaged lint.



Figure 36. Mirid bug

LEAF MINER

The leaf miner fly *Liriomyza trifolii* damages tender leaves of cotton and many other crops. Female flies puncture leaves and lays eggs in batches under the leaf surface. Eggs hatch in 3-4 days. Grubs create mines under the leaf surface in a serpentine pattern, thus deriving the name as serpentine leaf miner. Grubs feed on leaf chlorophyll and in their last instar stage drop on the ground to pupate in soil. Damage is severe on cotyledonary leaves, but seedlings recover rapidly



Figure 37. Leaf miner damage

GREY WEEVIL

The grey weevil *Mylocherus* spp. can generally be seen in cotton fields in Africa. Adults are seen fast moving on leaf margins when plants are in peak vegetative stage. This pest feeds on leaf lamina causing irregular holes on the tender upper foliage. No control measure needs to be adopted as the damage is negligible and the plants put forth fresh growth to overcome the damage.



Figure 38. Grey weevil

STINK BUGS

There are several stink bug species that damage cotton. *Nezara viridula* is one of the most common stink bugs that damages cotton in Africa. Almost all stink bugs are minor pests of cotton. However, damage to bolls can be severe when stink bugs puncture green bolls and transmit infection of yeasts mostly *Nematospora coryii* which causes internal boll rot called stigmatomycosis and a disease called yeast spots on green bolls. Cotton lint is stained dirty yellow to brown cotton lint and seeds get shrivelled and rot.



Figure 39. Stinkbug nymph



Figure 40. Stinkbug adult

GRASSHOPPERS

Grasshoppers primarily feed on leaves, on the peripheral portion of the leaf lamina causing leaves to have irregular margins. Grasshoppers feed on any vegetation and can be seen on weeds adjoining cotton fields. Grasshoppers can migrate onto the border plants and consequently inflict damage of low economic significance. Young cotton plants are more vulnerable to damage. No control measure needs to be adopted as the insect incidence is very sporadic, restricted to rain-free windows of the monsoon season.



Figure 41. Grasshopper

POLLEN BEETLES AND MIDGES

Several species of pollen beetles and midges damage flowers in Africa. The *Meligethes* genus of pollen beetles are common in Africa. Grubs of midge flies attack flowers and have recently been recorded as emerging pests. Midge maggots feed on anthers, staminal column and style to cause distortion and consequent decay of floral parts. Cotton flowers are damaged to some extent, but serious economic losses have not been recorded in Africa.



Figure 42. Pollen beetles

SPODOPTERA

Three species, namely *Spodoptera exempta*, *Spodoptera littoralis* and *Spodoptera frugiperda* have been reported to damage cotton in Africa. *Spodoptera exigua* and *Spodoptera litura* have been reported from Africa. *Spodoptera* species cause maximum damage as their larvae are nocturnal defoliators. *Spodoptera* is a polyphagous insect and larvae skeletonize the leaves and bore into squares and bolls. Damaged leaves have fecal pellets near the feeding sites. *Apanteles* spp. and *Bracon* spp. are the common parasitoids found in this pest. *Spodoptera* can be effectively controlled by collection and destruction of egg masses that contain between 100-500 eggs per batch.



Figure 43. *Spodoptera* damage



Figure 44. *Spodoptera* damage



Figure 45. *Spodoptera litura* moth

SPODOPTERA FRUGIPERDA

The fall armyworm, *Spodoptera frugiperda*, is a major pest of maize and many other crops. Sporadic damage to cotton has been reported from different parts of India and Africa but severe losses have not been recorded yet. The pest was first noticed in Africa in 2016 on maize and is currently widespread almost all through the African continent. Moths lay 100-200 eggs in batches during night mostly under leaves. Egg batches are covered in a hairy tuft. Larvae cause damage as top-shoot borers to cause symptoms like that of the spotted bollworm. Larvae bore into the stem and stunt growth of the plant. Older larvae were found to cannibalize on younger larvae. Fall armyworm larvae were reported on cotton mostly in regions where maize was grown together and the insects move into cotton fields after harvest of maize crop.



Figure 46. *S. frugiperda* larva



Figure 47. *S. frugiperda* moth

HAIRY CATERPILLARS

Different species of hairy caterpillars can occur at random in the cotton field especially during the vegetative stage. They feed on leaves causing little or no economic damage. They serve to function as bio factories allowing the multiplication of beneficial larval pupal parasitoids that also parasitize the dreaded cotton bollworms.



Figure 48. Hairy caterpillars

SEMILOOPERS

Amongst many semilooper insects, *Anomis flava* occurs commonly on cotton in Africa. Larvae feed on cotton leaves mainly during the peak vegetative stage of the crop. Larvae make large irregular holes in the leaf lamina. This pest rarely causes economic damage and is in fact known to step up host plant resistance against the bollworms by inducing host plant defense responses. Semilooper larvae also act as bio-factories in the field by allowing the multiplication of *Apanteles* spp. and *Bracon* spp. while also being controlled by, *Brachymeria* spp., and *Charops* spp., which are the major parasitoids of the cotton bollworms.



Figure 49. Semilooper larva

Figure 50. Moth

COTTON LEAF FOLDER

The cotton leaf folder *Haritalodes derogata* folds tender leaves into funnel shaped structures and feeds inside the leaf rolls. It is a minor pest of cotton that is biologically controlled by naturally occurring parasitoids such as *Apanteles* spp., *Brachymeria* spp., and *Xanthopimpla* spp. The pest rarely causes economic damage.



Figure 51. Leaf folder larva, pupa (topright) and moth (bottom)

AMERICAN BOLLWORM / AFRICAN BOLLWORM

The American bollworm *Helicoverpa armigera* is a major pest on many crops such as cotton, pulses and vegetables. Larvae display high levels of resistance to almost all the major insecticides that are recommended for control. American bollworm has been under control in countries that adopted Bt cotton. Larvae feed on squares causing the square to flare and shed. An individual larva bores into a green boll and feeds on the inner contents with half its body inside the boll and half outside. On non Bt-cotton, the pest can be managed through IPM strategies. Chemical insecticides are considered as the least preferred choice. Insecticides such as indoxacarb, spinosad, emamectin benzoate and chlorantraniliprole have been reported to be effective in managing the pest.

Figure 52. *Helicoverpa armigera* larva Figure 53. Moth

SPOTTED BOLLWORMS

There are three major species of spotted bollworms in India and Africa. *Earias vitella* and *Earias biplaga* occur in high rainfall areas and *Earias insulana* in dry regions. Larva bores into the shoot terminals to cause withering of the growing terminals when it occurs as an early season pest. Larvae also bore into developing squares and bolls when they cause serious damage at the reproductive stage of the crop. Okra acts as a reliable trap crop for spotted bollworms.

Figure 55. Larvae: *E. vittella* & *E. insulana*

Figure 54. Spotted bollworm damage

Figure 56. Moth: *E. vittella*

PINK BOLLWORM

The Pink bollworm, *Pectinophora gossypiella* is a serious pest of cotton in Africa. It usually occurs at the time of flowering and resurfaces again as late season pest to cause severe boll damage. Early formed bolls are generally free of damage by the pink bollworm and late pickings are severely affected. At the time of flowering, pink bollworm damage displays symptoms in the form of rosette flowers. Late season damage causes bad boll opening, stained and poorly formed lint. The pink bollworm recently developed resistance to Bt-cotton and has emerged as a very serious pest on Bollgard-II Bt-cotton in India and Pakistan while it has been eradicated in the United States of America. Since *Pectinophora* feeds mainly on cotton, it is important to destroy residual bolls that may harbour diapausing larvae and maintain a closed cotton-free season for at least 6 months in a year to keep the pest under check.



Figure 57. Pink bollworm larva and damage



Figure 58. Pink bollworm pupa (top left) rosette flower & moth

FALSE CODLING MOTH

The false codling moth, *Thaumatotibia (Cryptophlebia) leucotreta* (Meyrick) larvae enter bolls and feed on tender seeds, similar to the pink bollworm, *Pectinophora gossypiella*. Full grown larvae are 1.2 to 1.8cm long. Adults are 0.6 to 0.8cm long. Larvae and adults are similar in size to the pink bollworm. However, the ventral side in older larvae of *Thaumatotibia* is slightly yellowish and the moths look distinctly different from *Pectinophora gossypiella*.



Figure 59. *Thaumatotibia* larva and moth

RED BOLLWORM

The red bollworm, *Diparopsis* is comprised of four species, namely *Diparopsis castanea* (Hampson), *Diparopsis watersi* (Rothschild), *Diparopsis tephrogramma* (Bethune-Baker) and *Diparopsis gossypoides* (Clements). *Diparopsis castanea* occurs in southern and east African region where it is a major pest of cotton, while *Diparopsis watersi* occurs in West Africa and is a major pest in most of the West African countries. The other two species have been reported only in parts of the Southern and East African regions but are not recognized as key pests.

Diparopsis larvae feed on squares, flowers and green bolls. Pupae undergo diapause as an overwintering mechanism. Moths are about 1.5cm long and full-grown larvae reach 2.5 to 3.0 cm in length. Moths and full-grown larvae are almost double the size of pink bollworm, *Pectinophora gossypiella* and the false codling moth *Thaumatotibia (Cryptophlebia) leucotreta*.



Figure 60. *Diparopsis castanea* larva

COTTON STAINER BUG

Cotton stainer bug *Dysdercus fasciatus* is a late season pest that feeds as nymphs and adults, on developing seeds in open and partially opened bolls and affects seed germinability. The bugs also stain lint and cause stickiness particularly in unpicked open bolls. It is quite common to see large number of these bugs of uniform age on open bolls.



Figure 61. Adults: *Dysdercus fasciatus* & *D. cingulatus* adults



Figure 62. Nymphs: *Dysdercus cingulatus*

COTTON SEED BUG

The cotton seed bug *Oxycarenus hyalinipennis* damages lint and seeds in open bolls. The bugs are dark greyish in color much smaller in size than the cotton stainer bug. Nymphs and adults both feed on developing seeds in open and partially open bolls. Their feeding affects seed germinability, staining and stickiness of lint and affects fibre quality.



Figure 63. Dusky cotton bugs

MEALY BUGS

The cotton mealy bug, *Phenacoccus solenopsis* is the most common of mealybugs that attack cotton in Africa and India. Adult bugs are coated in waxy covering and occur in colonies on a plant. Crawlers are active moving along the main stem. They often occur on stressed plants and on isolated plants in a field but can spread through the field by wind, water, and human interventions. Infested plants dry up and may be uprooted and destroyed. Affected squares, flowers and bolls do not develop properly and shed. Infestation by bugs is seen to be more severe in winter months and during moisture stress. Several parasitoids effectively manage mealy bug populations in the field and this pest does not often require insecticide intervention.



Figure 64. Mealybug crawlers



Figure 65. Mealy bug colony

THE GOOD BUGS

There are many insects in the cotton ecosystem, especially beneficial insects which are difficult to identify. Cotton crop is damaged by insect pests. But nature has an inbuilt mechanism within ecosystems to control insect pests. Natural biological control of insect pests mainly happened through predators, parasitoids and pathogens. Predators eat insect pests pretty much like a lion hunting a deer. Parasitoids lay their eggs inside insect eggs or larvae or pupae so that their younger stages use the insect pest as food and complete their life cycle. This results in pest control. Insect pathogens cause disease in the pest to keep their populations under control. Natural biological control is nature's gift to farmers. Insect pests can gain advantage through any of the human interventions such as those in the form of a new variety or improper use of fertilisers or indiscriminate and incorrect use of pesticides or inefficient water management or improper weed management or changes in agronomy. However, the biggest threat to natural biological control comes from the use of broad-spectrum insecticides and insecticide mixtures that devastate populations of natural predators and parasitoids whereas insect pests tend to survive better due to larger numbers and their propensity to develop resistance to insecticides. Many insecticides cause pest resurgence and outbreaks, especially when used indiscriminately.

MEALYBUG DESTROYER

The mealybug destroyer, *Cryptolaemus montrouzeri* is also known as mealy bug ladybird and is recorded in Africa. It is an important predator of mealy bugs and soft scales. Adults lay eggs near mealybug ovisacs. The eggs hatch and grubs start feeding on mealybug crawlers, adults and other soft bodied insects near them. The grubs grow up to 1.3 cm and have woolly appendages that make them resemble mealy bugs. *Cryptolaemus* grubs feed on both nymphs and adults of mealybugs, aphids, scales and many other insect pests and are effective biological control agents when the prey populations are high.



Figure 66. *Cryptolaemus* grub and adult (right)

LADYBIRD BEETLES

There are hundreds of Ladybird beetle species across the world. Adults and nymphs (grubs) are voracious feeders of soft bodied insects such as young larvae, aphids, mites and insect eggs. Adults also feed on plant sap, nectar, pollen and honey dew. Grubs can be readily seen on cotton leaves on the undersurface when the crop especially during the peak vegetative stage (40 to 80 days old crop), particularly when the field is unsprayed. Their density is directly dependent on the density of the insect pest, like aphids.



Figure 67. Eggs and grub of Ladybird beetle



Figure 68. Ladybird beetle pupa and adult

LACEWING BUGS

Green lacewing bugs, *Chrysoperla* species and Brown lacewing bugs, *Micromus* species are predatory as their grubs feed on soft bodied insects. The third instar grub is the most predacious of all stages. High populations of the predator coincide with populations of jassids, aphids and mealy bugs. Aphids are the most preferred prey.



Figure 69. Lacewing egg, adult & grub feeding on aphid (bottom)

SYRPHID FLIES

Syrphid flies are also called as hover flies. There are several more than 230 species of syrphid flies in Africa. They are the second most important insects for pollination after bees. Syrphids are predatory in the grub stage. Adult flies feed on pollen, nectar and honey dew while grubs feed on soft bodied insects such as aphids, jassids, thrips and small insects. The grubs are light green in color and their numbers are high when aphid populations are high early in the season. It is important to avoid insecticides that disrupt syrphid populations, especially until the early flowering stage of the crop to allow their survival and multiplication.



Figure 70. Grub and adult of syrphid fly

ORIUS BUG

The minute pirate bug, *Orius* Spp.-nymphs and adults feed on leaf hoppers, aphids, scales, mites, leaf roller larvae and thrips. They also feed on eggs and young lepidopteran larvae that occur on cotton. Orius nymphs and adults pierce and suck body fluids from the prey using their stylet. The bugs are fast moving and become phytophagous feeding on pollen in the absence of prey. Organophosphate and pyrethroid insecticides are highly toxic to the grubs and adults. Biopesticides like *Beauveria bassiana* are less toxic.



Figure 71. The pirate bug

BIG EYED BUG

Big eyed bugs, both as nymphs and adults are predators of several insect pests across crops. Insecticides such as Flonicamid, Dinotefuron, Methomyl used on any crop are very highly toxic to these bugs and must certainly be avoided on cotton when these bug numbers are high.



Figure 72. Big eyed bug

Figure 73. *Feltiella* grub

FELTIELLA GRUB

Feltiella acarisuga grubs are the most important predators of spider mites and have been recorded in Africa. Their larvae and cocoons are commonly found among colonies of spider mites. The eggs are laid on the leaf undersurface and their grubs are slow moving. Biocidal plant extracts, including sprays of essential oils that are used to manage mites are safe to *Feltiella acarisuga*.

VERTEBRATES

Many kinds of vertebrate animals such as birds, lizards and frogs predate on insects. However, these animals feed on any insect irrespective of its status of being harmful or beneficial to the crop. The possibilities of feeding on insect pests are high because of their larger numbers in the field and because compared to beneficial insects, harmful insect pests reside in the crop for a longer time to feed on the crop and are therefore more easily accessible as prey for predators.



Figure 74. Lizard

Figure 75. Birds

SPIDERS

Spiders are predatory in nature. They trap small flying insects such as jassids, whiteflies and winged aphids in their web or feed on bollworm larvae directly without trapping them in webs. Under a high-density planting system of cotton, with minimal intervention, one is likely to encounter more spider webs as the plants are closer spaced. The spider web is so spun, that the insect does not escape by breaking the web-strands or by slipping through the weave because the strands are strong, fine and sticky and are closer to each other.



Figure 76.. Spider feeding on Spodoptera

PREDATORY STINK BUGS

There are several species of predatory stink bugs in Africa. The African shield bug, *Afrius* sp., is widely distributed in Africa. It belongs to the pentatomid family and plays an important role in biological control. *Podisus maculiventrius* is another pentatomid predator that feeds on a wide number of lepidopteran larvae, including the Fall armyworm. It injects a toxin into its



Figure 77. *Eocanthecona* nymph



Figure 78. *Eocanthecona* adult

prey, immobilizes it and then gradually sucks the internal fluids, leaving behind a shriveled caterpillar carcass. The adults are more voracious than in nymphs in feeding on insects that have fed on chlorophyll rich food. The predacious bugs have specially adapted mouthparts for piercing and sucking body fluids of the host caterpillar/bug. When touched they emit a foul odor and hence the name stink bug.

ASSASSIN BUGS

Assassin bugs are long limbed bugs and belong to the family Reduviidae. They are predatory on soft bodies insects. Both nymphs and adults are predatory in nature and nymphs are seen clumped together soon after hatching. Assassin bugs have beaks that are at least twice as thick as their antennae. However, the beaks are shorter, stouter, and curved. The beak tip fits into a groove between the front legs. Assassin bugs actively hunt for prey. Assassin bugs are especially vulnerable to predation when they are in the nymphal stage.



Figure 79. Assassin bugs

PREYING MANTIS

Preying mantis insects feed on virtually anything they can catch, such as flies, beetles, crickets, moths, and grasshoppers. They are ambush predators, sitting and waiting or very slowly stalking with the front legs raised up, poised to clamp down on whatever insect of the appropriate size that moves in front of them. Since they feed indiscriminately large mantid number may be detrimental to biological control.



Figure 80. Preying mantis

ODONTOMANTIS

Odontomantis insects belong to the Mantid family, also known as the Asian ant mantis. The nymphs look like black ants. The mantid mimics a black ant as the latter is aggressive, moves in large numbers and is acidic to taste thereby are avoided by predators. These nymphs lose their ant like appearance and look like conventional praying mantids as adults.



Figure 81. *Odontomantis*

EXORISTA

This parasitic fly belongs to family Tachinidae and is present in Africa. It is gregarious and polyphagous in its feeding habit preferring larvae belonging to the Noctuid family, like *Spodoptera*, *Helicoverpa* etc. The adult fly lays eggs on the integument of the prey and the grubs enter the host larva on hatching. *Exorista* flies have a keen sense of smell and visual cues that help them to attack bollworms and other larval pests of cotton.



Figure 82. *Exorista* fly

PAEDERUS

Paederus is also known as rove beetle. It is an insect predator, belonging to the family Staphylinidae. Females produce a defense secretion that is a toxin called pederin. Rove beetles live in vegetable debris and under stones and other materials, such as leaf litter. They are predaceous on insects like thrips, and other small insects or may eat plant debris.



Figure 83. *Paederus* adult

PARASITOIDS

APHELINID WASPS:

Aphelinid wasps lay eggs singly inside insects such as aphids, whiteflies and scales. Parasitized aphids will have a growing grub of *Aphelinus* inside their body, but they continue to feed and grow to finally become mummified into a papery cas- ket. Aphelinid wasp completes its full growth inside an aphid and punctures a hole in the mummified aphid to emerge out. *Aphidius colemani* is found parasitises *Aphis gossypii*. It is commonly found in many African countries.



Figure 84. *Aphidius*

TRICHOGRAMMA WASPS

Trichogramma species are egg parasitoids, meaning that they lay their eggs inside the eggs of other insects. The parasitoid egg hatches inside the host egg; the grub feeds inside the host egg and emerges as a wasp. *Trichogramma minutum* and *T. pretiosum* are the popular species of this egg parasitoid group. They can be readily mass multiplied in the laboratory on eggs of *Corcyra* (rice moth) and released in the field. *Trichogramma* species are dominant egg parasitoids of the fall armyworm, *Spodoptera frugiperda*, False codling moth, *Thaumatotibia leucotreta*, pink bollworm *Pectinophora gossypiella* and the American bollworm, *Helicoverpa armigera* in Africa on cotton.



Figure 85. *Trichogramma* wasps

BRACON WASPS

Bracon wasps are reported from Africa. Each wasp lays one to eight eggs inside larvae of bollworms, *Spodoptera*, semi-loopers, leaf folders and hairy caterpillars. The eggs hatch and grubs feed inside to complete their larval cycle. In the final stage the grubs make holes in the body of the host larva and come out to spin silken white cocoons. The adult wasps feed on the nectar produced by the cotton plant.



Figure 86. *Bracon* wasp parasitizing *Helicoverpa* larva

CHELONUS WASPS

Chelonus insularis is recorded in Africa parasitising *Helicoverpa armigera* and all *Spodoptera* species including the fall armyworm, *Spodoptera frugiperda*. *Chelonus* is an egg-larval parasitoid, meaning that it lays its egg on the host egg and emerges from the host larva after completing its life cycle. Thus, the wasp does not kill the egg but cause damage to larvae of insect pests by developing in them.



Figure 87. *Chelonus* wasps

PARASITOIDS ON PINK BOLLWORM

Eulophid wasps belonging to the genus *Tetrastychus* and *Elasmus* parasitize soft bodied lepidopterans, grubs, and leaf miner larvae. Adults of some species act as predators feeding on eggs and immature stages during the process of feeding. *Elasmus* parasitizes larvae of pink bollworm and the false codling moth. Some species develop as ectoparasitoids and may occur as groups on the body of the host. Wasps of *Brachymeria* belong to family Chalcidae. The adults are heavily armoured, and the femur of the hind legs is very well developed which is a distinguishing feature of Chalcidae. Eulophid wasps usually parasitize pupae of bollworms, *Spodoptera*, Leaf folders, semi-loopers and hairy caterpillars. and have been reported in Africa.



Figure 88. Wasp on pink bollworm larva

PATHOGENS

METARRHIZIUM ANISOPLIAE

Metarrhizium is a fungus present in soils and in the plant rhizosphere. *Metarrhizium anisopliae* causes fungal infection in bollworms, Spodoptera, leaf folders and semilooper larvae in cotton fields under high humidity. The spores adhere to the skin (integument) of the insect. The fungus produces special hyphae that emerge on spore germination. The hyphae use enzymes and mechanical pressure to penetrate the insect cuticle. Fungal hyphae colonize infected insects causing death. This entomopathogenic fungus is available commercially and can be manufactured under small scale production systems. The fungus attacks lepidopteran larvae, pupae, sucking pests and mites.

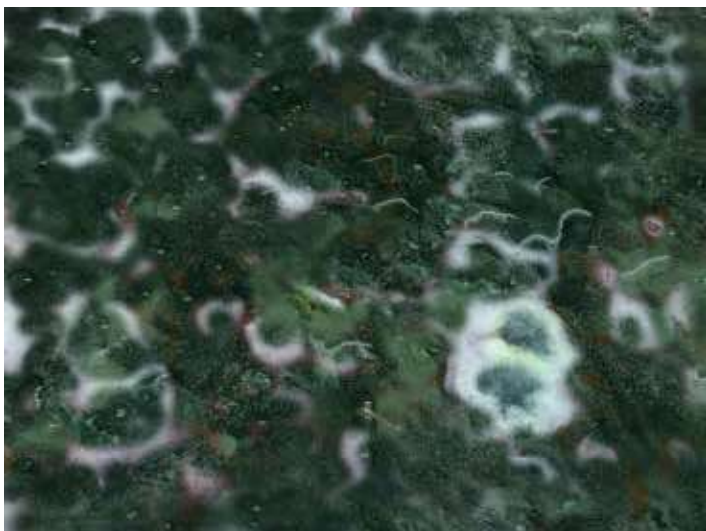


Figure 89. *Metarrhizium* colony

VERTICILLIUM LECANI

Verticillium lecanii is an entomopathogenic (pathogenic to insects) fungus that can cause epizootics in the tropics and subtropics. It is effective in causing fungal disease in soft bodied sucking pests such as whiteflies nymphs and adults, aphids, mealybugs and mites. *Verticillium lecanii* is available commercially as a formulation that does not require high humidity to be an effective entomopathogen. The mycelium sticks to leaf under-surface and infects insects that come in contact with it. It is widely used in organic cotton production to control sucking pests.



Figure 90. *Verticillium* formulation

BEAUVERIA BASSIANA

Beauveria bassiana is a soil-borne fungus. It causes the 'white muscardine disease' in insects. When the microscopic spores of the fungus come in contact with the body of an insect host, they germinate, penetrate the cuticle and grow inside, killing the insect soon. A white mold emerges from the dead insects and produces new spores. A typical isolate of *Beauveria bassiana* can attack a broad range of insects; various isolates differ in their host range. The fungus provides control of soft bodied insects like aphids, mites, bollworm larvae in cotton and can be a plant protection input in organic cotton production.



Figure 91. *Beauveria bassiana* culture

NUCLEAR POLYHEDROSIS VIRUS (NPV)

Most of the NPV viruses are species specific to lepidopteran caterpillars. NPV acts as an oral and contact insecticide. A virus infected insect stops feeding, grows slowly and becomes soft to touch. The infected larva is filled with viral particles that it releases by climbing to the top of the plant and hanging down to facilitate the fat bodies to exert pressure causing the insect body to burst. The virus particles are thus released from an infected insect to contaminate foliage below. Other insects of the same species can acquire the disease by feeding on foliage coated with these virus particles. Virus infected dead insects are foul smelling, appear black and liquify when touched. *Helicoverpa armigera* NPV and *Spodoptera* NPV are available commercially in some countries and are used for pest management in organic cotton.



Figure 92. *Spodoptera* NPV

BIOLOGICAL PESTICIDES

Biopesticides are micro-organisms and natural products that are used to control insect pests and crop diseases. Biopesticides are derived from living organisms that include plants, fungus, bacteria, nematodes and plants. Genetically modified crops are also considered as biopesticides in the United States of America.

There are five main categories of biopesticides:

1. Microbial biopesticides: Insect disease causing viruses, bacteria, fungi etc.
2. Entomopathogenic nematodes transmit diseases to insect pests.
3. Botanicals: Plant extracts and oils that either repel or kill insect pests.
4. Pheromones are used to mass trap insect pests.
5. RNAi pesticides: Ribonucleic Acid interference products

BOTANICAL PESTICIDES

Most botanical extracts and vegetable oils act either as anti-feedants or repellents to sap sucking insect pests. Neem sprays are effective as antifeedants on aphids, jassids, whiteflies, leaf eating caterpillars and early instars of bollworms.

The most used botanical pesticides in India and Africa are based on neem and extracts of locally identified pesticidal plants such as *Chrysanthemum (Tanacetum) cinerariifolium*, *Tephrosia vogelii*, *Tithonia diversifolia*, *Azadirachta indica* (neem), *Carapa procera* and *Cassia nigricana*.

Neem seed powder (5Kg) is soaked overnight in 100 litres of water, filtered and sprayed on one acre field. Neem oil (1 Litre) is mixed with 100 litres water, 50ml liquid soap and 100g asaphoetida to be sprayed in one acre.

Green chillies (7.5Kg), garlic (2.5Kg) and onion (2.5Kg) are ground to paste and soaked in 20 litres water overnight. The extract is filtered, diluted and sprayed in one acre.

Botanical mixture pesticides are also prepared using a mixture of neem oil (1 Litre) + chilli powder (200g) boiled in water + 50g crushed garlic + powders of pyrethrum flowers (20g) + 50ml liquid soap. These mixtures are used against all insect pests of cotton.

A traditional botanical pesticide called 'Dasaparni' (ten leaves) is prepared in India by crushing ten different types of leaves (200g each) and soaking them in water mixed with cow dung (500g) and cow urine (500ml) for 5-6 days in about 20 litres water. The extract is filtered and diluted to 100 litres to be sprayed in one acre.

The ten commonly used plant species are: Castor: *Ricinus communis*; Custard apple: *Annona squamosa*; Chinese chaste tree: *Vitex negundo*; Morning glory: *Ipomea carnea*; Oleander: *Nerium indicum*; Datura: *Datura fastuosa*; Pongame: *Pongamia pinnata*; Papaya: *Carica papaya*; Calotropis: *Calotropis procera* and Neem: *Azadirachta indica*.



Figure 93. Neem tree



Figure 94. Neem seeds



Figure 95. Preparing neem pesticide



Figure 96. The top ten botanicals used in India



Figure 97. Botanical mixtures for pest management

INSECT TRAPS

Insects can see UV light and get attracted to light. There are at least three innovations that have made light traps practical and selective for insect pest management. The three innovations are, wavelength-specific LED lamps, solar powered batteries and innovative designs to filter harmful insects from beneficial ones. Light emitting diode (LED) based light traps have emerged as a recent innovation especially because of their low cost, low voltage operation, high energy efficiency and long life-span. LED lights at 385-395nm were found to attract *Helicoverpa armigera*. UV-LED lamps were found to attract *Pectinophora* efficiently. Solar powered light traps can be placed anywhere in cotton fields in the absence of electricity.



Figure 98. Light trap



Figure 99. Light trap with timer

Pheromone traps are designed to trap male adults using female pheromones as attracting scents.

The female sex scent is synthesized and placed in a septum for slow controlled release. Male adult insects get attracted to the scent and get trapped in devices that are sticky or have insecticides or in water pans.

Almost all pheromone traps are species specific. The most commonly used pheromone traps in cotton pest management are designed to attract the American bollworm, pink bollworm, Spodoptera or the spotted bollworm.

Pheromone traps are used for monitoring infestation levels, or for mass trapping or for mating confusion.

There are several types of sticky traps that are used to attract insects. Most of the sticky traps are designed to attract small flying insects belonging to the sap-sucking pest category.

One of the most commonly used traps is a yellow sticky trap in cotton fields.

Yellow sticky traps are used to attract whiteflies. Blue and purple sticky traps are used to attract thrips.



Figure 100. Pheromone traps



Figure 101. Yellow sticky trap



Figure 102. Blue sticky trap

CROP RESIDUE MANAGEMENT

Pink bollworm seeks shelter in unharvested bolls in cotton fields and remain as diapausing larvae to infest the crop in the subsequent season. There are a few other insects and pathogens that also get carried from crop residues. Crop destruction is recommended to prevent the carryover of insect pests and diseases. One of the best methods for crop destruction is the production of biochar from crop residues. Biochar not only destroys residual pests but also sequesters carbon from cotton stalks and unharvested bolls and adds carbon to the soil.



Figure 103. Cotton crop residues being burnt (bad practice)

BASIC PRINCIPLES

The foundation of IPM is laid primarily by delaying the application of synthetic pesticides as long as possible early in the season to allow the establishment of beneficial insects in the cotton ecosystem.

There are a few basic steps that can help to delay the first application of synthetic pesticides to support beneficial insects in the field all through the season.

1. Use a cultivar that is resistant to sap-sucking insect pests.
2. Treat the resistant seeds with appropriate chemicals or microbial pesticides to enhance seedling resistance to early season sap-sucking insects.
3. Early sown crops are generally more resistant to sap-sucking insects and escape early season pest attacks.
4. Grow intercrops such as cowpea or green gram or black gram or sorghum that attract and provide shelter for good bugs
5. Avoid excessive urea because it makes plants susceptible to sap-sucking insects.
6. With the above five steps, it will be possible to avoid chemical insecticides early in the season and also later as long as possible.
7. Delay the application of insecticides as long as possible, because chemical insecticides applied early in the season will disrupt the ecology by killing more of the beneficial insects compared to insect pests which tilts the balance in favour of harmful insect pests to cause pest resurgence soon. While insect pests resurge easily, parasitoids and predators reappear in fewer numbers.
8. Use biopesticides and other IPM techniques that are safe for good bugs but can control the bad bugs.

HABITAT MANAGEMENT

The survival of insect populations in an ecosystem mainly depends on abundance of their food supplies, micro-environment, habitat and operating natural mortality factors. Natural mortality causing factors include naturally occurring predators and parasitoids that keep the insect pests under check.

Agro-ecological engineering for pest management operates through a push-pull strategy wherein trap crops attract (pull) the pests and border plants repel (push) the pest away by producing volatile chemicals. A few intercrops attract more populations of beneficial insects to serve as a bio-control repository that controls pests in the main crop. Many other ecological strategies are deployed to provide advantage to the beneficial insects and make survival difficult for harmful insect pests.

Many insects have a range of common host plants. Some plants are preferred more as food and shelter compared to others. Plants that are most attractive and are most preferred by insect pests can be used as trap crops when grown as strips or patches or borders for a main crop that is comparatively less preferred by the pest. Some of the most commonly used trap crops are alfalfa, maize, okra, sunflower, safflower, cowpea, squash, sorghum, marigold etc., to trap insects such as lygus bugs, thrips, aphids, whiteflies and bollworms.



Figure 104. Marigold trap crop



Figure 105. Sunflower trap crop

EPILOGUE

The movie ends with the girl's narrative that her uncle tells them that thousands of farmers across the world benefit from IPM. But sometimes despite the good IPM techniques, things that are outside our control like the weather can make the number of bad bugs grow so fast that the good bugs can't keep the numbers down. When this happens if left unattended, the crop loss would be more than it would to use a pesticide. This is called an economic threshold. When this is reached, the fields can be sprayed a couple of times with pesticides. The good news is that there are some pesticides that kill more bad bugs than good ones, and which aren't too harmful to the environment. By practicing IPM her father doesn't need to spray many harmful insecticides any longer because the good bugs are more in numbers compared to the few bad bugs. As yields improved expenses on harmful chemicals decreased substantially. Thanks to IPM she walks happily in their fields now without being worried of the pesticide residue. The air is fresh, and water is clean. The family is happy because with more use of natural methods of pest control, they are more close to nature and the environment.



Figure 106. Variety resistant to sucking pests



Figure 107. Cotton at harvest

MODULE-2: BEST SUSTAINABLE PRACTICES FOR HIGH YIELDS

INTRODUCTION

Cotton is the best natural fibre produced on earth. More than 28 million farm families in 80 countries across the world grow this crop. Cotton provides employment and livelihood to more than 100 million persons. Yields are very high in some countries and very low in others. Sadly, cotton yields in Africa and rainfed farms in India are very low. They are less than half the world average.

Can cotton yields be increased in Africa and rainfed farms of India? The challenge is to increase yields in the small rainfed farms of Africa and rainfed Indian farms, but without increasing input costs on irrigation, fertilisers, pesticides or mechanisation. While cotton yields in the past 20 years have doubled in Australia, Brazil, China, Mexico and Turkey, yields in Africa and India have been stagnant. Studies show that the high yielding countries made a few small changes in their production systems that made a big difference in yields.

This Virtual Reality movie explores these global lessons and strategies to identify those that can be adoptable in the small rainfed farms of Africa and India. In this movie, we will examine the common steps that high yielding countries follow and that can be followed easily by Africa and other countries.

THE FOUR SIMPLE STEPS FOR HIGH YIELDS

The movie focuses on four main strategies that have been found to drive sustainable cotton production in the high yielding countries. The strategies are

1. Soil health
2. Seed health
3. Integrated Pest Management
4. Improved harvest index

These strategies lead to a good plant stand and high retention of early formed bolls to get high yields

SOIL HEALTH

A healthy soil is most important for a healthy crop. Sadly, soils in many parts of the world are getting degraded. Soil erosion is the greatest problem. A healthy soil is rich with organic matter and soil organisms. Soils rich in organic matter help plants to absorb nutrients easily. They also retain water better. A healthy soil helps in good boll formation and good boll retention.

Here we are using four main techniques for soil health

1. Recycle crop residues
2. Conservation tillage
3. Enrich organic matter
4. Cover crops

CROP RESIDUE RECYCLING

The principle of crop residue recycling is to 'give back the soil what you take from it'. Cotton crop absorbs nutrients from the soil to grow branches, roots, leaves and bolls. We harvest bolls. But the rest of the plant biomass must be returned to the soil. Most farmers in Africa burn cotton stalks. In India and Pakistan, cotton stalks are used as firewood, or burnt or allowed to rot near bunds. These are bad practices. A better practice is to slash cotton stalks and layer the bits over the soil as an organic mulch. The stalks and leaves can be either converted to compost or layered on the soil to decompose and enrich soil organic carbon and nutrients that could be used by the subsequent crop. The crop residue could be converted to biochar, a process in which pathogens and insect pests get destroyed, while the organic biomass enriches soil carbon when applied to the soil.

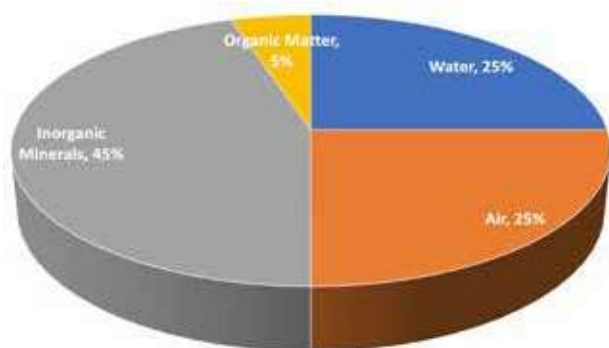


Figure 108. Soil composition



Figure 109. Topsoil run-off due to tillage (bad practice)



Figure 110. Shredding of cotton stalks

Conservation tillage

Conservation tillage can be minimum tillage wherein a small part of the field is tilled, or zero-tillage wherein seeds are directly sown into the soil without tillage.

In a zero-tillage field, cotton seeds are directly dibbled in rows without ploughing the field. Grassy millets or fodder or legume crops are grown in winter as cover crops and the crop residues are allowed to dry in the field. The cover crop roots hold the topsoil and prevent soil and water erosion. The cover crop also adds organic matter, prevents soil crusting and minimizes weeds. It acts as an organic mulch to minimize transpiration losses.

Soils rich in organic matter improve water infiltration into the soil, help in nutrient uptake and foster a healthy crop. Ploughing the field leads to soil erosion by wind and rain. Minimum tillage practices ensure that the topsoil is least disturbed and erosion is minimized. Cotton seeds can be dibbled directly or sown in rows sliced with a chisel plough. Chisel ploughs slice rows in less than one-fourth of the row width. This practice conserves more than 50% of the residue cover of the previous crop.



Figure 111. Crop in conservation tillage



Figure 112. Crop in conservation tillage

Cover crops

Cover crops not only protect the top soil by holding it together with their roots to reduce soil erosion, but they also enrich soil organic matter. Legume cover crops fix nitrogen. Many cover crops act as mulches or trap insect pests or support beneficial insects and minimize weeds. Cover crops can be grown in crop rotation or intercrops or relay crops. Sesbania, sunnhemp, hairy vetch etc., fix good amount of nitrogen and can be used as cover crops. Legume seeds are treated with Rhizobium to help them fix nitrogen better.



Figure 113. Hairy vetch & Mix (clover + rye + vetch) cover crop

Enriching soil organic matter

Wherever available, apply poultry manure or cattle manure or compost at least once every two years and green leaves of Glyricidia and neem to layer them as a crop mulch and green manure. Generally, one tonne of the green manure biomass provides about 20-30 Kg nitrogen, 5-10Kg phosphorus, 10-40 Kg potash and other micronutrients.



Figure 114. Sunn hemp green manure being mowed

SEED HEALTH

Good seed health, seedling vigour and high germination rate are important for high yields.

Picking for the best seed

You can save cotton variety seeds from your farm to sow them in the next season. Bolls with the best seeds for sowing purposes can be harvested from specific locations of the plant.

1. Early formed healthy bolls
2. Bolls of the first and second fruiting points
3. Bolls from mid region of the plant
4. Bolls picked within a week after opening

Seed processing

Cotton seeds are delinted so that they can be graded for vigour and treated efficiently for protection against pests and diseases.

Fuzzy seeds obtained after ginning. Many farmers in Africa sow 4-6 fuzzy seeds per spot. Fuzzy seeds can have poor germination rate because of which large gaps in fields are very common in Africa. This leads to low yields. Clumps of seedlings at a spot are also commonly seen in Africa. These clumped plants do not yield well because of competition. Fuzzy seeds can carryover pest and diseases if used for sowing. Therefore, linters are removed either by brush de-linting or by treating with acid.

De-linted seeds are generally clean and free from diseases and insects. These seeds can easily be graded for high vigour either on sieves or by sinking them in a bucket of water at home. Seeds that sink have a specific gravity more than 1.0 which is a simple indication of high vigour.

De-linted seeds are convenient for treatment with insecticides or fungicides or bio-fertilisers.

A simple germination test can be conducted at home before seeds are treated and sown.

If germination is more than 90% one seed can be sown per spot. If it is 70 to 90% 2 seeds must be sown per spot and if it is 50 to 70% 3 seeds are sown per spot. Seeds are sown on ridges at 1-2 cm depth in wet soil. The preferred row direction of the ridges is generally north-south.



Figure 115. Fuzzy seeds



Figure 116. Delinted seeds

SEED PROCESSING



Figure 117. Grading of delinted seeds in water & gravity separation (right)



Figure 118. Germination test

HIGH HARVEST INDEX

A high harvest index is an indicator of high nutrient use efficiency. Harvest index is the relative proportion of the weight of seed-cotton in the total plant above-ground biomass. This tells us whether plants are diverting their resources more towards bolls or more towards vegetative biomass. In Australia, USA, China etc., the weight of harvested bolls is 40 to 50% of the total plant weight, while it is about 20 to 30% in Africa, India and Pakistan. This low harvest index is because of a wide spacing between plants which leads to excessive number of vegetative branches and bushy growth.

High harvest index and high yields are achieved through three strategies that distinguish high yielding countries from Africa and India.

1. High density planting and a good plant stand
2. Retention of early formed squares and bolls.
3. A shorter critical window



Figure 119. More boll weight in relation to rest of crop biomass

High Density Planting

High density planting means a greater number of plants within rows, generally at 8-12 plants per meter row. Delinted, graded and treated seeds are used for sowing to ensure a high germination rate. And a good plant stand.

The row spacing in high density fields in developed countries is wide at 90-100cm, but plants are sown very close at 10cm spacing within the rows. Thus, there are about 10 plants in a meter within a row.

In Africa and India, there are only 1-3 plants in a meter within a row. This practice is common in all the low yielding countries. The plant density in high yielding countries is about 3-6 times higher than Africa and India. Yields are 3-6 times lower in Africa and India compared to the larger rainfed farms of USA and Brazil; and the small holdings of one-acre farms in China.

To get high yields from a low-density crop you will have to wait for each plant to produce a greater number of bolls per plant. This means waiting for a longer crop period, cumbersome management of pests and nutrients which leads to low yields.

Because of low planting density and poor germination rates, the plant stand is very poor in Africa and yields are low. Low plant density leads to a bushy crop.

A bushy crop leads to shedding of early formed squares. Square shedding leads to compensatory plant growth and a longer boll formation window and low yields.

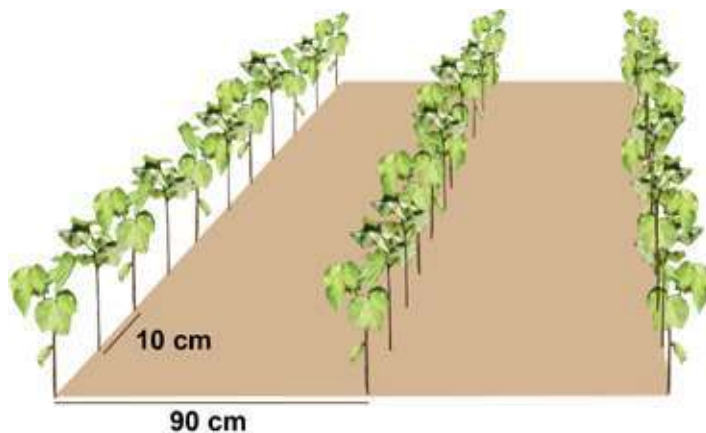


Figure 120. High density planting



Figure 121. High density planting

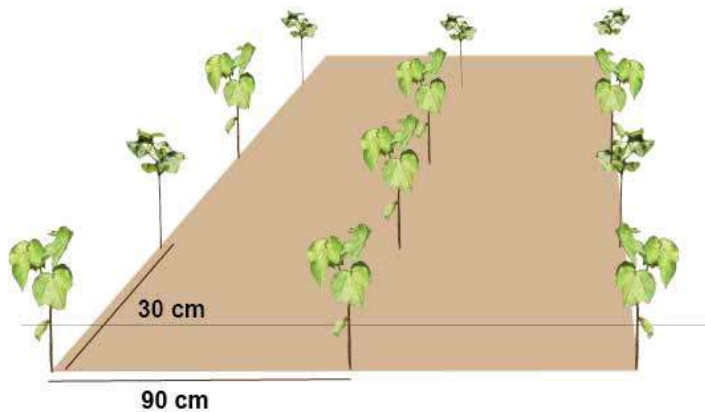


Figure 122. Low density planting



Figure 123. Low density planting



Figure 124. Square shedding



Figure 125. Retention of squares and bolls

RETENTION OF EARLY FORMED SQUARES AND BOLLS

Early formed squares and bolls can be retained by several strategies. Retention of early formed squares leads to a shorter and compact boll formation window and high yields in a short season.

Square shedding

It is important to understand the causes of square shedding and know the methods to minimize shedding. A fruiting branch produces a square at every node. A fruiting branch can be recognised by its zig-zag appearance. The fruiting parts are known by their positions on the branch as a first position square that is in the proximal part and closest to the main stem; the second, the third etc., which are away from the main stem in the distal parts of the branch. An empty fruiting position node on the branch indicates a shed square.

Four major factors could cause square and boll shedding

1. Bushy Rank growth
2. Cloudiness, excess heat, drought or waterlogging
3. Deficiency of Nitrogen, Phosphorus or Boron
4. Insect damage

TECHNIQUES TO MINIMIZE SQUARE SHEDDING

Square shedding can be minimized by preventing rank growth or controlling insects or treating with plant growth hormones or by rectifying nutrient deficiencies.

- Rank growth can be detected when the average internodal length exceeds 4cm.
- The distance between these two fruiting branch nodes of the main stem is called internode.
- Avoid excessive nitrogenous fertilisers to prevent rank growth
- Spray plant growth regulators to restrict if growth is in excess during 60-90 days. Take care not to spray growth regulators on stressed plants.
- Square shedding can occur due to cloudy conditions or excessive heat. This can be minimized with hormone sprays. Napthalene acetic acid is an example.
- To remedy nutrient deficiencies, application of Boron or DAP minimizes square and boll shedding
- Mirid bugs and bollworms cause shedding of early formed squares. Spray sulphur or neem or eco-friendly pesticides to control the pests without harming beneficial insects. At emergency, acephate may be sprayed.
- Plant trap crops such as alfalfa or safflower or sunflower or mung beans as border or intercrops and spray insecticides in the trap crop to manage mirid bugs.
- Use sticky traps
- The field must be kept weed free to avoid mirid bugs and also to avoid competition for nutrients and water.

PLANT HORMONES

The following plant hormones may be used to combat the effects of drought, waterlogging, excessive temperatures and adverse weather:

1. Alpha-Naphthalene Acetic Acid (NAA)
2. Aminoethoxy Vinyl Glycine (AVG)
3. Methyl-cycloprene (MCP)
4. Triacontanol
5. Amino-oxy-acetic acid (AOA),
6. Tri-iodo-Benzoic Acid (TIBA),
7. Silver thiosulphate,
8. Silver nitrate and
9. Trans-cyclo-octene

Alpha-Naphthalene Acetic Acid (NAA) is most commonly used at 4.5g active ingredient mixed in 100 litres of water (40 ppm) as spray fluid.



Figure 126. Retention of fruiting parts

A shorter critical window

The green boll development stage is the critical window for cotton yields. Management of nutrients, water and bollworms during the green boll development stage are most critical for high yields. The length of the critical window depends on the density of the crop. Cotton is grown as low-density crop in India or Africa. Because a low-density crop has less plant population, each individual plant is required to produce a greater number of bolls which takes a longer seasonal duration of 6-8 months and a longer critical window of about 100 days. However, because of a longer critical window that is difficult to manage, only a few farmers manage to get high yields despite using more fertilisers.

Generally, majority of farmers get high yields from a high-density crop in a shorter season of about 5 to 5.5 months. This is because a high-density crop has a greater plant population and individual plants are required to produce a limited number of bolls within a short period for high yields. The critical window is short at 50-60 days which is relatively easier to manage for nutrients and pest control.

INTEGRATED PEST MANAGEMENT

A healthy ecosystem results in a healthy crop.

The ecosystem includes the soil, the cotton crop, intercrops, trap crops, border crops, insects, birds, arthropods and microorganisms.

The keys to a healthy ecosystem are:

1. A sucking pest resistant variety
2. Healthy seeds treated for pest resistance
3. Balanced crop nutrition
4. Trap crops and legume intercrops
5. Biological insecticides or selective insecticides
6. Insect traps



Figure 127. An IPM field

Conserving and augmenting natural biological control in the field greatly strengthens IPM.

Application of broad-spectrum insecticides early in the season devastates the ecosystem and causes pestilence. Therefore, it is important to delay the first application of synthetic insecticides as long as possible by relying on host plant resistance, seed treatment and other biological methods that help plants to combat sap-sucking insects.

Sucking pests arrive early in the season and cause more damage to susceptible varieties. Varieties resistant to sucking pests will help to avoid insecticide application early in the season. This helps beneficial insects to establish and control insect pests all through the season.

- Avoid excessive nitrogen fertiliser applications that make the crop more susceptible to sucking pests.
- Reduce dependence on only chemical insecticides. Use insecticides only as a last resort.
- Strictly avoid insecticide mixtures and highly hazardous pesticides.
- A combination of trap crops, insect traps, and selective insecticides disadvantages insect pests and helps friendly insects to control insect pests.

Thus, a healthy ecosystem results in a healthy crop.

PLANT GROWTH MAPPING

We are now in a rain-fed cotton farm that uses sustainable strategies for high yields. These seedlings have just emerged. The wide row spacing of 90cm allows good sunlight. Look at the close distance of 10cm between plants in the row. At this stage, check for gaps where seedlings have not emerged. Fill the gaps either by sowing seeds in the gaps or by transplanting seedlings. This is a border row of alfalfa. Alfalfa border rows act as trap crops for mirid bugs and aphids. They host beneficial insects too.

0-45 Days old crop

When seedlings are 15 days old, there are two operations that can be done at this stage. Apply one bag of NPK per acre as basal dose. Band application improves efficiency. Avoid excessive nitrogen to prevent excessive vegetative growth and sucking pests. At this stage you may broadcast seeds of a legume intercrop between the cotton rows. Crops such as cowpea, alfalfa, blackgram or broadbeans can be sown between rows now and mowed down after two months.

Root growth is very active at the seedling. It can be expected to see 40-60cm long tap root when the plants turn 30 days old. Good root growth now will help the plants to combat drought later. If root growth is unsatisfactory apply 1.5% Diammonium phosphate (DAP) fertiliser as a foliar spray. Keep the field well drained. Remove weeds. When the crop reaches 45-days, the root length is expected to be 60 to 90cm.

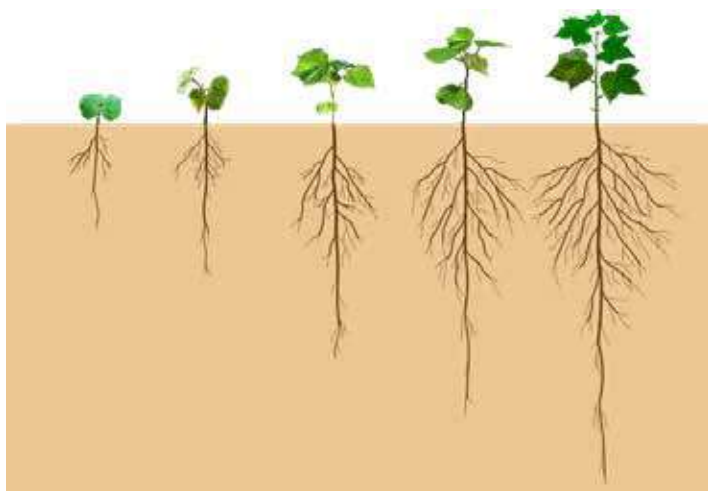


Figure 128. Root growth at 10 days intervals

45-75 Days old crop

Plants start to produce flower buds called squares. On an average, the plant could produce one new square every day over the next two months. A square takes about 20 to 25 days to bloom into a flower. Weed competition can be detrimental to the crop at this stage. Keep the field free of weeds. Apply one bag of urea per acre when the crop reaches 45-50 days, so that young developing squares get proper nutrition. The above ground crop grows rapidly at this stage to form fruiting branches and squares.

Monitor plant height every week at this stage of the crop to prevent excessive vegetative growth. Use mepiquat chloride to keep the average internodal length below 4cm. It is extremely important to focus on strategies to retain early formed squares. Shedding of early formed squares leads to plant stress. When shedding occurs, the crop tries to produce fresh squares to recover. In this process, the crop switches to tall growth, longer season, delayed maturity and low yields. Higher retention of early formed squares and bolls guarantees high yields. Early formed bolls are located on the first and second fruiting points of the fruiting branches. Studies showed that the bolls on the first point of the fruiting branch are most favoured by the plant and contribute to about 60% of the total yield. Bolls on the second fruiting points contribute to 30% and bolls on the third fruiting points contribute to about 10% of the total yield. However, in a low-density crop, the vegetative branches produce more bolls but require more nutrients because of the excessive vegetative growth. Aim for high retention of the first and second fruiting node bolls for high yields and better fibre quality.

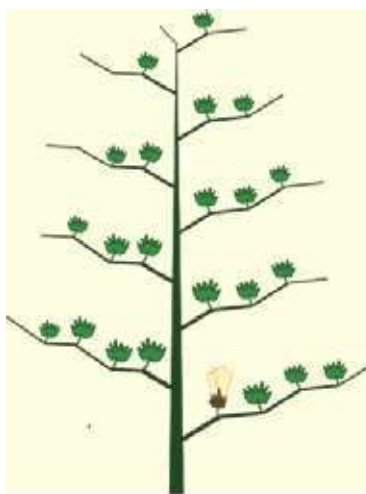


Figure 129. Nodes above the first white flower (NAWF)

75 Days old crop

Nodes above the first white flower (NAWF)

The crop enters its flowering stage. The flower on the first fruiting point of the lowest fruiting branch is called the first flower. This is the right time to monitor the number of fruiting branches above the first flower. More than nine branches above the first flower indicates proper growth. Less than nine fruiting branches will need extra attention for management of nutrients or irrigation.

Vegetative branches are produced at the bottom of the plant. They grow upright to cause shading, which leads to square shedding from the fruiting branches. Vegetative branches also produce squares and bolls but consume disproportionately high amounts of nutrients. In low density fields more than half the boll load is carried on vegetative branches. Chinese farmers manually remove vegetative branches at the early stages itself. In many countries, varieties are genetically selected to produce fewer vegetative branches. Interestingly, a high-density crop with closer spacing within rows leads to plants with fewer vegetative branches. Plants in low density fields produce 3-8 vegetative branches, whereas plants in high density fields generally have 1-2 vegetative branches. A greater number of vegetative branches generally leads to lesser number of fruiting branches.

Flowering marks the beginning of green boll formation stage. Most flowers self-pollinate but bees and other insects also help pollination. This yellow flower will turn pink tomorrow soon

after pollination. The pink petals wither away a day later. A small boll develops from the ovary of the flower. Green bolls reach their full size in 20 days and take another 30 days to mature fully and open. The developing bolls have high demand for nutrients and water.

Intensify integrated pest management (IPM) techniques at this stage. Pheromone traps, light traps and sticky traps can be installed for pest monitoring and mass trapping. Flared-up squares like these are good indicators of bollworm damage and can be used for monitoring. Monitor for bollworms to initiate pest control measures if damage to squares and bolls is more than 5 to 10%. It is important to use selective insecticides that are toxic to target pests and least toxic to beneficial insects. Strictly avoid insecticide mixtures.

MANAGING THE CRITICAL WINDOW (80-110 days)

Green bolls develop actively from 80 to 120 days. This is considered as the main critical window for nutrient and bollworm management. A shorter critical window makes it easier for effective and efficient management. In high density planting, the critical window is short at less than 60 days.

Firstly, cotton plants at this stage need more than 70% of their total water and nutrient requirement during the green boll development stage. Hunger or thirst at this time will lead to low yields. Green bolls that suffer moisture stress, nutrient stress and excess heat are aborted and malformed. Efficient management of water, nutrients and bollworms during now and the next 40 days is crucial for high yields.

Nutrients can be provided through chemical fertilisers or legume cover crops or manures or compost or biofertilisers. Soils with high organic matter retain soil moisture better. Mulches minimize transpiration losses. Planting on ridges helps plants to tide over drought and flood. Furrows capture rainwater water and act as drain channels when opened up. Retention of early formed bolls ensures that the critical boll formation window coincides with peak monsoon and adequate soil moisture.



Figure 130. The critical window:
Peak boll formation stage

The second major management concern during the critical window now is to protect tender young green bolls from bollworm damage.

Bollworms are attracted by the floral scent and are most active during this period.

Bollworms prefer to lay eggs on green bolls that are younger than 20 days. Green bolls reach their full size in 20 days after which they are relatively safer from fresh bollworm attack. Retention of early formed bolls allows most of them to escape bollworm infestation.

100-140 Days

The crop enters its peak flowering stage at about 100 days. Plants divert all their energies towards green bolls. Formation of new fruiting branches and squares slows down significantly. Ensure adequate soil moisture and remedy nutrient deficiencies. Pay special attention on bollworm monitoring and IPM

Examine full size green bolls for bollworm damage at regular intervals. Dissect about 20-40 randomly picked full size green bolls from 10-20 plants to check for the presence of bollworm larvae. Successful retention of at least 10-15 full size healthy bolls per plant in a high-density field could result in yields higher than the world average. If 5-10% of the bolls are damaged by bollworms, use biopesticides or selective insecticides.

Green bolls reach their peak numbers on plants at 125-135 days. Green bolls need nutrients and water. New squares and flowers compete with green bolls and weaken them. Therefore, it is important to remove the freshly formed squares to avoid competition to bolls. If the number of nodes above the topmost white flower is less than 4, it is better to de-top the plants. If possible, also clip the edges of the 4-5 top-fruiting branches to remove new squares. This stage is called cut-out when fresh growth is forced to stop and most of the energy is best diverted into developing bolls. This will help the plants to focus all resources on the existing healthy bolls. New flowers could take more than 60 days from now to develop into open bolls.

It is not worth keeping squares and flowers after this stage. If manual de-topping is not possible, a high dose of a plant growth regulator can be sprayed to curb further vegetative growth.

Crop Maturation

A crop in high density planting reaches its final harvest stage at about 150 days, whereas in low density planting systems the crop continues to mature over a longer period, in some cases extending up to 240 days or more.

In high density planting, each plant may have about 15 open bolls. Each boll gives about 1.5 grams of fibre.

With about 100,000 plants per hectare, it is possible to get 2000kg fibre which is 2.5 times the world average yield. Extending the crop period beyond the normal duration of 150 days without enforcing cut-out will encourage pink bollworm infestations. Generally, bolls on the first and second fruiting points have better seed health. For seeds to be sown in the next season, bolls must be picked within a week after they open fully. Red cotton bugs, dusky cotton bugs and mealy bugs will attack open bolls if they are retained for more than a week on the plant.

Once the crop is harvested, cotton crop residues must be chopped to be returned to the soil. A legume crop can be grown in crop rotation or legume seeds can be broadcast so that they grow and fix nitrogen in the fallow land. The strategies shown in the VR movie represent sustainable best practices that are validated and accredited across the globe. These practices have been used by growers in Brazil, China, Australia, Turkey and USA to obtain high yields consistently over the past 2-3 decades. The ICAC hopes that these basic principles of cotton crop production and pest management will help to enhance profitability and sustainability in low-income and middle-income countries.