

TMC MM I.5 :	Simulation models/Sensor based gadgets for Cotton Protection and Production
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Lead Centre :	CICR, Nagpur
Cooperating centres	CICR,Coimbatore; CICR,Sirsa; CRIDA, Hyderabad; NCIPM, New Delhi; ANGRAU, Hyderabad; UAS Raichur; NRSC, Hyderabad; UAS Dharwad; Competitive/ Consultancy mode

Introduction

Major accomplishments in the area of cotton crop protection were under three heads during the first phase of the Technology Mission on cotton. Development and evaluation of location specific IPM modules for eco friendly cotton production was executed. Development of pest and disease forecasting systems was attempted. Identification of intra-specific variation in insect pests and diseases was elucidated. Morphological and taxonomical tools for identification of such variation were carried out through the use of conventional taxonomy with support of molecular biology and genetic engineering.

In the second phase of the Technology Mission, projects on identification and characterisation of emerging and key pests of cotton were carried out with immense zeal. This phase of the project saw creditable, fast paced work that worked in tandem with the demands of the current scenario of cotton. Emerging pests such as the mirids, the safflower caterpillar, and the mealy bug were studied in detail. In fact, detailed management protocols were elucidated especially for the mealy bug *Phenacoccus solenopsis*. Biology of new endemic pests such as the Tea mosquito bug, the gall midge on cotton was studied. Genetic diversity studies of key pests resulted in the identification of intra-specific variability in leaf hoppers across the country. Insecticide resistance in leaf hoppers was quantified using populations across the country and resistance to neonictinoids was reported for the first time. Economic threshold levels for *Spodoptera* and *H. armigera* were elucidated at different centres on Bt cotton versus non Bt cotton. IPM modules were revisited, refined and validated in different ecosystems. Diagnostics for pathogen detection by researchers were developed. PCR based diagnostics to identify common cotton pathogens directly from the affected plant parts were standardised. Farmer friendly GM detection kits such as several Cry toxin detection kits were developed and commercialised.

It is now time to move ahead. The project being envisaged now is oriented towards the development of products for use by farmers, researchers, administrators- in short, all stake holders of cotton. Farmers currently face an acute shortage of labour. It is unreasonable for a researcher to encourage the farmer to resort to pest scouting to enable him to make a pest

management decision. Providing him with a gadget to detect and quantify pest incidence is the ultimate goal of the project so as to provide timely, reliable decision support. Development of pest scouting gadgets is not easy as it requires the application of knowledge and expertise on crop pests, their damage and its conversion to design reliable and robust end products with market appeal.



Use of information technology is also critical for this project in the area of development of models for pest forecasting/forewarning. Using historical data generated by the All India Cotton Improvement Project models to forewarn pest incidence will be developed. This would have an impact on all stakeholders involved in the cycle of cotton production.

Providing and generating reliable data is essential so that, using information technology, models can be developed to predict the production of cotton and its price in international and local markets. The area of cotton in the ensuing season is often influenced by this. These models are expected to impact major decisions of economic importance to the country.

In short, project designing under the different phases of the Technology Mission has evolved from projects that yielded small scale location specific outputs to research directed towards the development of products of national and international significance.

Development of pest scouting gadgets

Cotton pest scenario changed dramatically with the introduction of Bt-cotton in 2002. Bt cotton suffers more damage by sucking pests than by bollworms. Traditionally important bollworms viz., American Bollworm, Spotted bollworm and Pink bollworm occur in fewer numbers on Bt-cotton while sucking pests, especially leafhoppers, have emerged as major constraints in yield maximisation of Bt cotton especially in Central and South India. Amongst pests, whiteflies and CulCD are some factors that limit realisation of the full yield potential of Bt cotton in North India while pink bollworm limits yield in Gujarat and in parts of Maharashtra, if left unprotected. Successful Bt cotton cultivation, like conventional cotton, relies on the use of insecticides. Although in India, pesticide use is low (527 g active ingredient ha^{-1}) compared to Korea, Italy, Japan and USA, pesticide consumption pattern is highly skewed towards a few crops and among agricultural crops, cotton accounts for nearly 21% of the pesticides used in the country.

Sucking pests which were controlled by insecticides applied for cotton bollworms have now become unmanageable, even with insecticides, due to resistance development. This was a consequence of the release of a large number of sucking pest susceptible Bt-cotton hybrids

released (>2000) for cultivation over a short span. To mitigate losses farmers resort to repeated sprays of insecticides without assessing pest levels since the latter is cumbersome and time consuming. Excessive insecticide sprays harm environment besides causing resistance development.

Organic compounds with vapor pressures high enough under normal conditions vaporized into the atmosphere are termed as volatile organic compounds (VOCs) (Dicke & Loreto, 2010). Plants produce a vast range of VOCs that when released into the atmosphere (Piesik, 2011) are involved in the interaction with the environment. VOCs from the plant interact with microorganisms, fauna, and neighbouring plants, protect plants from ultraviolet radiations and act as antioxidants. Among the different VOCs emitted by the plant some attract beneficial insects or microorganism or others kill or act as repellent to phytophagous insects. More than 100,000 chemical products are known to be produced by plants and at least 1,700 of these are known to be VOCs.

VOCs are involved in a range of ecological functions, including indirect plant defense against insects, pollinator attraction, plant-plant communication, plant-pathogen interactions, thermo-tolerance and environmental stress adaptation. These VOCs are liberated into the environment from a variety of plant tissues, leaves, fruit, flowers, and roots. Many of these compounds act as long distance regulators of responses to pests, diseases, environmental stress, nutritional deficiencies, and other physiological disorders. A number of plant species like corn, cotton, lima beans and cultivated tobacco are known to release VOCs when under herbivore attack (Dicke et al. 1990; Turlings et al. 1990; Loughrin et al. 1994; De Moraes et al. 1998).

Ethylene is one of the simplest VOCs with biological activity. Ethylene gas is a plant hormone responsible for the regulation of developmental change and the perception of stress. Chemically this is, a small colorless, odorless gas composed of two carbon and four hydrogen atoms (C_2H_4), is responsible for both beneficial and undesirable effects in on crops. The involvement of ethylene in plant responses to a variety of biotic and abiotic stresses is well known (Abeles et al, 1992). It is important for normal development in plants as well as for their response to stress (Deikman, J. 1997). Many aspects of the growth of vegetative organs such as roots, stems and petioles, and all stages of development are affected by



ethylene (Deikman, 1997). Ethylene synthesis is regulated by developmental cues and other hormones, such as auxin, gibberellin (GA), cytokinin and brassinoride, and is greatly enhanced by diverse stresses, such as wounding, salt, drought, cold, ozone, flooding, and pathogen and

insect attack. Thus, ethylene has a pivotal role in the coordination of internal growth, defense and survival in response to environmental challenges (Yoo et al 2009). A variety of other plant processes involve ethylene including rhizobia nodulation of legumes, rooting of cuttings, and plant



response to heavy metals, ozone, pathogens and flooding. The production of ethylene is regulated by a large number of factors including temperature, light, gravity, nutrition, and other plant hormones. Abeles (1973) described 'ethylene stress' as the acceleration of ethylene biosynthesis associated with environmental and biological stresses including pathogen attack (Morgan and Drew 1997). The increased level of ethylene formed in response to trauma inflicted by chemicals, temperature extremes, water stress, ultraviolet light, insect damage, disease, and mechanical wounding can be the cause of some of the symptoms of stress. Ethylene can be monitored using variety of sensors, through which we may gain insight that represent a summation of metabolic processes ongoing within a plant. Measurement of the ethylene is therefore an attractive avenue for non-invasive monitoring of stress.

Plants and microorganisms sensitive to VOCs are reported in literature. High levels of VOCs such as ethylene often cause indicator plants to wilt. This has been demonstrated in confined conditions such as greenhouses. This idea can be applied in the field with appropriate modifications through research. Use of sound produced by insect feeding can be converted readily into an acoustic sensor. The sound produced by pink bollworm feeding inside green bolls has been monitored and separated from background noise.

Sensing technologies can be a useful tool in detecting biotic / abiotic/nutrient stress that may bring in the accuracy for detecting these stresses based on real time data so that timely measures can be adopted which in turn aids proper input management. Presently, detecting biotic/ abiotic/ nutrient stress is cumbersome and time consuming with substantial error. The development of hand held gadgets, which should necessarily be cost effective and efficient in detecting stress, is the need of the hour. Such gadgets would be immensely useful in strengthening integrated pest management (IPM)/ integrated nutrient management (INM) that emphasize appropriate decision making.

Pest Models

In India, cotton is currently cultivated in about 12.19 million hectares (2011-12) with a production and productivity of 345 lakh bales and 481 kg lint/ha., respectively. The crop is grown in three agro-ecological zones of the country comprising the irrigated North zone, rainfed Central zone and Southern zone, covering nine major states viz., Punjab, Haryana,

Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu. With the introduction of Bt-cotton cultivation in India since 2002 and its present successful country-wide coverage, bollworms are no longer significant yield limiting factors as they are under check due to the incorporated Bt-toxin except pink bollworm which occurs late late in the crop season. However, sucking pests continue to pose problems and farmers usually respond with indiscriminate pesticide sprays unduly escalating protection costs with concomitant decline in profitability. Pest incidence data records collected from a variety of trials conducted by 11 Main Centres and 10 Sub-Centres in North, Central, and South zones spanning 15 Agricultural Universities under the aegis of the All India Coordinated Cotton Improvement Project (AICCIIP) are available for the past 10 years or more. It is proposed to use these historical data sets for identified key pests in each zone for elucidating pest-weather relationships with an intention to develop prediction rules / forewarning models for application in pest management advisories on Bt cotton. Earlier such efforts were concentrated on pest data (predominantly bollworms) collected in the pre-Bt era (prior to 2005). Since sucking pests viz., especially the weather-driven insects: thrips and whiteflies have assumed importance on Bt cotton in recent years and pink bollworm is re-emerging as a pest, it is prudent to utilize the historical data sets on these pests collected both on non-Bt (prior to 2005) and on Bt cotton (after 2005) in modeling efforts as envisaged in the proposed project. Earlier under the NATP project and in several other projects across the country, location specific regression models were developed for whiteflies, jassid and pink bollworm on cotton. These location specific regression models will be tested for their effectiveness by laying out field experiments, recording pest incidence both under unprotected and protected conditions and also weather data as inputs to models in the first year. Developed new and refined models will be validated under field conditions in the second year.

Bollworm adaptability to Bt cotton

It is now widely acknowledged the world over that the benefits accrued from Bt-cotton outweigh risks substantially. However, one of the primary concerns of deployment of genetically engineered insect-resistant crops in a developing country like India, is the durability of resistance. Studies showed that *H. armigera* has a high capacity to develop resistance to Cry1Ac under laboratory selection. Development of bollworm resistance to Bt-toxins is considered to be an inevitable evolutionary eventuality, considering the intense selection pressure that Bt-cotton is likely to impose on the insects due to constitutive expression of toxins throughout the plant for the entire growing season. A progressive increase in the concentration of resistance



in the concentration of resistance

conferring alleles in pest populations due to sustained selection pressure, results in a concomitant decrease in the pest control efficacy of the transgenic crop. Ultimately, a complete control failure is expected when the frequency of resistant alleles in the pest population reaches 0.5. Resistance management strategies aim to conserve susceptible populations through a spatial or temporal restriction of toxin deployment. Preservation of susceptible alleles indefinitely would mean enforcing severe restrictions on the use of the technology that may curtail the benefits significantly. Hence a rational deployment of Bt-cotton to ensure at least 10–15 years of bollworm control efficacy would be in the best interests of the technology and the farming community. The development of insect resistance to toxins expressed in transgenic crop plants is affected by a number of interacting influences. Significant amongst these are genetic factors such as initial resistant allele frequencies, additive genetic variance, dominance, mode of inheritance, relative survival rates of the RR, RS and SS genotypes on the toxic and non-toxic plants, and all factors influencing Hardy–Weinberg equilibrium. Other factors such as relative host preference, natural survival, insecticide survival random mating, mating synchrony between resistant and susceptible genotypes, relative fitness of the genotypes and accessible abundance of non-toxic hosts, will have a significant impact on the dynamics of resistant allele changes. Resistance development is thus a complex phenomenon, which is governed by several variables. Modelling remains one of the few alternatives for exploring region-wide resistance to transgenic crops. Simulation models can integrate population genetics and population dynamics so as to assess the rate of development of resistance in field populations under any defined conditions. Many input parameters used in models are either inherently variable or are unmeasured in the real world. Hence model outputs cannot be treated as predictive. They assist in the identification of parameters that have the largest effects on resistance development. Once the critical factors and conditions responsible for rapid development of resistance are properly identified through simulation, it would then enable the development of proactive resistance management strategies. Implementation of such well defined strategies can ensure a rational spatial exposure of pests to the toxin, so that a steady source of sufficient susceptible alleles is made available to dilute the frequency of resistant alleles (drawn fully from the paper by Kranthi and Kranthi, 2005). We do not have similar models for the pink bollworm in India. However extensive research on pink bollworm modelling has been carried out in the US where the pest is a problem on Bt cotton. In fact reports of resistance to Cry 1Ac in *H.zea* are available. It is therefore important to develop stochastic models for pests such as the pink bollworm to single gene and dual gene transgenics in India where more than 90% of the area is under Bt cotton. In the absence of adoption of suitable refuge strategies, especially, the risk of resistance development runs high.

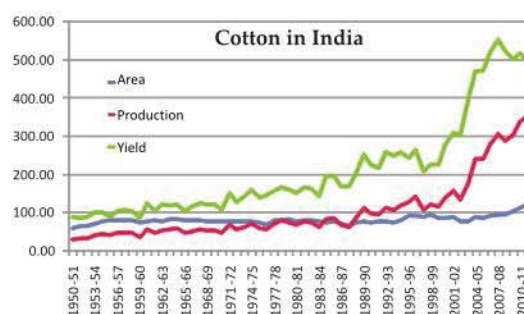
Cotton area production and Prices

The major reason for low yield in India is more than 65 % of cotton being rainfed and hence, year-to-year fluctuation in yield is too large. Though, soil, variety, weather, input use and crop management influence the cotton yield; under rainfed condition, weather has the

major bearing on yield. The present production estimations based on either the crop area sown and crop-cutting experiments show wide variability because of their inability to capture crop response to weather conditions. Unreliable production estimations are posing serious problem to planners to take timely import - export decisions. Reliable yield prediction methods are therefore needed to help planners and policy makers to take strategic decisions to safeguard the national interest.

Crop simulation models, which account for daily variation in weather, are being used to predict the year-to-year fluctuation in yield. Most of the available simulation models like, COTOM, GOSSYM-CALGOS etc are western models suited to narrow crop period for determinate type hirsutum varieties. In India sowing time of cotton stretches from Feb to Sept, grown in irrigated to low rainfall dry areas on shallow light soil to heavy black clay soil. Attempts were made to use these models for prediction of yield, however wide variations were found in observed and predicated yield. During the X and XIth plan period under Technology mission on cotton CICR in association with other co-opt centres successfully developed INFOCROP model for Cotton The model working on a simple generic model to simulate cotton production in tropical and sub-tropical environments. Infocrop satisfactorily simulates the effects of weather, soils, agronomic management (planting, nitrogen, residues and irrigation) on crop growth, yield, soil carbon, nitrogen, water, and greenhouse gas emissions but was not validated for insect pests. Therefore it was decided to adopt this model to simulate the growth and yield of cotton. However, crop simulation models, when run with input data from a specific field site, produce a point output which cannot directly be upscaled to a regional level. This is achieved by providing spatially varying inputs (soil, weather, crop management) using a geographic information system (GIS). The interfacing of models with GIS facilitates the temporal and spatial analysis of yield on a regional scale as crop behavior has a spatial dimension and simulation models produce a temporal output. The spatial distribution of the crop can be estimated quite accurately with remote sensing data. Thus, integration of crop simulation models with RS and GIS tools provide an accurate and scientific methodology for crop monitoring, modeling and forecasting of cotton production. With this preamble the present project is proposed to develop multifactor model – using suitable Econometric tools for yield forecasting, pest and disease surveillance across the agro-ecological zones.

The role of price information has long been a subject of study in economics. Producers need accurate price information to make production and marketing decisions. In turn, these decisions, directly and indirectly, have impacts on groups such as plant breeders and ginners, and vice versa. The importance of price information, however, is not limited to the production sector. Merchants have a stake in accurate price information to be able to effectively fill orders and demands by



textile mills. Textile mills need accurate price information to be able to minimize costs while producing products demanded by consumers. The more decision makers know about the market situation, the more likely that correct decisions will be made, but the information must be accurate to be of benefit to decision makers. Price is the most important economical factor which suppliers and demanders in each market especially in organized markets such as commodity exchanges base their decisions on. According to the importance of amount and direction of price changes, forecasting its future values is necessary for market participants. These forecasts will help the policy makers to take appropriate decisions.

Objectives

Development of pest scouting gadgets

- Evaluating available sensors (acoustic, chemical visual, biological) for diagnosis of biotic stress.
- Identification, characterization and quantification of temporal and spatial signals emitted due to biotic stress at different growth stages of cotton crop.
- Development of sensor based gadgets for diagnosis of biotic stress.
- Validation of sensor based gadgets at the field level in multi location trials.

Pest Models

- To create a database on historical pest and weather data sets available with AICCIP centres
- Analyze historical data to develop pest-weather relationships & models for use in pest management advisories
- Generate experimental data on missing gaps in knowledge on pest population dynamics required for model development
- To test and validate existing and new pest prediction models

Bollworm adaptability to Bt cotton

- Validation and refinement of available stochastic models on bollworm resistance to Bt-cotton
- Generation of input data on parameters that are not available in public domain for the bollworms.
- To develop stochastic models for pink bollworm resistance to Cry toxins.

Cotton area production and Prices

- To identify the physiological and agronomical parameter which influences yield enhancement
- To develop cotton yield prediction model
- To develop the database for the national and global cotton trade including production, consumption, export, import, prices, stocks etc.
- To develop an appropriate price model to forecast cotton prices

Technical programme

S.No.	Activities	Cooperating centres
Development of pest scouting gadgets		
1	Shortlisting of available sensors (biological, chemical visual, acoustic) for quantification of measurable biotic stress.	CICR, Nagpur CICR, Coimbatore
2	Procurement of different sensor based gadgets to detect volatiles & for quantification of measurable biotic stress.	
3	Prepare baseline crop-ecology parameters for healthy and stressed micro-environment	
4	Refine the existing sensor based gadgets or develop novel hand held gadgets based on biological, chemical, acoustic or visual sensors	
5	Develop pest and disease indices (ETL and EIL) for use of gadgets	
6	Validation of gadgets in multilocation trials	
Pest Models		
1	To generate a data base using historical data on insect pests, diseases and weather parameters.	CRIDA, Hyderabad; CICR, Nagpur CICR, Coimbatore; NCIPM, New Delhi
2	To analyze historical data to develop pest-weather relationships and models for use in pest management advisories	
3	Generate experimental data on missing gaps in knowledge on pest population dynamics required for model development	
4	Validation and refinement of existing Decision Support Systems to forecast/ forewarn cotton pests and diseases	
Bollworm adaptability to Bt cotton		
1	Generating input data for insect resistance modelling to Bt	ANGRAU, Hyderabad; CICR, Nagpur; CICR, Sirsa; UAS Raichur
2	Validation and refinement of stochastic models on bollworm resistance to Bt-cotton	
Cotton area production and Prices		
1.	Identify key variables and the extent to which they influence yield and prices	CICR, Coimbatore CICR, Nagpur NRSC, Hyderabad UAS Dharwad
2.	Collection of Data on key variables	
3.	Development of algorithms	
4.	Development of software models	
5.	Validation and refinement of the models	
6.	Predicting cotton area, production and prices	

Time frame

Sr. No.	Activity	Time frame									
		2012-13		2013-14		2014-15		2015-16		2016-17	
		I	II	I	II	I	II	I	II	I	II
	Development of pest scouting gadgets										
1	Shortlisting of available sensors (biological, chemical visual, acoustic) for measurement of volatiles being released by plants.										
2	Procurement of different sensor based gadgets to detect volatiles										
3	Prepare baseline crop-ecology parameters for healthy and stressed micro-environment										
4	Refine the existing sensor based gadgets or develop novel hand held gadgets based on biological, chemical, acoustic or visual sensors										
5	Develop pest and disease indices (ETL and EIL) for use of gadgets										
6	Validation of gadgets in multilocation trials										
	Pest Models										
1	To generate a data base using historical data on insect pests, diseases and weather parameters.										
2	To analyze historical data to develop pest-weather relationships and models for use in pest management advisories										
3	Generate experimental data on missing gaps in knowledge on pest population dynamics required for model development										
4	Validation and refinement of existing Decision Support Systems to forecast/forewarn cotton pests and diseases										
	Bollworm adaptability to Bt cotton										
1	Generating input data for insect resistance modelling to Bt										
2	Validation and refinement of stochastic models on bollworm resistance to Bt-cotton										

Sr. No.	Activity	Time frame									
		2012-13		2013-14		2014-15		2015-16		2016-17	
		I	II	I	II	I	II	I	II	I	II
	Cotton area production and Prices										
1	Identify key variables and the extent to which they influence yield and prices										
2	Collection of Data on Key variables										
3	Development of algorithms										
4	Development of software models										
5	Validation and refinement of the models										
6	Predicting cotton area, production and prices										

Output

- Sensor based gadgets for pest scouting.
- Models to predict insect infestation and/or disease outbreaks.
- Models to predict bollworm resistance to Bt toxin
- Models to predict cotton area, production and prices

