Scalable Climate Smart Technologies for Sustainable Rainfed Cotton Production In India

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INTRODUCTION

Cotton production is quite sensitive to climatic anomalies and to extreme weather events. Extreme weather events like prolonged dry spell, extended wet spell, heavy precipitation events have become more widespread in Central India (Roxy *et al.,* 2017) and Peninsular India where majority of the cotton is grown under rainfed conditions.

The indeterminate growth habit imparts a certain degree of resilience in cotton plants to biotic and abiotic stresses. The adverse impact of these stresses on the cotton yield depends upon the duration and severity of the stress and plant growth stage (Khan *et al.,* 2018). The inherent resilience can be enhanced by increasing the degree of adaptation through management interventions like selection of appropriate crop varieties, crop diversification, adjusting the planting pattern, and proper management of soil, water, pests and diseases (Olesen *et al.,* 2011, Macholdt *et al.,* 2019, Zampiery *et al.,* 2020 Zhang *et al.,* 2015).

Cotton 2040, a multi-stakeholder initiative recently observed that cotton production in all the six major cotton growing countries *viz*. India, USA, China, Brazil, Pakistan and Turkey are exposed to increased climate risk. A Climate Risk and Vulnerability Assessment study assessed the risk to cotton production and processing using 41 climate hazard variables and socio-economic indicators across the three major cotton growing states of India-Maharashtra, Gujarat and Telangana. The study indicated an increased stress and enhanced vulnerability in cotton production by 2040 than the present day conditions (source: https://www.preventionweb.net/news/fashioning-climate-resilient-cotton-sector). Climate smart technologies aimed at adaptation to climate variability and mitigation of climate change need to be validated and upscaled to moderate the adverse effects. While long term mitigation efforts to reduce the impact of climate change should continue, immediate focus should be on scaling up robust adaptation plans. In this context the paper discusses the following scalable technologies for climate resilience in rainfed cotton production systems-

- High density cotton planting system with early maturing genotypes.
- Long-linted *Gossypium arboreum* cotton for drought prone areas.
- Soil moisture conservation to harvest rainwater.
- Legume based intercropping systems for soil health and climate resilience.
- Pest and disease forecasting/forewarning/modelling.
- Remote sensing and pesticide delivery through UAVs.
- Pest and disease alerts and contingent advisory to farmers.
- Shredding of cotton stalks after harvest

High Density Planting System (HDPS) with early maturing genotypes

Currently, about 95% of the cotton area is planted with BG II hybrids. Majority of the popular hybrids are medium to long duration (180-200 days) and are planted at wide spacing of 90-120 cm between rows and 45-60 cm within row, thus accommodating a population of 14,000-24,000 plants/ha. The plants are robust with low harvest index (0.2-0.3%) and have a long fruiting window making the fruiting bodies vulnerable to both biotic and abiotic stresses (Kranthi, 2020). This system may not be ideal for shallow to medium deep soils, where cotton is cultivated under rainfed conditions, since the period of the crop's peak water requirement occurs during the post-monsoon period and the soil moisture retained is insufficient to meet the high water-demand, resulting in poor boll formation/retention and consequently low yields. Straight varieties of cotton are conventionally planted at 45,000-55,000 plants/ha but their area is less than 5%.

Figure-1. Field view of HDPS cotton at ICAR-CICR, Nagpur.

During 2009-10, ICAR-Central Institute for Cotton Research (CICR), Nagpur conceptualized an alternate high density planting system of cotton production wherein semi compact genotypes are planted at closer spacing of 60, 75/80 or 90 cm spacing between rows and 10-20 cm between plants (Venugopalan *et al.,* 2011, Venugopalan *et al.,* 2013). Originally plant densities varying from 1.0 lakh to 2.5 lakh plants / ha were evaluated and recommended (Venugopalan *et al.* 2013, Pradeep and Murthy, 2019). Today, considering the prospects of mechanization, architecture of available genotypes, plant density ranging from 74,000 to 110,000 plants/ha for *G. hirsutum* varieties and 60,000 to 74,000 plants/ha for hybrids is recommended. Experimental results indicated a strong three-way interaction between genotypes, soil depth and spacing.

ICAR-CICR in coordination with the research centers of All India Coordinated Project on Cotton evaluated more than 60 genotypes and identified the most appropriate genotypes (Table 1) for HDPS along with the most appropriate spacing for different locations. A complete production technology to retain first set bolls and hasten crop maturity was also developed (Venugopalan *et al.*, 2013). ICAR-CICR also standardized crop architecture management technique using mepiquat chloride applied in two equal splits @ 25 g ai/ha or in 3 splits @ 17 g ai/ha. Today, there is ample evidence to indicate that HDPS has the potential for enhancing the productivity of rainfed cotton, improve efficiency, reduce input costs and minimize risks associated with present cotton production system (Pradeep and Murthy, 2019). Recently, Kumar *et al.,* 2020 reviewed genetic, agronomic, plant protection interventions and prospects of HDPS and concluded that HDPS along with appropriate genotype and management is a viable approach to break the current stagnation in yield.

Table 1. Suitable genotypes for HDPS

State	Genotype
Punjab	F2381, F 2383
Haryana	CSH 3075, F 2383
Gujarat	G Cot 16, CCH 12-2 (Suchitra)
Madhya Pradesh	CCH 12-2 (Suchitra)
Odisha	BS 29, BS 279
Maharashtra	PKV 081, NH 615, Suraj, Suchitra, Phule Dhanwantari, Suraksha, PA 812, PA 810 and PA 740
Andhra Pradesh and Telangana	ADB 39, NDLH 1938, ADB 542, Subiksha, Suraksha
Karnataka	ARBC 1601, ARBC 1651, DSC 99
Tamilnadu	Co 17, Co 15, Anjali, KC 3, Subiksha, Suraksha

More than 5000 demonstrations were undertaken between 2012-13 and 2016-17 in 30 districts of 11 cotton growing states – Punjab, Haryana, Gujarat, Rajasthan, Madhya Pradesh, Maharashtra, Telangana, Odisha, Karnataka, Andhra Pradesh and Tamilnadu under varying soil and climatic regimes. The technology received mixed success but showed consistent (more than 20%) higher yields on shallow to medium deep soils, under low moisture conditions and in drought years. The crop matured 10-15 days earlier than when planted at conventional spacing. Another clear pointer was that canopy management using growth retardants and retention of early formed bolls were pre-requisites to success of this system, particularly on deep fertile soils and during seasons receiving more than normal rainfall.

A spin-off of HDPS technology was a change in the agenda of cotton breeders of both public and private sector to focus on early maturing, compact plant types suitable for HDPS with emphasis on more bolls per unit area than robust plants with more bolls per plant. Both public sector and private seed companies have developed some good compact early maturing hybrids for HDPS and are demonstrating this technology with fair degree of success (Kannan *et al.,* 2022). HDPS demonstrations in Rajasthan indicated that a spacing 80 cm x 15 cm with a plant population of 83333 plants/ha yielded 26.14 q/ha, an increase of 50.85% over the production in check plots with conventional planting (CITI-CDRA 2018). Unlike varieties, the high cost of hybrid seed is a concern for upscaling.

There are about 38 lakh ha in 20 districts across states of Maharashtra, Telangana and Madhya Pradesh where the current cotton productivity is less than 300 kg lint/ha and the risk of crop failure due to rainfall aberrations is high. Cotton is predominantly cultivated under rainfed conditions in these districts where most of the soils are shallow to medium deep. Priority is to up-scale the HDPS technology with Bt varieties/hybrids and long-linted *Gossypium arboreum* varieties, each tailored with location specific crop management technology. This would help in breaking yield barriers, effectively combat the serious menace of PBW, lower the unit production cost and climate proof the rainfed cotton farmer. The technology would also facilitate mechanical harvesting of cotton. HDPS is becoming popular in rainfed areas and in the summer-cotton growing areas of Cauvery River delta of Tamilnadu, where the growing season is short.

Long-linted *Gossypium arboreum* cotton for drought prone areas

It is widely acknowledged that *G. arboreum* is not only a reservoir of important stress resistance genes, but it is well adapted to dry land, low inputs conditions. Long-term research at ICAR-Central Institute for Cotton Research, Nagpur (1986-2000) clearly demonstrated that under rainfed conditions, yield under monocropping of *G. arboreum* cotton was higher than that of *G. hirsutum* cotton in 13 out of 15 years (Figure 1) across a wide range of rainfall conditions and nutrient management regimes (Venugopalan and Pundarikakshudu 1999 and Venugopalan *et al.,* 2003). From the same study Tiwary *et. al.,* (2013) concluded that the Sustainable Yield Index, an index for climate resilience, across nutrient regimes was also higher for *G. arboreum* (0.18 to 0.60) as compared to *G. hirsutum* (0.15 to 0.49). Stability index, another index for climate resilience was also higher for *G. arboreum* (Blaise *et al.,* 2006).

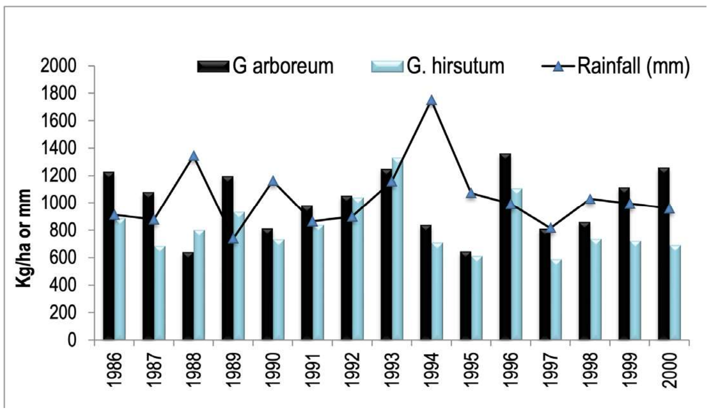

Figure 2. Seed cotton yield of *G. arboreum* and *G. hirsutum* cotton varieties on rainfed Vertisols

Unlike *G. hirsutum*, the *G. arboreum* cottons are more tolerant to sucking pests, drought, salinity and are immune to the cotton leaf curl virus disease. Despite these virtues, the *G. arboreum* cottons were not preferred due to their poor locule retention, small boll size, longer duration and bushy plant type and inferior fibre quality that fetched lower price. Nevertheless, few high yielding *G. arboreum* varieties like RG 8, LD 327, AKA 8401, AKA 7, JK 5, Y1, Jawahar Tapti, JK 5, K 10, K11, G Cot 15, Mahanandi along with a few varieties from the Private sector are still grown in isolated pockets.

Breeding efforts with *G. arboreum* in the last two decades resulted in development of superior *G. arboreum* varieties with good fibre properties and better locule retention. These include – Parbhani Thurab (PA 255), Vinayak (PA 402), Rohini (Na 48), Sawata (PA 183), DLSa 17, and K 12 with fibre length of 26-28 mm and fibre strength of 21-23 g/tex making them spinnable at 30s to 40s counts. More recently, some improved cultures like PA 812, PA 785, PA 778 and PA 740 with 29-30 mm fibre length and good fibre strength have been developed (Chinchane and Baig 2018). A recent study at ICAR-CICR indicated that the yield from these *G. arboreum* genotypes can be enhanced under High Density Planting System (Venugopalan *et al.,* 2018), and the varieties can be planted at 60x10 cm spacing on medium deep soils. Blaise *et al.,* (2020) recommended an optimum plant density of 2.21 lakh plants/ha for Phule Dhanwantary, a coarse *G. arboreum* variety suitable for surgical cotton production.

These developments indicate that in the era of climate change and market uncertainty, a revival *of G arboreum* cotton would offer a cost effective, sustainable (long-term) and resilient (short-term) alternative. There is a genotype x environment interaction in long-linted *G. arboreum* cotton for yield, fibre quality and agronomic traits (Venugopalan *et al*. 2021) and this interaction can be exploited to recommend the most appropriate varieties for specific agroecological situations and upscale this technology, particularly in the drought prone areas of Central Maharashtra.

Soil moisture conservation to harvest rainwater

Erratic monsoon is a norm in the rainfed cotton growing areas. Short heavy spells of rainfall are interspersed by dry spells. Under such conditions, the success of rainfed cotton production depends on the ability to capture rainwater store it in the soil profile or recycle it from harvested structures.

A variety of *in-situ* soil moisture conservation measures like contour bunding, land shaping (ridge furrow, open furrow, broad bed furrow) bench terracing and agronomic measures like-tillage (sub soiling, conservation tillage), cover crops and intercrops have been recommended. These measures reduce the impact of raindrops, alter run-off, increase infiltration rate and water absorption and/or reduce evapotranspiration (Kumawat *et al.,* 2020). Slope of land, soil type, planting geometry and rainfall characteristics govern the choice of most appropriate technique.

Table 2 provides a summary of some soil moistures conservation measures recommended/adopted for cotton. *In-situ* soil moisture conservation techniques include contour bunding, graded, narrow or broad ridges or beds separated by furrows, ridges and furrow, opening of furrow after every row/alternate row of cotton, black polythene mulching (25 microns) and spreading of crop residue were found to be promising for rainfed cotton (Sankaranarayanan *et al.,*2010).

Harvesting excess runoff water and reusing them for life saving irrigation at the critical stage between peak flowering and peak boll development can increase yield of rainfed cotton by 4-8 q/ha and increase rainwater use efficiency (Bhaskar *et al.,* 1998).

Intercropping systems for soil health and climate resilience

Intercropping in cotton is a strategy to combat crop failure, improve productivity and profitability. It can strengthen and stabilize production systems under climate change by improving resource use efficiency, enhancing soil water holding capacity and increasing the diversity and quality of habitat for beneficial insects, including pollinators (Huss *et al.,* 2022).

Table 2. Effect of in-situ soil moisture conservation measures on the performance of rainfed cotton

	Location, Situation	Soil moisture conservation technique	Results	References
1	Nagpur, Maharashtra. Hot, semi-arid eco-region with very deep black soil	Ridge and furrow + recycling of water	Ridge and furrow + recycling of water gave 4.6 q/ha more yield than flatbed (8.9 q/ha)	Bhaskar *et al.*, 2005
2	Hyderabad, Telangana. Hot, semi-arid eco-region with sandy loam red soil	Poly mulch on broad bed furrow	521 kg /ha more yield than flat bed. Higher BC ratio of 1.76 compared to 1.49 in flat bed.	Pragathi Kumari *et al.*, 2018
3	Parbhani, Maharashtra. Hot, semi-arid eco-region with deep black soil	Cotton+soybean intercropping	Higher seed cotton equivalent yield, Net return and B:C ratio compared to opening of furrows or straw mulch	Gokhale *et al.*, 2012
4	Virudhunagar, Tamilnadu. Hot, semi-arid eco-region with medium deep Vertisol.	Broad bed and furrows	Broad bed and furrows gave 8.3% and 17.7% higher seed cotton yield over ridges and furrows and compartmental bunding, respectively.	Ashraf *et al.*, 2020
5	Raichur, Karnataka. Hot, arid eco-region with deep black soil	Ridges and furrows	Higher seed cotton yield with ridges and furrows (2403 Kg/ha) as compared to broad bed and furrows (2222 Kg/ha) and flatbed sowing (1743 Kg/ha).	Ambika *et al.*, 2017
6	Akola, Maharashtra. Hot, semi-arid eco-region with medium deep black soil	Broad bed and furrows	Broad Bed Furrow gave higher seed cotton yield, net returns and B:C ratio than flat sowing, opening of furrow at 40-60 days after sowing	Paslawar and Deotalu 2015
7	Junagarh, Gujarat. Hot, semi-arid eco-region with deep black, clayey soil	Ridge + furrow system with plastic mulch (25 micron)	Sowing Bt. cotton at the distance of 120 cm x 45 cm with ridge and furrow was superior to broad bed and furrow. mulch (25 micron) was superior to straw mulch@5T/ha	Vekaria *et al.*, 2020
8	Perambalur, Tamil Nadu. Hot, semi-arid eco-region with deep black clay	Incorporating coir pith (5 tons/ha) + Broad bed furrow	Incorporating coir pith (5 tons/ha) was superior to summer/chisel ploughing. Broad bed furrow was superior to ridge furrows, tied ridges and basin listing.	Vivek *et al.*, 2017
9	Nagpur, Maharashtra. Hot, dry subhumid eco-region with medium deep black soil	Bio-mulch with sesbania + ridges after second interculture at 50-55 days.	Seed cotton yield with flatbed system was 1198 kg/ha. Additional 299 kg/ha was realized with bio-mulch and 300 kg/ha was realized when ridges were made.	Venugopalan 2019
10	Nagpur, hot, dry sub-humid eco-region with very deep black soil	Growing intercrop (sorghum/ sunn hemp) and retaining its residues as in-situ mulch	In situ mulch between the cotton rows improved soil microstructure, water stable aggregation and infiltration rate, and helps in soil moisture conservation	Blaise *et al.*, 2021

Cotton is a long duration, widely spaced crop. It grows slowly during the initial two months. The inter-row spaces remain bare during this period; the soil in the inter-row space is either exposed to lashing rains causing loss of topsoil due to erosion or the space is filled with weeds that compete with the crop for resources and their management adds to the cost of cultivation.

The inter-row space can be favourably utilized by growing a variety of intercrops (Table 3). In some cases, the yield of cotton is slightly reduced, but the combined yield and net returns is in favour of intercropping systems. A wide range of crops including cereals, pulses, oilseeds, vegetables and flowers have been tested as intercrops with cotton (Gopalakrishnan *et al.,* 2010). The choice of intercropping system is usually based on soil type, local climate, economic situation and preference of the farmers.

Table 3: Intercropping systems recommended in rainfed cotton

State	Intercropping
Madhya Pradesh	cotton + black gram (1:1 or 2:1), cotton +soybean (2:1)
Gujarat	cotton + groundnut, cotton + black gram, cotton + sesame
Maharashtra	cotton + green gram, black gram, cotton + soybean, cotton + groundnut, cotton+ red gram (strip cropping), cotton + cowpea
Odisha	cotton + red gram
Karnataka	cotton+ chilly/onion (irrigated)
Tamil Nadu	cotton + onion, cotton + groundnut, cotton + black gram (paired row), cotton + horse gram, cotton + minor millets
Andhra Pradesh	cotton + black gram (1: 2), cotton + pigeon pea, cotton+ chili, cotton+ soybean
Telangana	cotton + green gram, cotton + soybean

Studies from different locations across India over several years indicate that 200-600 kg/ha of yield from intercrop can be harvested without adversely affecting the main crop of cotton (Venugopalan, 2021). Positive soil nitrogen balance was also observed in several cotton+ legume intercropping studies. A summary of the results of 60 on-farm demonstrations on intercropping, with green gram and black gram, conducted in Aurangabad district, Maharashtra, during 2014-2016, presented in Table 4 indicates the advantages of intercropping cotton with green gram and black gram in monetary terms (Zade *et al.* 2020).

Table 4: Yield and economics of demonstrations of cotton + pulse intercropping system in farmers' fields

System	Cotton yield (kg/ha)	Intercrop yield (kg/ha)	Gross returns (Rs/ha)
Sole cotton	1567	-	73050
Cotton + green gram	1490	627	99324
Cotton + black gram	1441	505	94098

Intercropping of rainfed cotton is an important scalable risk minimizing and climate proofing strategy. Access to seeds of appropriate varieties of intercrops and farm implements is to be ensured through institutional support for wider adoption of intercropping.

Pest & disease forecasting/forewarning/modelling

Cotton crop is infested by several insect pests and diseases. Cotton cultivation in India has a history of experiencing and dealing with pesticide resistance (bollworm, leaf hopper), pest resurgence (whitefly) and emergence of new / invasive insect pests (mealy bugs). Prior to introduction of Bt cotton, focus was on bollworm control and cotton consumed 49% of the total value and 40% of the total volume of insecticides used in India in 1997. By 2018, insecticide usage share in Bt cotton declined to 18% of value and 20% of volume of the total insecticides used in India (ICAC Recorder March 2020). In recent years, field surveys indicated that greater number of insecticidal sprays is directed against management of sucking pests such as leaf hopper, thrips and whitefly. Among bollworms, Bt cotton (BG II) resistant populations of pink bollworm are widely spread out across all the cotton growing zones and the pest is a serious threat to cotton productivity and fibre quality. In addition to management woes, outbreak of sucking pests and diseases such as boll rot and fungal diseases is also aggravated due to changing climate.

Irrigated cotton is predominantly cultivated in about 1.7 M ha in the north zone states of Punjab, Haryana and Rajasthan. More than 65% of cotton cultivated (>8.0 M ha) is in the rainfed tracts of the central and southern zones which is facing increased frequency of extreme weather events. Dry spell conditions coupled with warmer temperatures during July-August; cloudy weather and excess rainfall during September/October are being experienced since 2018. Increased occurrence of leaf spots, grey mildew, internal and external boll rot is observed, probably aided by excess vegetative growth and high humidity in the crop canopy in heavy soils. Climate forecasts coupled with pest forecast/ forewarning of impending pest and disease outbreaks can help farmers cope with variable climate.

Phenology models and pest distribution maps are crucial for understanding seasonal dynamics and formulation of climate smart pest management technologies that can manage and prevent spread of both native and invasive pests of cotton. Insect phenology modelling has been applied for understanding bio-ecology, population dynamics and pest prediction in case of the invasive mealy bug, *Phenococcus solenopsis* Tinsley (Prasad *et al.*, 2012, Sreedevi *et al.*, 2013, Peddu *et al.*, 2020) and pink bollworm (Fand *et al.*, 2021). Spatial risk maps and GIS tools have been applied to map potential distribution of whitefly (Prabhulinga *et al.*, 2017) and the invasive solenopsis mealybug due to changing climate (Fand *et al.*, 2014). A degree day-based model using data of adult male moth catches across survey locations has been devised to predict pink bollworm activity in cotton. The timing of third brood of pink bollworm based on accumulated heat units has been identified for executing management/ insecticidal spray decisions (Fand *et al.*, 2021). Superimposed weather maps with historical and in season pest density data at weekly intervals from crop pest surveillance and advisory project (CROPSAP) operational since 2010 in the largest cotton growing state of Maharashtra are in use by extension functionaries and researchers engaged in issue of pest alerts (Crop Pest DSS, http://www.icar- crida.res.in:8080/naip/gismaps.jsp accessed on 15 June 2022).

Remote sensing & pesticide delivery through UAVs

Detection of crop stress is one of the major applications of remote sensing in agriculture. Spectral signatures of pest and disease infested cotton canopy can help in detection of stress in a geospatial perspective and the mapped locations can be made use for precise delivery of pesticides. In case of cotton, hyper-spectral vegetation indices have been developed for detection of stress due to leafhopper and mealy bug infestation (Prabhakar *et al.*, 2011 and 2013). These vegetation indices based on hyper-spectral/ multi-spectral radiometry have potential use in precision delivery of pesticides in cotton. Use of drones in agriculture is currently gaining momentum in a favorable policy environment unfolding in India. Field spray operations are sometimes impossible immediately after a wet spell of rains in black cotton soils of the central cotton belt. Drone based pesticide sprays could therefore come handy in such situations arising in the aftermath of inclement weather. Area-wide management of insect pests and diseases is thus facilitated in a timely manner, thereby can prevent spread and limit severity of crop damage. Also, foliar sprays of nutrients and plant growth regulators can help retain early formed fruiting bodies thereby eventually leading to timely crop termination. Adoption of integrated crop management practices has the potential to prevent unwarranted extension of crop season for taking up additional harvests /pickings to compensate any yield loss experienced at the time of first picking and thereby also limit pink bollworm population build up late in the season (Dec-Jan).

Table 5. Key insect pests and diseases of cotton triggered and driven by climate variables

Insect pest/ disease	Diagnostic symptom	Crop stage	Peak window	Congenial weather	Reference
Leafhopper *Amrasca biguttula biguttula* (Ishida)	Hopperburn on leaves	Squaring to flowering	July-Aug	Hot humid conditions, intermittent rains, fewer BSS	Patel and Radadia, 2018
Thrips *Thrips tabaci* Lind	Rusty patches on underside of leaves	Squaring, flowering, boll development	July-Aug	Dry weather, higher than normal temperature	Nemade et al., 2018
Aphids *Aphis gossypii* Glover	Crumpling and downward curling of leaves, honey dew and sooty mold	Seedling and boll opening	July/ Dec	Lower than normal temperature	Vennila et al., 2000
Whitefly *Bemisia tabaci* (Gennadius)	Honey dew, sooty mold	Boll development and maturity	Aug/Sep	Dry weather	Prabhulinga et al., 2017, Kranthi, 2015
Root rot (*R. solani* and other spp.)	Drooping of leaves and wilting	Seedling	May/June in North Zone June/July in central zone	High soil moisture and high temperature	Monga et al., 2007
Myrothecium leaf spot (*Myrothecium roridum*)	Small, circular, light brown spots, later shot holes	Seedling to squaring	July-Aug	High relative humidity and warm temperature (28-36°C)	
Corynespora leaf spot (*Corynespora cassicola, C. torulasa*)	Circular to irregular, dark red spots on leaf which turn to brown lesions with dark border (target board appearance)	Squaring to Flowering	Aug-Sep	High relative humidity and warm temperatures (>32°C)	Salunkhe et al., 2019
Bacterial leaf blight (*Xanthomonas citri* pv. malvacearum)	Water soaked, circular light to dark green, small spots on leaves, Angular leaf spot, black arm, vein blight and boll rot	Squaring to flowering	Aug-Sep	Windyand rain splashes, high relative humidity (>90%)	Sandipan et al. 2016
Alternaria leaf spot (*Alternaria macrospora, A.alternata*)	Brown or tan spots on cotyledons, leaves, bracts and bolls, concentric rings coalescing into blighted leaf	Flowering, boll development	Aug-Sep	High relative humidity and intermittent rainfall, optimum temperature (20-30°C)	Prasad et al. 2019
Grey mildew/ Areolate mildew (*Ramularia areola*)	Pale, irregular and angular white spots delimited by veinlets. Dirty white powdery growth on leaf, yellowing and premature defoliation	Boll development	Oct/Nov	High relative humidity, intermittent rains and Low temperature (20-30°C)	Bhattiprolu et al. 2017,
Boll rot complex (phyto-pathogenic fungi, bacteria and saprophytes)	Internal boll rot – discoloration in developing fibers and immature seeds, yellowish to brown, slimy swollen appearance. Fungal/external rot- Light brown or black spots may cover entire boll with growth of mycelia	Flowering and boll development	Aug-Nov	High relative humidity, low light intensity, warm and rainy weather (>95relative humidity)	Nagrale et al. 2020

Pest, disease alerts & contingent advisory to farmers

Information and knowledge on crop-pest-disease weather relationships in cotton are being used for issuing pest management advisories linked to weather forecast (http://cicr.org.in/weekly_advisory.htm accessed on 15 June 2022).

The weekly advisories are based on knowledge generated by researchers across the country (Table 5) and are closely linked to the crop window based pest management strategy developed for cotton.

Voice messages in local languages are being delivered to registered farmers under the Insect Resistance Management (IRM) project funded by the National Food Security Mission on Commercial Crops (Cotton).

Figure-3. Long linted *G. arboreum* variety PA 812

Figure-4. Long linted *G. arboreum* variety PA 812 at harvest

Shredding & incorporating cotton stalks

Crop residue incorporation is an effective adaptation option for mitigating the impacts of climate change. It improves WUE, and this practice is more effective in hot and dry environments (Liu *et al.,* 2017). In the long run it has the potential to improve soil health. Around 26 million tonnes of cotton plant stalks are generated annually in India. Cotton stalks contain about 67.3-70% hemi cellulose, 24.3-28.2% lignin and 5.9-8.3% ash. They are rich in nutrients with 51.0% C, 4.9% H, 0.62-1.0% N, 0.61-0.68% K, 0.08- 0.1% P, 0.43% Ca, 0.15% S and 0.12% Mg, 324 ppm Fe, 147 ppm Mn, 27 ppm Zn, 9 ppm Cu and 1.6 ppm of Mo (Dubey *et al.*, 2004; Sutaria *et al.*, 2016). Cotton stalk is harder and stiffer than most other annual crop stalks and hence need to be shredded before incorporation for decomposition.

Figure-5. Shredding of cotton stalks after harvest.

A multi-crop shredder operated by any ≥ 45 HP tractor with dual clutch and powered by PTO with 540/1000 rpm can be used to shred cotton stalks after final picking. Cotton stalks from 1 ha can be shred in 2.5 h. A rainfed cotton field yielding 2 tonnes/ha stalk when shred and incorporated can recycle 12.4-20.0 kg N, 1.6-2.0 kg P2O5 and 12.2-13.6 kg K2O/ha, besides improving the water holding capacity of the soil (Ramanjaneyulu *et al.,* 2021).

Incorporation of shred residues increased hydraulic conductivity, decreased bulk density, increased available NPK and organic carbon in the soil (Senthilkumar and Thilagam, 2015). Microbial formulations are available for spraying to accelerate the decomposition of cotton stalks and these are found useful in semi-arid eco-regions. Shredding cotton stalks would also be useful in controlling the pink boll worm.

Climate change is adversely affecting the quality of land resources and impacting the livelihood of farmers. Simple, scalable climate smart technologies presented herein have the potential impart climate resilience and improve cotton productivity. Engaging with multiple stakeholders along the cotton value chain is essential to spread awareness among cotton farmers about these technologies and facilitate their subsequent adoption.

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