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Editorial

It is widely acknowledged that the future of agriculture is under threat because our soils are degrading. The FAO states that "*Although soils are essential for human well-being and the sustainability of life on the planet, they are threatened on all continents by natural erosion*"

Soil provides food for life and is home to more than a quarter of our biodiversity. A simple operation of tillage can destroy the soil cover, remove the fertile topsoil, cause erosion and degradation of diversity within a just a few days to undo the creation of the organic matter in the 15cm to 20cm topsoil that has taken thousands of years to form. Excessive dependence on synthetic agrochemicals can lead to further erosion and disruption of biodiversity and ecosystem services by soil flora and fauna. FAO states that by 2050, soil erosion may reduce crop yields up to 10 per cent, which is equivalent to removing millions of hectares of land from crop production. Overexploitation of natural resources by humans today for food, clothing, shelter, transportation, comforts and luxury not only worsens the effects of climate change today but also threatens the future.

Modern agriculture depends on fossil fuels and agrochemicals to increase productivity. It is not uncommon to see agricultural scientists justifying the imperative dependence on agrochemicals such as synthetic fertilizers and pesticides, genetically modified crops, irrigation, tillage and energy intensive practices on the pretext of meeting the current needs and gearing up for the future to feed the impending burgeoning population. It is paradoxical in many ways that we justify our dependence on fossil fuels to meet our current needs, knowing fully well that the more we use now, the more problems we create, that which may necessitate still more dependence on fossil fuels in the future only to aggravate the problems further. Beyond doubt, global commitments and determined actions by major polluting nations could lessen the damage by reducing greenhouse gas emissions and by increasing carbon sequestration through regenerative practices.

Agricultural practices are responsible for emission of more than 9.0 Giga tonnes (Gt) of CO2 equivalent greenhouse gases (GHGs) every year. While crop lands including rice cultivation are responsible for only about 15% of the total agricultural GHG emissions, 31% of emissions are from livestock and manure and 23% emission are of nitrous oxide from nitrogenous fertilizers. The production of nitrogenous ammonia fertilizer from fossil fuels is reported to consume 1.0% of the total global energy use annually. Ironically, agricultural scientists are fully aware that legume crops can capture nitrogen from the atmosphere in quantities in far more inexpensive manner that can greatly exceed the total needs met from synthetic nitrogenous fertilizers. However, in a fast-moving world, quick fixes look more attractive than durable long-term solutions

It is also well known that regenerative agricultural practices benefit soil health. Better soil health is the bedrock of sustainable agriculture. Enriching soils with organic matter such as composts and manures not only create ideal conditions for survival and growth of soil organisms and increased availability of nutrients for plants, but also improves soil structure that is better aerated for the growth of beneficial microorganisms that antagonize harmful plant pathogens. Moreover, soils with good aeration operate as net sinks of methane due to methane utilization by methanotrophic bacteria that colonize aerobic soils. Healthy soils foster healthy vegetation that captures more carbon and promotes the growth of soil microorganisms that sequester more carbon and also greatly reduce greenhouse gas emissions. Therefore, a combination of regenerative agricultural practices plus enrichment of soils with composts and manure can contribute towards mitigation of climate change effects..

This edition of the ICAC RECORDER carries four articles that describe solutions and approaches to mitigate climate change and to rejuvenate soil health. The first two articles deal with climate-smart solutions, commitments, strategies and efforts that are underway in India and Bangladesh, while the last two articles focus on the importance of rejuvenating soil health with organic matter in the form of compost. All the four articles address the issue of enhancing carbon sequestration by enriching soils with organic matter to improve soil heath and reducing GHG emissions through regenerative agricultural practices. It is clear, that with half-hearted efforts, weak Government commitments, the technical solutions available at hand will fall short in combating the humongous problem of atmospheric CO2 that we created over the past hundred years. We may be filling small mugs with water with plans to place them in the tiny hands of our children in our preparedness to douse a huge wild forest fire. Hope the world wakes up in time before it is too late to douse the fire.

– Keshav Kranthi

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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).

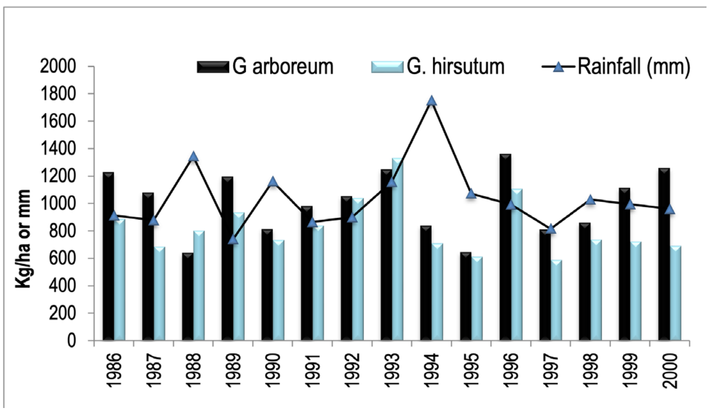

Figure 2. Seed cotton yield of *G. arboreum* and *G. hirsutum* cotton varieties on rainfed Vertisols

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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Application of Climate Smart Technologies for Sustainable Cotton Production In Bangladesh

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INTRODUCTION

Bangladesh is one of the largest deltas of the world and its rivers and floodplains support life, agriculture, livelihood, and economy. The country is defined by the fertile alluvial delta, with almost a third of the country lying in less than five meters above sea level. However, the coastal zone, the low-lying area, is highly vulnerable, especially to cyclones and storm surges. In addition, salt-water intrusion, floods, sea level rise, thunder intensify the vulnerability of the community of the areas. These problems are likely to become even worse due to climate change adverse impact.

Bangladesh's Delta Plan 2100 (BDP 2100) takes into consideration the unique long-term challenges for development outcomes presented by climate change and natural hazards. In Delta Plan 2100, there are six geographic hotspots: 1) Coastal Zone 2) Barind Tract and Drought Prone Areas 3) Haor and Flash Flood Areas 4) Chattogram Hill Tracts 5) River System and Estuaries and 6) Urban Areas.

The BDP 2100 seeks to integrate the medium- to long-term aspirations of Bangladesh to achieve upper middle income (UMIC) status and eliminate extreme poverty by 2030. From there the goal is a prosperous country beyond 2041 with the longer-term challenge of sustainable management of water, ecology, environment, and land resources in the context of their interaction with natural disasters and climate change.

Figure.1 Cotton is a livelihood crop in Bangladesh

Bangladesh faces increasing catastrophic impacts of climate change that could result in a 6.8% loss in GDP per year by 2030 if not addressed. For this reason, we need to build Bangladesh's resilience to make sure that these impacts do not affect the country's prosperity. Thus, the Mujib Climate Prosperity Plan Decade 2030 includes several ambitious new and strengthened adaptation efforts to build resilience in populations and ecosystems. Minimizing and averting loss and damage is at the heart of this plan. Mujib plan also serves as the nation's climate resilience strategy and co-benefits from long-term low GHG emissions.

THE CLOTHING HERITAGE

Bangladesh has a rich heritage in clothing during the 17^{th}-18^{th} century. Muslin cloth was the finest ever fabric produced in handlooms by the local weavers, made from the cotton cultivated in Bengal (Currently Bangladesh) during Mughal Empire. Dhaka muslin is a cotton fabric of plain weave. Hand-woven from an uncommon and delicate yarn, it was found in Bangladesh and as a favourite of the Romans, muslin was sought by merchants of the Roman Empire and subsequently reached other parts of Europe. Muslin was exported to Europe in 17^{th} and 18^{th} century. After independence of Bangladesh in 1971, readymade garments export started in the early 80's and are now exported all over the world, contributing to more than 80% of all exports from Bangladesh.

With the growth of readymade garments (RMG) export, investment in backward linkage industries (i.e. dyeing & finishing, weaving and knitting, and spinning) also grew steadily. The total investment by 2020 in Primary Textile Sector (PTS) in Bangladesh was US$ 12 billion and more investment is expected.

Figure-2. Comparative statement on export of readymade garments (RMG) versus all other commodities exported by Bangladesh. Value in Million US$. Source: Export Promotion Bureau (EPB) Compiled by BGMEA

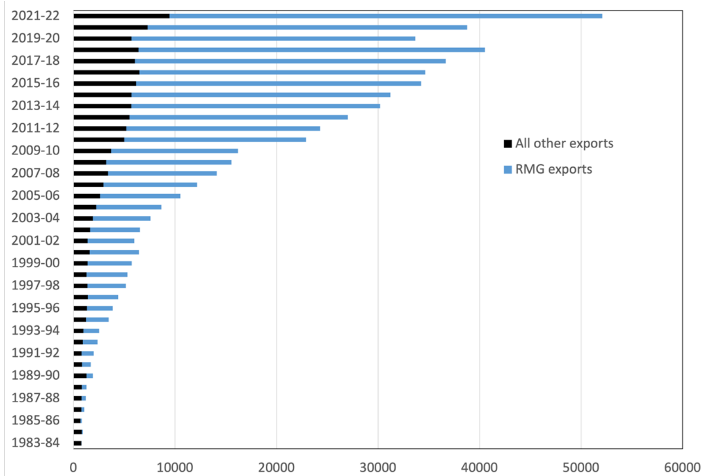

Figure-3. A snapshot of PTS of Bangladesh, Source: BTMA, November 2021

Yarn manufacturing mills:	500
Installed spindles 14 million	Rotor: 0.24 million
Yarn annual production capacity:	3,270 Million kg
Fabric Manufacturing (Annual capacity)	
Woven:	4,100 Million Meters
Knit:	3,690 Million Meters
Dyeing/Printing/Finishing (Annual capacity):	4,000 Million Meters
Total investment in PTS:	Around $12 Billion USD

Demand for 80% and 40% of knit and woven fabrics required by export-oriented garments industry is supplied by primary textile sector (PTS) while 90% of yarn is supplied by export oriented local spinning mills.

Primary textile sector is vertically integrated in cotton but not in synthetic yarn and fabric. Value addition in knit fabrics is more while woven is import dependent. Due to graduation from LDC to middle-income country, 'Two stage transformation' would be required after 2026 (With the three-year grace period 2029). This would induce development in backward linkage in synthetic fabric other fabrics that are currently based on imported fabrics which would also create scope for new investment in dyeing & finishing, fabric, yarn, and fibre.

The demand gap of yarn is mostly for synthetic, specialty and woven yarn. Woven garments are mostly based on imported fabric so are the active and sportswear fabrics of knit garments export.

It is interesting that although the share of cotton with respect to global production of fibre is only 24.2% (As per Textile Exchange Preferred Fibre & Materials Market Report 2020), global demand for cotton for spinning and weaving is 55% (As per ITMF 2016 Report). In Bangladesh, the share of cotton is 89% (As per BTMA) of the total fibre imported for spinning.

Table-1. A snapshot of demand-supply situation of yarn in Bangladesh (Source: BTMA) Values in Million Kg

Period	Production (In Mil kg)	Consumption (In Mil kg)	Gap (Consumption - Production) (In Mil kg)
2017	894	1,043	149
2018	1,004	1,189	185
2019	1,545	2,189	644
2020	1,570	2,212	642

Figure-4. A snapshot of demand-supply situation of yarn in Bangladesh (Source: BTMA) Values in Million Kg

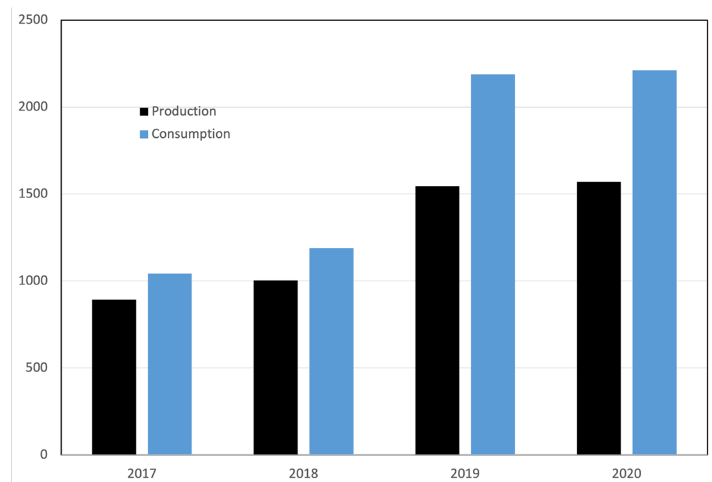

Table-2. A snapshot of import of raw materials for spinning in 2020 (Source: BTMA).

S.No	Description of raw material	Import (In Mil kg)	% of total import
1	Cotton Fiber	1,401	89.0%
2	PSF Fiber	97	6.2%
3	Viscose (VSF) Fiber	71	4.5%
4	Modal/Tensile/Lyocell Fiber	6	0.4%
	Total	1,575	100.0%

As per BTMA, the annual cotton requirement of spinning industry in future would remain roughly 8-10 million bales and mostly imported from different countries like India, Africa, USA, Australia, CIS, etc.

JOURNEY TOWARDS SUSTAINABLE COTTON CULTIVATION

Bangladesh has very limited agricultural land (8.5 million ha) and cotton competes with other high value crops for this scarce land resource. Most of the farmers grow cotton under rainfed condition while a few apply one or two supplementary irrigations for better yield. Smallholder farmers generally include short duration intercrops such as red amaranths, radish, mung bean, coriander leaf within cotton rows.

Bangladesh is regarded as a country where agriculture is highly vulnerable to the unpredictability of weather patterns (Erratic rainfall, flooding, and seasonal drought) that result from climate change. Against this backdrop, to better understand the potential for the sustainable expansion of cotton production in Bangladesh, we examine the cotton's agricultural value chain and projected climate risks associated with different phases of the chain. We identified associated stakeholders at different phases of cotton production, engaged with them to understand climatic and non-climatic threats and developed an integrated set of recommendations for climate-risk management by improving the connection of producers to markets, increasing economic returns to small farmers, and improving efficiency along the value chain. We discussed our estimated climate projections with stakeholders to understand the challenges at different stages of production and marketing cotton and its by-products, to explore and identify probable solutions. This research offers a new and evolving approach to assess climate change impact on agriculture utilizing a holistic approach, which could be adopted for other crops.

Global cotton production and consumption is confined within about 25-26 million metric tonnes. So, fundamentally cotton supply is limited while 89% of raw material of our export oriented spinning mills is cotton. In addition, the domestic fibre consumption demand is at 0.36 million tonnes considering the local per capita consumption at about 2.0 kg fibres for 180 million persons. Therefore, if cotton production has to be sustainable, there is a need to focus on domestic cotton production to ensure raw material security by producing a significant portion (i.e. 24%) of the cotton consumption and also save foreign currency substituting imported cotton. If the demand of 24% of our cotton use has to be met from domestic production, it would be necessary to allocate about 150,000 hectares of land for only six months for cotton cultivation (Say; 75 and 150 thousand ha land, respectively during 2022-2030 and 2031-2041, respectively) to produce 2.4 million bales of cotton, we can secure cotton for spinning mills, save foreign currency, at the same time contribute in Gross Domestic Product (GDP). In addition, the cotton crop provides edible oil, cottonseed oil cake, firewood, and create employment and business opportunity in the rural areas.

The cotton production thrust areas of Bangladesh are as follows:

- Drought prone area (Mainly Barind Tract)
- Hill area
- New Alluvial Char Land
- Coastal Saline and non-saline area
- Cotton in Agroforestry
- Intercropping with other crops
- Tobacco replacement
- Introduction of 3 crops in Cropping Pattern (Cotton-Lentil/wheat-Mung bean/Sesame/Pumpkin).
- Finally, unlike tobacco, cotton is an eco-friendly fibre that can ensure long term sustainability to the clothing value chain along with a better life for the farmers if climate smart technology supported cotton production can make it sustainable in the long run.

Globally, most of the major cotton spinning countries, such as China, India, Pakistan, and Turkey produce their own raw material. However, Bangladesh and Vietnam depend on imports of cotton as raw material. Therefore, there is need to increase sustainable cotton production in Bangladesh to reduce dependence on imports.

Figure 5. RMG sector in Bangladesh

The earlier approach of cotton cultivation was based on low yielding seed varieties with conventional cotton that remained economically unviable and had a very insignificant contribution in meeting the demand (Only 1%) of its spinning industry. However, the recent change in the approach to focus on introduction of new hybrids and high yielding varieties along with a comprehensive approach to integrate sustainable practices promoted by Primark Sustainable Cotton Program (PSCP) farming in Bangladesh has brought positive result in productivity, quality and profitability for the farmers. Cotton Development Board along with 'CottonConnect' trained 1500 farmers in the 2021-2022 cropping season to follow protocols of a pilot program. As a result, farmers now produce better quality cotton to sustain the readymade garments industries. The efforts can be intensified in future by engaging more farmers in the program.

The seed-cotton yield of cotton in Bangladesh has improved significantly in recent years to about 5000 Kg/ha with the introduction of hybrid cotton and advance technologies developed by the Cotton Development Board. This effort of improved yield needs to be carried out in future to double the productivity to 9000 Kg/ha from the current level that would add to the long-term viability of cotton farming in Bangladesh. As per the USDA January 2022 report one hectare of land produced 2,217 kg, 1,976 kg, 1,804 kg and 1,720 kg of cotton fibres in Australia, China, Turkey and Brazil, respectively, in 2020/21 while Bangladesh could produce only 734 kg of cotton lint which is better than India (462 kg/ha) and Pakistan (614 kg/ha).

Introduction of new seed verities not only increased productivity but also improved quality of cotton being produced in Bangladesh. The quality of fibres is good and suitable for ring spinning of yarn where the average count is Ne 30/s and major count range of Ne 6/s-12/s, Ne 20/s-40/s and Ne 16/s-40/s for denim, knit and woven yarns. Efforts are being done for improvement in quality further by improving mic and ginning out-turn.

Figure-6. Fabric processing in Bangladesh

SUSTAINABILITY ISSUES AND FUTURE CHALLENGES

Following the Brundtland Report definition: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*", the key issues for the cotton industry were organized into the three pillars of sustainability – environmental, economic and social – each comprising a number of themes.

The environmental pillar comprises five themes: Pest and Pesticide Management, Water Management, Soil Management, Biodiversity and Land Use, and Climate Change.

The economic pillar comprises two major themes: Economic Viability, Poverty Reduction and Food Security, and Economic Risk Management.

Finally, the social pillar comprises four themes: Labour Rights and Standards, Worker Health and Safety, Equity and Gender, and Farmer Organization.

Cotton production's carbon footprint is even better than neutral. Net on-farm emissions of GHGs in cotton growing are negative because the plant stores more carbon (for example, in the lint and seed) than is released from fuel and fertilizer during growth.

The future focus would be on sustainable cotton production that encourages other sustainable cotton initiatives to be engaged with the value chain to ensure environmental, economic and social sustainability pillars with a view to cater the need of clothing value chain that is responsible (Labour Rights and Standards, Worker Health and Safety, Equity and Gender, and Farmer Organization), transparent, traceable and sustainable by using smart technologies suitable for Bangladesh.

Agriculture sector in Bangladesh is climate-sensitive and highly vulnerable to increasing weather variability and climate change. Weather vagaries and climate change impacts have become major barriers to achieving food security and alleviating poverty in Bangladesh. Several studies indicated that production of major crops in Bangladesh could be significantly impacted due to erratic rainfall, increase in temperature, cyclone, tidal surge, saline water intrusion, flood and seasonal drought affect crop production across the country.

Majority of the farmers in Bangladesh are still practicing conventional agriculture. Additionally, they are producing cotton using conventional agricultural management practices such as applying high dose of fertilizers, pesticides and excessive irrigation water. Consequently, conventional cotton farmers incur higher cost of production at low resource use efficiency.

The three basic pillars of Climate Smart Technologies are: increased productivity, resilience to climate change and reduced greenhouse gas emission. Cultivation of cotton in Bangladesh suffered multiple shocks i.e., market volatilities, climate change and poor agricultural management practices resulting in substantial decrease in crop production. It has been observed that implementation of Climate Smart Technologies significantly minimized the adverse effects of climatic stresses, increase crop productivity, farm income and cropped area.

Farmers are advised to follow Climate Smart Technologies (CST) that are water-smart, energy-smart, carbon-smart and knowledge smart. Water smart technologies include raising seedlings on bed, laser land levelling, conjunctive use of water and drainage management, foliar fertilizer application to manage late season drought. Energy-smart technologies include no tillage or minimum tillage. carbon-smart technologies include less use of chemicals and increased use of organic fertilizer and biological pest control measure. Knowledge-smart technologies include legume crops in cropping patterns, improved use of digital technologies, adoption of varieties tolerant to drought, flood and heat/cold stresses. Most of the farmers were of the view that they are adopting CST due to the limited supply of surface water, climate change and to combat drought in drought- areas especially the hilly and Barind tracts.

Using these climates smart technologies, farmer have been able to get uniform germination, desired plant population, higher yield and better financial returns. Implementation of CST for judicious use of water and fertilizers, focus on groundwater quality, access to extension services, and appropriate method and time of picking were found to have a significant impact on the gross value of cotton product (GVP) through increase in resource use efficiency.

CONCLUSION

With appropriate policy support, leadership and continued engagements with different stakeholders of the value chain the cotton farming in Bangladesh would progress towards sustainability with smart technologies and to efficiently meet the demand of the value chain.

Climate Smart Initiatives for Cotton Farming in Zambia

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INTRODUCTION

Climate change is clearly affecting small holder rainfed farmers. The altered monsoon patterns in different regions and intensified hot weather together are the greatest threats to Zambian farmers who depend solely on rains for their agrarian livelihoods. Cotton production is shrinking in Zambia. Productivity is amongst the lowest in the world. The ever-increasing costs of chemical fertilizers and pesticides makes matters worse. Agriculture is not a choice for the smallholder farmer in Zambia, it is part of their life. It provides them with food, fibres and livelihood.

The International Trade Centre (ITC) Geneva and the International Cotton Advisory Committee (ICAC), Washington DC initiated a project titled 'Doubling Participating Smallholder Farmers Income in Zambia.' The project is funded by the European Union (EU). The three-years project was was launched in 2021 in collaboration with the Cotton Development Trust (CDT), the Cotton Board of Zambia (CBZ), the Zambian Cotton Ginners Association (ZCGA) and Cotton Association of Zambia (CAZ). The project focuses on using climate smart innovations to empower small holder farmers to combat, adapt and mitigate climate-change effects. The long-term goal is to rejuvenate soil health, increase productivity, enhance biodiversity and establish robust environment-friendly and sustainable cotton production systems to enable climate resilience in small farms of Zambia. The three-years project has been validating innovative climate smart technologies in the research station of CDT and across different cotton growing regions of the country.

Figure-1. Field banner at a project site

The average seed-cotton yields in Zambia range from 500 to 600 Kg/ha. ICAC data shows that with a yield of 600 Kg of seed-cotton per hectare, Zambian farmers obtain a gross income of US$ 168 and a net income of US$ 93 per hectare. The project aims to increase the average seed-cotton yields to 1000 Kg/ha in 3 years without increasing the cost of cultivation for the participating farmers. With 1000 Kg/ha of clean cotton, farmers could get a gross income of US$ 300, which would double their net income to more than US$ 200 per hectare. Even a modest estimate of income enhancement by US$ 50 per hectare will increase the total farmers' income by at least US$ 5,000,000 per year in Zambia.

The ICAC is equipping smallholder semi-literate farmers with interactive e-tools such as an artificial intelligence based mobile Application (App) and immersive learning experiences through virtual reality (VR) training modules to enable an expert-independent e-decision support for farmers.

The project is also addressing contamination reduction through clean cotton-picking techniques, which would increase the market value of their seed-cotton. Ginners would greatly benefit from clean cotton free of contamination.

Another related important outcome would be in terms of the renewed confidence of farmers in enhancing their yields in a sustainable and eco-friendly manner.

THE FARMER-TRAINING TOOLS

ICAC has developed three major tools for e-extension and training technologies:

1. e-Training Modules and Manuals
2. Soil and Cotton Plant Health App
3. Virtual Reality Training modules on Cotton Best Practices and Eco-friendly Pest Management

Training Modules, Manual and Field Diary

The ICAC developed online training modules and in-person training curriculum on sustainable cotton production by rejuvenating soil health, biological pest management, conservation of biodiversity and innovative agronomy. A training manual was created on regenerative agricultural practices for soil health improvement and high yields and a field diary on problem diagnostics, plant mapping and eco-friendly technologies for crop production and pest management.

Soil and Cotton Plant Health App

The ICAC Soil and Plant Health Mobile Application (App) was designed to meet the major challenge of training illiterate farmers in diagnosis of problems in cotton fields and to assist experts in prescribing solutions, communication of best practices and dissemination of information on markets, weather, soils and environment-friendly agricultural inputs, especially to illiterate farmers. The ICAC mobile Application was developed with support and technical collaboration from Cotton Incorporated and financial support from the German Agency for International Cooperation (GIZ), Germany. The European Union supported development of Zambia specific modules in Nyanja and Tonga. Artificial Intelligence (AI) based mobile application (App) helps farmers on instantaneous plant health diagnostics and find solutions from local resources available in Zambia. The App enables interactive digital exchange of problems, their diagnosis and remedial measures both at the individual farmer level and at community level. Moreover, the tools will provide farmers and their community with real-time remedies in line with National advisories for weather, soil health strategies and their impact on biotic and abiotic stresses. The interactive App is based on voice descriptions, images and videos to facilitate its use even by illiterate farmers. The App is a handy tool as a concise multi-media encyclopedia on cotton farming built specifically for small scale farmers in developing and least developed countries. The App has more than 252 diagnostic images, 86 videos and 86 pdf information sheets on soil and plant health diagnosis. The App was developed for download from both iOS and Android. The first phase of the App features voice based one-way interaction for complete diagnosis on plant and soil health. In the second phase, it is planned to upgrade the App with artificial intelligence (AI) modules for voice and dialect recognition in Nyanja and Tonga.

The App is functional in 25 languages including 11 African languages. The App helps in the diagnosis of all abnormal symptoms and provides basic information and recommendations through videos and animations. Once the App recognizes the problem, it shows the farmer the relevant short descriptive videos after which a pdf info sheet is voiced or read describing the subject in greater detail. The technical training content is completely voice-pictorial interactive so that low literacy levels do not become an impediment in training farmers thus empowering them in decision support.

Virtual Reality Training modules

The virtual reality training modules are based on computer technology to create a simulated environment. The GIZ Germany funded the development of two VR training modules that were launched in Cameroon and used in training programmes conducted in Burkina Faso, Kenya, Zambia and Mozambique. The VR films train farmers on regenerative agricultural practices, integrated pest management and innovative agronomy for higher productivity. The virtual reality training modules enable trainees to experience field visits in a virtual world. Trainees will be able to walk in cotton fields and traverse through time to see stage-wise growth of cotton plants, effects of best practices, effects of harmful pesticides, insect pests and diseases in 3-D. The training modules also showcase live interactions between insect pests and their predators and parasitoids so that trainees would be able to distinguish between good insects and bad insects and also gain confidence on naturally occurring biological control.

Figure-2. Farmer field day

Figure-3 VR Headsets in the camp

Figure-4 Mr Martin Simasiku, plant breeder, CDT supervising the VR training

The first module deals with cotton integrated pest management (IPM), designed to show the importance of naturally occurring biological control of insect pests; harmful effects of insecticides, excessive irrigation and nitrogen and; best practices of pest management with production practices, cropping systems, resistant varieties, nutrient management, pheromones, light traps, trap crops, bio-pesticides, biological control and selective insecticides.

The second module deals with the sustainable best management practises in cotton production. These strategies are being followed around the globe for obtaining high yields in a sustainable manner. It deals with the importance of seed health and vigor, plant density, canopy management and high yields without increasing the use of inputs per unit land.

Both modules focus on regenerative agricultural techniques and demonstrate simple eco- friendly strategies in crop protection and production to increases cotton yields and profitability while ensuring sustainability.

TRAINING PROGRAMMES

The ICAC is liaising with CDT, CBZ, CAZ and ZCGA to set up small-scale and about 500 large-scale technology demonstration farms, coordinate field exposure visits and trainings for 500 staff members of CAZ and ZCGA. Several online trainings were conducted. In-person trainings, field visits and farmer field days were conducted using the VR modules and video-based training curriculum.

Figure 5. Farmers viewing the VR in a village

Figure-6. A practical training camp in cotton fields

The ICAC is assisting the CDT, CBZ, CAZ and ZCGA to facilitate training programmes to be conducted by the 500 ICAC-trained trainers that will result in training of 100,000 farmers. Each trained trainer will supervise a field demo in farmer fields and also conduct four training camps @ two training camps per year to train a total number of 200 farmers @ 50 participants per training programme. Thus 500 trainers would have trained 100,000 farmers.

Figure-7. A training session at CDT, Magoye

Figure-8. Trainers with trainees at CDT, Magoye

CLIMATE-SMART INNOVATIONS

The above-mentioned capacity building activities under all outputs will enable empower farmers to address the following crucial elements of cotton productions, namely:

1. **Enhanced Carbon sequestration:** Conversion of farm waste and cotton stalks into biochar and enriching it with composting and in-situ nitrogen fixing by legume crops not only increases carbon sequestration several-fold but also rejuvenates soil health. Regenerative agricultural practices of reduced tillage, maintaining a live soil cover, organic mulches, enrichment of soils with organic matter and increasing crop diversity, minimize soil degradation and increase water and nutrient use efficiency.
2. **Doubling productivity:** The global standard planting geometry of 8-10 plants per meter row with rows spaced at 80-100 cm reduces the physiological load on individual plants. A combination of high-density planting with techniques to retain early formed bolls has the potential to double productivity in a short time. Dense planting reduces the duration of the critical window of boll formation to facilitate efficient water and nitrogen management. it increases harvest index. Research workers, extension workers and farmers are being trained on monitoring plant health and plant growth based on heat units and agronomic practices,
3. **Novel botanicals for eco-friendly pest management:** Zambia has abundant botanical resources that can be used to rejuvenate soil health and to manage insect pests and diseases most effectively. The project is developing new formulations of botanical pesticides using the locally abundant *Tithonia diversifolia, Solanum incanum*, *Neem* and *Tephrosia vogelii* to ensure effective pest control and to conserve natural biological control.
4. **Clean picking and storage:** Contaminants of human hair, plastic threads and extraneous trash reduce the commercial value of cotton fibres. Farmers will be trained on the use of head gears, clean picking using ergonomically designed cotton cloth bags and storage conditions that prevent the addition of contaminants into cotton

Figure-9. Abundant bio-pesticidal *Tithonia diversifolia* plants as weeds along the roadside.

The shrinking cotton production in Zambia, necessitated urgent interventions in production practices. In addition of the digital extension services, the use sustainable soil amelioration activities are being taught to farmers in order to revamp the degrading soils. Zambian farmers know how to convert farm waste and dry farm stalks in biochar -a carbon rich product that enhances nutrient retention in the soils for a long period of time making the long nutrient deprived soils fertile and more productive with least application of expensive synthetic fertilizers.

Figure-10 Farmers with experts from ITC, CDT and the ICAC

Pesticides for controlling bollworms and sucking pests have become very ineffective and expensive making them unsustainable. Zambia has a rich diversity of botanical resources that are being used to develop photostable botanical insecticides that are more effective and less costly. The biopesticides are being developed by the CDT with guidance from ICAC.

Figure-11. Mr Dafulin Kaonga, consultant ITC explaining the high-density technology to farmers.

The future of Agriculture depends on the next generation of young people and several experienced technocrats who will be available to give their sound advice. Many young people with the potential to take lead in the dynamics of agriculture both in research and crop production, need to be ready to apply themselves to the evolving changes in the agricultural practices of today. Key to these changes are the digital tools that are commonly trending to enhance precision farming, impart skills, improve productivity and thus maximizing profits of farmers. Cotton is grown by about 200,000 smallholder farmers in Zambia. These farmers are directly or indirectly linked to the young people in their many households and hence influence the future generation in one or another. Because of the farmer's attachment to the young people, a number of them are now conversant with the benefit of using mobile phones and other electronic gadgets to obtain information agrarian skills and knowledge.

Figure-12. Experts interacting with a farmer in his field.

Additionally, a lot of farmers are now familiar with social media and share information and knowledge. This positive attitude towards digital agriculture is a good indicator of the receptivity and adoptability of farmers toward new tools.

The latest technological advancements and more novel tools are helping the younger generation to gear up towards adopting new eco-friendly technologies. The aim of these agricultural tools should be to send a message that the farmers will understand in the simplest, most convenient way possible.

It is said that a picture is worth a thousand words, but a video is worth much more and a VR is proving to be priceless in its power of training. The new digital Virtual Reality (VR) modules have added a new dimension to farmer training and agricultural extension.

Women farmers who were unable to attend training camps due to their household responsibilities or cultural restrictions are thrilled to be virtually trained in an immersive learning experience within the four walls of their homes using the VR Headsets.

The project was started when COVID was at its peak. All though 2021 and until April 2022, the ICAC team and the Zambian collaborators tried their best to conduct training programmes and set up technology demonstration plots. It was only in April 2022, that the ICAC team was able to travel to Zambia, conduct in-person trainings, participate in field days, travel across Zambia to visit fields and initiate activities based on local resources for biopesticide production and fertile-biochar. The project activities are now assuming full speed towards top-gear. Farmers are excited with the novel digital training tools, encouraged with the results and enthused to share their experiences.

Figure-13. Recording observations in HDPS fields.

We earnestly hope that the project will trigger a significant positive change not just for enhanced productivity and profitability but also will make production systems climate-resilient, carbon-negative and climate-positive.

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Effects of Poultry Manure on Cotton Cultivation

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INTRODUCTION

Cotton is the engine of economic development in several countries. Cotton cultivation has brought about significant changes in national economies by creating means of subsistence for farmers and business through the organization of producers, trade, employment, transport, education, health (Traoré *et al.*, 2021; Soumaré *et al.*, 2020). However, the sustainability of cotton-based production systems is often debated because of their effects on soils and the negative impacts of chemicals used on the environment and human health (Soumaré *et al.*, 2020). Thus, support projects for the agro-ecological transition and the creation of departments in charge of the environment within cotton companies show the need and the desire to transform current production systems towards more ecological systems: reduction of the use of chemical inputs, promotion of agro-ecology and organic farming and diversification and use of organic products in conventional farming. Indeed, recent research shows that soils are degrading; one of the causes of which is the excessive use of chemical inputs. Excessive dependence on agro-chemicals is one of the main obstacles to the sustainable development of cotton (Traoré *et al.*, 2021). It has been observed that soils that have been repeatedly exploited for cotton cultivation for several decades using chemical inputs are characterized by a sharp drop in fertility and in most cases have turned acidic (Bacye *et al.*, 2019; Soremi *et al.*, 2017).

Degraded soils threaten productivity. Continuous use of chemical inputs further aggravates the crisis. Therefore, efforts are made with a view to ensure that nutrient management becomes effective and efficient using ecological inputs (Soremi *et al.*, 2017) so that soil health can be rejuvenated. It is in this perspective that the development of organic cotton appears as a sustainable alternative. Sustainable principles recommend fertilization of crops using organic manure and to practice biological control against diseases and insect pests. The contributions of poultry manure as an efficient alternative to chemical fertilizers in the cultivation of cotton are many-fold ranging from positive effects on yield, soil health and crop health.

EFFECT ON SOIL HEALTH

The use of poultry manure in crop production is recommended as it enhances the stability of soil structure; improves soil organic matter status, nutrients availability thereby resulting in high crop yields (Adeleye *et al.*, 2019). Poultry manure application improves soil physical properties, reduces soil bulk density, temperature and increases total porosity and soil moisture retention capacity. Poultry manure is an excellent agricultural input in general. Poultry manure was found to induce immediate positive effects on plants when applied in sufficient doses. Studies show that the combined supply of poultry manure with chemical fertilizers reduces nutrient losses and increases the efficiency of nitrogen (Jan, 2018). It is reported, for example in west part of Burkina Faso, poultry manure is an important fertilizer and constitutes about 35.72% of the production of organic manure which caters to the crop nutrient requirements in nearly 4.50% of the total cultivated areas (Gomgnimbou *et al.*, 2019).

Figure-1. Poultry

NUTRIENT SOURCE

Poultry manure is rich in nitrogen, phosphorus and potassium which constitute the major nutrients that are essential for crop growth including cotton. Broiler litter is not just a good source of N, P and K for cotton cultivation, but also supplies secondary and micro nutrients such as Fe, Cu, and Mn in full and Zn (Tewolde *et al*., 2005). Incorporation of poultry litter into the surface soil enhances its retention capacity of nutrients and carbon sequestration over non incorporation, indicating losses of nutrients without incorporation (Adeli *et al*., 2008). Application of litter at the higher rate exceeded cotton nutrient utilization as evidenced by increasing soil nitrate (NO_3) and accumulation of P, K, Cu, and Zn in the top 5 cm of the soil.

EFFECTS OF POULTRY MANURE ON SOIL pH

Soils turn acidic, largely due to previous production practices, specifically, due to application of nitrogen fertilizers (Sharry, 2019). Amelioration of soil acidity may be required to maximize profitability of cotton production in some conditions. Lime is commonly used as an amendment to remediate acidic soils.

Application of poultry manure for several years on a cotton farm maintains the soil pH in a stable manner (Reddy *et al*., 2008). In fact, application of poultry manure increases the content of calcium hydroxide in soils to raise the pH. Farm experiments in Nigeria showed that poultry manure application increased soil pH from 6.1 to 7.17 when applied a rate of 10 t ha^{-1} (Soremi *et al*., 2018).

Similar results were reported from experiments conducted in Burkina Faso using repeated application of poultry droppings (Gomgnimbou *et al*., 2019) wherein an increase in the pH from 3.95 to 5.72 was recorded.

Table 1 : Some chemical properties of the poultry manure (Soremi et al., 2017).

Parameter	Value	Parameter	Value
Nitrogen	23.6g kg^{-1}	Iron	70 g kg^{-1}
Phosphorus	14.9 g kg^{-1}	Sulphur	5.7 g kg^{-1}
Potassium	14.2 g kg^{-1}	Zinc	53.50 mg kg^{-1}
Calcium	4.3 g kg^{-1}	Organic carbon	128.4 g kg^{-1}
Magnesium	1.8 g kg^{-1}	C/N	5.44

Cotton crop is relatively tolerant to changes in pH above or below 7.0 to an extent. However, the best yields are obtained when the soil pH is between 5.5 and 7.5. Consequently, it is recommended to avoid cultivating cotton in acidic soils with pH less than 5.5.

Work from Georgia by showed that. In studies conducted in Georgia, when soil pH was increased through lime application, cotton yield like other crops increased significantly (Gascho and Parker, 2001; Sharry, 2019).

In addition, the soil pH has an influence on cotton lint yield and fibre properties. Generally, lint quality is best when pH is greater than 6.0.

EFFECTS ON EXCHANGEABLE CALCIUM, POTASSIUM AND MAGNESIUM

Poultry droppings improve the cation exchange capacity of soils and constitute a good amendment (Bambara, 2017, Gomgnimbou *et al*., 2019). Poultry manure is a good source of nutrients and exchangeable cations. It has been estimated that 1 ton of dry droppings contains 30.5 kg of nitrogen and 20 kg of potassium. Studies showed that poultry droppings at a dose of 10 t/ha improved the exchangeable Ca in soils to reach a value of 3.90 cmol/kg with higher concentrations of Ca, K and Mg compared to the control (Soremi *et al*., 2017). It also, improves soil organic matter, total N, available P, and exchangeable Mg, Ca and K. Application of poultry manure also increased nutrient uptake, growth and yields significantly. Residual effects of poultry manure, and combined application of reduced quantities of poultry manure and NPK fertilizer gave higher soil organic matter, N, P, K, Ca, Mg and micro-elements contents compared to application of 300 kg/ha NPK 15-15-15 fertilizer (Adeniyan and Ojeniyi, 2003).

IMPACT ON NEMATODES

Studies showed that chicken droppings had a negative effect on the population density of the lance nematode *Hoplolaimus columbus*, that damages cotton plants (Koenning *et al*., 2003). However, for a better control, 13t to 21t/ha of poultry manure was recommended to be applied in mid-season. Poultry litter application in cotton farm was found to reduce the effect of the root knot nematode *Meloidogyne incognita* (Riegel and Noe, 2000). *Meloidogyne incognita* reduces plant dry weight, root weight, leaf area, boll number, and boll dry weight (Lu *et al*., 2014). Poultry manure not only contributes to reduction in nematode populations, but also helps in better crop growth of cotton by supplying essential nutrients and micronutrients.

EFFECT ON SOIL FUNGI

Studies conducted in China showed that application of poultry manure resulted in an increase of fungal populations (Huang *et al*., 2006; Pratt and Tewolde, 2009). Poultry manure when used alone is not known to have any deleterious effects on soil fungi populations. Observations show that when poultry manure is used as a fertilizer for commercial cotton production, soil fungal population levels may increase over time due to enhanced soil fertility and better plant growth.

EFFECTS ON COTTON PRODUCTIVITY

Cotton yield was found to be positively correlated with manure application rate up to a maximum application of 13.4 t/ha; beyond this dose, the correlation becomes negative (Koenning *et al*., 2003).

When poultry manure is applied, about 75% of N and almost 100% of P and K contained in poultry droppings are available to plants during the year of their application (Islam *et* al., 2014). Other studies have shown more beneficial effects when poultry manure application is associated with chemical fertilizers in cotton cultivation. Studies using poultry manure as fertilizer showed an increase in yields of cotton and maize compared to application of mineral fertilizers such as Nitrogen (N), Phosphorus (P) and Potassium (K). However, the effects on yields were more pronounced when poultry droppings were combined with chemical fertilizers (Gomgnimbou *et al.*, 2019; Reddy *et al.*, 2007).

0Integrated nutrient management studies show that if poultry manure is applied in a proportion where 30 to 40% of nitrogen is provided by the manure and the rest comes from urea it was possible to produce around 3.48 tons of seed-cotton per hectare compared to 3.5 tons when the nitrogen requirement was supplied by urea alone (Islam *et al.*, 2014).

0Studies showed that composting fresh poultry litter (FPL) to make composted poultry litter (CPL) did not improve its impact on cotton growth or yield (Reddy *et al.*, 2007) as per observations wherein FPL produced the highest mean lint yield over a five-year period (1492 kg ha-1) compared with CPL (1392 kg ha-1) and urea (1391 kg ha-1).

CONCLUSION

Poultry manure can enrich soil health by improving structure, remediating acidity, providing macro and micronutrients, improving carbon sequestration, and increasing productivity of cotton and other crops. Its use in cotton cultivation can effectively replace or supplement mineral fertilizers. Poultry manure helps to control harmful nematodes, such as *Meloidogyne incognita* but improves soil fungal populations.

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Rejuvenating Soil Health with Manures and Composts

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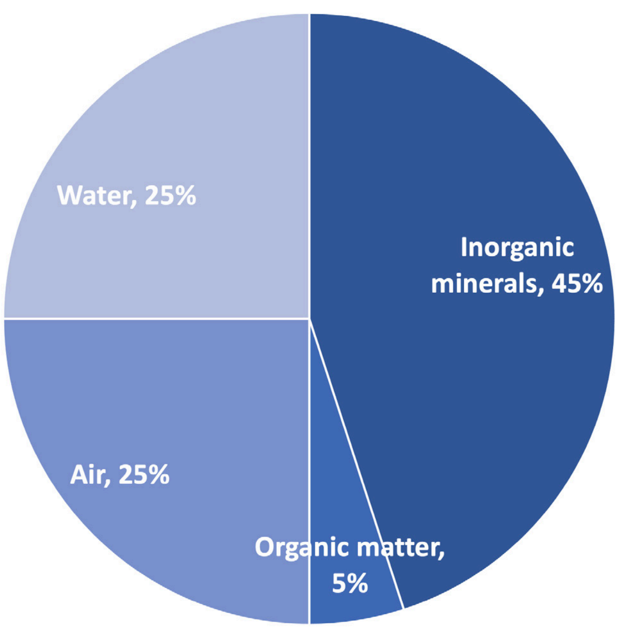
INTRODUCTION

Sustainable farming depends on healthy soils. Soil health depends on its organic soil content. Application of manures and composts leads to improvement in soil organic matter, so the structure is improved. Manures and composts provide nutrients and improve the soil biological, physical and chemical properties. Soil structure is important for microorganisms to survive and multiply. Soils that are rich with a structured food web of microorganisms such as amoebae, fungi, algae, bacteria, protozoans and other organisms such as micro-arthropods, insects, nematodes, earthworms, vertebrates add life to soils and make them healthy with decomposed organic matter. Soils rich with decomposed organic matter are fertile and contribute to better soil health and plant health.

A healthy soil is expected to contain about 25% air, 25% water, 45% minerals and 5% organic matter. Soils that have higher levels of organic matter have better aeration to allow better infiltration of rainwater and a higher water holding capacity. Manures and composts provide the complete set of nutrients that plants need. They provide nutrients for a longer period. Organic matter also checks soil erosion, The biggest advantage of manures and composts is that they can be prepared easily and are eco-friendly.

Figure-1. Composition of healthy soils.



TYPES OF MANURES

There are different kinds of manures and composts that can be prepared in the farm and applied to the soil to increase its organic carbon content and fertility.

There are two main categories of manures.

1. **Bulky manures:** The first category is called bulky manure, because these manures have a large organic biomass with less macro nutrients such as nitrogen (N), phosphorus (P) and potassium (K). Examples of bulky manures are farmyard manure, compost, vermi-compost and green manure.
2. **Concentrated manures:** The second category is called 'concentrated manures' because these manures have higher quantities of macro nutrients compared to bulky manures. Examples of concentrated manures are seed-oil cakes and animal-based manures such as blood-meal, fish-manure and bonemeal.

Bulky organic manures improve soil structure. They provide carbon to earthworms, soil insects and microorganisms to build carbon reserves and soil health. Bulk manures are mostly prepared by using cattle dung or chicken dung. Farmyard manure and rural compost have very low quantities of macronutrients such as N, P and K. For example, one tonne of farmyard manure, rural compost, buffalo dung and urban compost provide only 5 to 10 kg of nitrogen, 2 to 8 Kg of phosphorus and 5 to 15 Kg of potassium. Vermi-compost has higher levels of nutrients at 12 Kg nitrogen, 13 Kg phosphorus and 10 Kg potassium per tonne. Chicken manures have higher quantities of nutrients. One tonne of chicken manure provides more than 32 kg of nitrogen, 33 Kg of phosphorus and about 24 Kg potassium.

Table-1. Nutrient content (Kg) in one tonne of bulk manure

Type of Manure	Nitrogen (N) Kg	Phosphorus (P_2O_5) Kg	Potash (K_2O) Kg
Farmyard manure	5	3	5
Compost (rural)	5	2	5
Buffalo dung	10	8	7
Compost (urban)	10	5	15
Vermicompost	12	13	10
Swine dung	21	24	10
Cattle dung	24	7	9
Chicken - broilers dung	32	33	24

Table-2. Nutrient content (Kg) in one tonne of seed-cake manure

Type of Manure	Nitrogen (N) Kg	Phosphorus (P_2O_5) Kg	Potash (K_2O) Kg
Mahua cake	25	8	12
Karanj cake	39	9	12
Castor cake	43	18	13
Linseed cake	49	14	13
Rape seed cake	52	18	12
Sesamum cake	62	20	12
Cotton seed cake	64	29	22
Groundnut cake	73	15	13
Safflower cake	79	22	19

Table-3. Nutrient content (Kg) in one tonne of concentrated manure

Type of Manure	Nitrogen (N) Kg	Phosphorus (P_2O_5) Kg	Potash (K_2O) Kg
Steamed bone meal	20	300	-
Raw bone meal	40	250	-
Fish meal	80	70	20
Meat meal	105	25	5
Blood meal	120	20	10
Horn and Hoof meal	130	-	-

Farmyard manure

Farmyard manure is a bulk manure that is obtained from decomposed mixture of dung and urine of farm animals obtained from cattle sheds. Farmyard manure also contains residues of leftover fodder, litter or roughages. It contains low quantities of macro nutrients such as nitrogen phosphorus and potassium but is rich in organic matter that helps to improve soil structure and microbial life.

Figure-2. Farmyard manure

Green manure

Crops such as alfalfa, sesbania, hairy vetch, beans, mustard, etc. are used as green manure crops. One tonne of the green manure biomass provides about 20-30 Kg nitrogen, 5-10Kg phosphorus, 10-40 Kg potassium and other micronutrients.

Figure-3. Sunn hemp green manure

Oil-seed cakes

Seed cakes are a good source of organic matter and macronutrients (NPK). Seed cakes are obtained after extracting oil from seeds. In most cases edible seed cakes are fed to animals. The non-edible seed cakes can be converted to manures. One tonne of seed cake contains 25 to 79 Kg nitrogen, 8 to 29 Kg phosphorus and 12 to 22 Kg potassium. Cotton seed cake is rich in all the three major nutrients (NPK). It provides about 64 Kg nitrogen, 29 Kg phosphorus and 22 Kg potassium.

Figure-4. Seed cake manure

Animal manures

Animal based manures are prepared from dried meat or decomposed horns and animal blood. Animal based manures are generally rich in phosphorus. While meat-meal, horn-meal and hoof-meal have higher levels of nitrogen, bone-meals are an excellent source of phosphorus. Horn and hoof-meals have higher levels of nitrogen and bonemeal provide very high quantities of phosphorus at about 250 Kg apart from providing 40 Kg nitrogen per tonne.

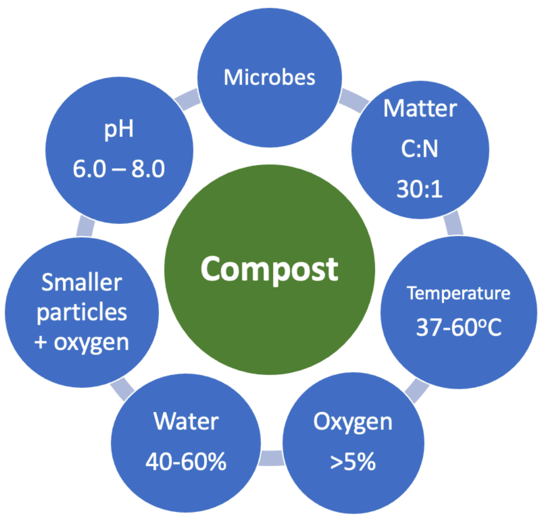
Figure-5. Bone-meal manure

COMPOSTING

Principles of composting

Organic matter contains nutrients. But it must be decomposed by microorganisms first so that the nutrients are available to plants easily. Composting is a process wherein organic matter is degraded by soil microorganism to produce compost that can be used to improve soil health.

Figure-6. Principles of composting

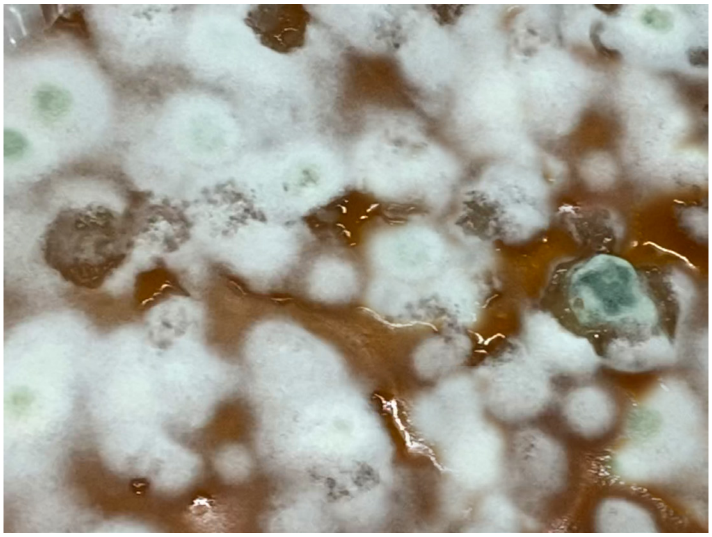


Soil microorganisms such as bacteria, actinomycetes and fungi, feed and decompose organic matter. These microorganisms need oxygen, water, air, warmth, carbon, nitrogen and other minerals for their survival. The efficiency of composting depends on the population and composition of different types of microorganisms, the carbon to nitrogen ration in the feedstock material, oxygen levels, moisture levels, temperature, the physical structure of the material and pH. Microorganisms degrade organic matter to produce compost that contains dark brown humus-like material which is an excellent soil conditioner.

Decomposers

Organic matter is degraded by billions of microorganisms present in the soil. These microorganisms are mainly fungus, actinomycetes and bacteria. Fungus feeds on tough dry organic waste that could be acidic and not usable as feed by bacteria. Actinomycetes bacteria degrade complex organic material that contains chitin, cellulose, lignin and proteins. Finally, bacteria play a major role by decomposing simpler forms of organic material. Thus, these three groups of microorganisms feed on plant and animal debris to convert the organic matter into compost. In this process of preparing compost, the microorganisms utilize oxygen and organic matter to release heat, carbon dioxide and water vapor.

Figure-7. Decomposers: Soil microorganisms



Nutrients: Carbon to Nitrogen Ratio

For efficient composting, the preferred ratio of carbon:nitrogen (C:N) should be about 30:1 within a range of 25:1 to 35:1 in the organic matter compost-feedstock. Though different microorganisms have different C:N ratios in their bodies, the average C:N ratio is considered to be 8:1 for the general pool of microorganisms, wherein carbon content could be eight times higher than the content of nitrogen. For rapid decomposition of organic matter into compost, the feedstock material must contain carbon and nitrogen in appropriate ratios to help microorganisms survive and multiply. From 30 units of carbon in the feedstock, microorganisms use 24 units of carbon of which

16 units are used as the source of energy, 8 units of carbon to be assimilated into their body biomass and the remaining 6 units of carbon being left in organic matter residues. The 16 units of carbon used for metabolism get converted to carbon dioxide. From the C:N ratio at 30:1 in the feedstock, microorganisms use the one unit of nitrogen for the synthesis of essential molecules such as DNA and protein. If the organic matter has more carbon and less nitrogen for example of C:N ratio at 60:1, decomposition will be very slow because microorganisms will excess carbon but an inadequate proportion of nitrogen for protein synthesis. The resultant compost will also be deficient in nitrogen because all of the nitrogen in the feedstock will be rapidly depleted. On the contrary, if the organic matter has a C:N ratio at 20:1, decomposition will be fast because microorganisms will use the excess nitrogen for DNA and protein synthesis but will rapidly exhaust oxygen to create anaerobic conditions. The excess nitrogen is also converted to nitrate and ammonia and creates compost with odour and consequently deficient nitrogen. In general, dry hay such as wheat straw contains more carbon to nitrogen and wet grass, or green leaf biomass contains less carbon to nitrogen. The time of composting can be as slow as 2 to 3 years if the organic material contains high levels of carbon to nitrogen. Composting will be efficient and faster within 6 months, if different organic materials are mixed to get the desired ratio of 30 carbon is to 1 nitrogen.

Oxygen

Composting is an aerobic process. The microorganisms that prepare compost are aerobic and need oxygen to survive. Therefore, adequate amounts of oxygen generally more than 6 per cent with a desired range of 16% to 18% are critical for efficient composting. When the oxygen levels fall below 6%, the aerobic microorganisms die to be rapidly replaced by other anaerobic microorganisms. The anaerobic microorganisms do not need oxygen to survive but are very slow and inefficient in composting. They produce gases such as methane, ammonia and hydrogen sulphide which have an unpleasant odour. Proper oxygen levels at more than 6% result in efficient composting and prevent odours and unpleasant smell.

Moisture

For efficient and rapid composting, the moisture level in the total organic material must be at 40% to 65% per cent of the total weight. Microorganisms use water to create a suitable living environment and to dissolve nutrients and consume them to grow and multiply. Moisture levels in excess of 65% restrict the flow of oxygen to create anaerobic conditions. This slows down the rate of composting. If the moisture levels go below 40% per cent, bacterial populations decline because their nutrient solubility becomes restricted.

Temperature

Temperature is a good indicator of the rate of degradation of organic matter in a compost pile. Therefore, regular monitoring helps to understand the rate and efficiency of composting. The optimum temperature for composting is 50°C to 60°C. Microorganisms generate heat in the composting material when they degrade organic matter. The organic pile insulates temperatures and heat is maintained within the heap. Consistent temperatures of 56°C to 58°C maintained for 2 to 3 days destroy plant disease causing pathogens and weed seeds. At temperatures above 42°C, heat loving microorganisms dominate and increase the rate of composting. However, when the temperature exceeds 60°C, the rate of composting slows down. Temperatures move away from the optimum range if oxygen levels drop below 6% or when moisture levels are less than 40% or above 60%.

Physical structure

Microorganisms prefer smaller organic material for degradation. Therefore, composting is faster with finely chopped organic matter. Accelerated composting in the shredded material leads to higher demand for oxygen and a greater need for air. However, smaller sized particles lead to compaction of the material which results in deficiency of oxygen. Care must be ensured to provide proper aeration in shredded organic material used as feedstock for composting.

pH

Microbial degradation of organic matter is most efficient between a pH of 6.5 and 8.0. If the pH drops below 6.0 towards acidity, most microorganisms die, and the process of composting becomes slow. If the pH increases above 8.0 towards alkalinity, nitrogen in the organic matter gets converted to ammonia and is lost. Low nitrogen levels lead to slow rate of composting. Generally, at the initial stage of decomposition the compost becomes slightly acidic but reaches a neutral pH at final stabilization stage.

METHODS OF COMPOSTING

Farmers across the world prepare manures and composts using different methods. It is interesting that most farmers prepare excellent manures and composts without knowing a few basic principles that help in faster and efficient composting.

Heap method

The most common method is called heap composting. In this method, different organic materials are laid out over each other to prepare a heap that is finally covered with a mixture of soil and cattle dung. The main ingredients of heap composting are green matter that is mostly grasses or green leaves, dry matter that can be obtained from hay of crops, cattle dung, water and soil. Apart from these main ingredients, farmers also use small quantities of lime to prevent acidity that builds up initially during composting. Gypsum is also added to prevent nitrogen losses. Gypsum converts ammonium carbonate into ammonium sulfate and calcium carbonate to reduce nitrogen losses. Ammonium carbonate is easily lost as ammonia compared to ammonium sulfate. Small quantities of compost are also added to serve as an initial source of inoculum of microorganisms.

Figure-8. Heap method

The most common size of a heap is 5 meters in length, 2 metres in width and about 1.5 metres in height. Different types of materials such as green matter and brown dry matter are spread and layered over one another alternately. Each layer is generally covered with a layer of soil containing dung and small quantities of lime, gypsum and compost. The layers are watered to provide moisture. Dry material is spread first followed by pouring of dung water and spreading of soil over the dry matter. Green matter is layered over the layer of dry matter. subsequently, soil plus dung plus gypsum is spread over the green matter. Some farmers also add rock phosphate to this layer. Generally, there are several layers of dry and wet material sandwiched with soil and dung till the heap reaches a height of about 1.5 metres above the soil. In the fifth step fine soil plus compost is layered on the top. The final layer is a paste of dung plus soil. The heap is left for a few months to a year before applied on the farm.

Pit method

The pit method of manure preparation or composting is also followed commonly across the world. This method is also like the heap method, but the layers are built one over the other first inside the pit. The pit can be of any size, but the general dimensions are three metres length, 2 metres breadth and 1 metre depth. The height of the heap layered in the pit reaches about half metre above ground. It is very common that the height of the heap gets lowered down as the composting progresses.

Open brick method

The open brick method is built as a tub of bricks with open spaces in between brick for aeration. The dimensions of the brick tub are generally 4 metres in length, 3 metres in breadth and 1 metre in height. This method provides aeration for efficient composting, without having the need to turn the composting material at regular intervals, generally every fortnight as is commonly done with the pit method or heap method of composting. The method of layering of different materials is almost the same as in any composting method. The bottom-most layer has farm waste up to 15cm thick. This layer is covered with dung water and a fine layer of soil. The process is repeated with alternate layers of farm waste, dung water and soil until the heap reaches a dome shape. Composting takes about four to ten months. Each tub can produce about 2.5 tonnes of compost.

VERMICOMPOST

Vermicomposting is prepared by using earthworms for faster and efficient conversion of organic matter into compost. Vermicompost is a good organic fertilizer that is rich in water soluble nutrients. It also serves as a good soil conditioner. Vermicompost promotes plant growth because it also contains plant growth promoting hormones secreted by soil microorganisms and earthworms. Structures of cement or plastic are made to prevent earthworms from escaping or burrowing into soil. The structures are about 5 metres in length or longer, one metre in breadth and 0.6 metres in depth. Two species of earthworms, namely *Esinia foetida* and *Udrilus uginii* are use very commonly for vermicomposting.

Figure-9. Earthworms

There are about five main stages in the production of vermicompost. The first step is the collection of biodegradable waste. The second step is mixing of the dung and organic waste in an equal ratio by weight. The third step is preparation of earthworm bed with the waste and dung mixture. The fourth step is generally at 60 to 70 days when vermicompost is collected and sieved. The final step is storage of vermicompost in conditions that ensures proper moisture to encourage microbial growth.

Figure-10. Vermicomposting unit

Vermicompost bed is prepared by using organic materials of dry straw (sorghum, wheat, maize etc.) layered as a 4 inches bed at the bottom of the bed, covered by a 4 inches farmyard manure. The second later comprises of 10 to 12 inches of farm waste, which is again covered by a 6 inches layer of farmyard manure. Earthworms are released over the top layer at about 1 kg worms per square metre. The layers are repeated until the heap covers the full depth of the structure. The bed is watered daily to keep it wet. Earthworms are most efficient when the organic matter is wet, but not too wet above 60% moisture. After 60 to 70 days, watering must be stopped for 3 to 4 days so that the upper part of the bed becomes dry, and earthworms will move down to the lower wet layers of the bed.

Vermicompost is harvested from the upper 3 to 4 inches of the bed and sieved to get finer particles and return any recovered worms back to the bed. Generally, a 2.0mm to 3.0mm sieve is used to get finer particles of compost. The sieved vermicompost is stored under shade and maintained to contain 15-20% moisture. First harvesting of compost is possible 25-30 days or more, after releasing the worms, depending on the management. Subsequently vermicompost is harvested at weekly intervals by withdrawing water for 3-4 days and scraping vermicompost from the top 3 to 4 inches of the bed. The duration for one cycle is 70-80 days.

VERMI-WASH

Vermi-wash is a liquid form of compost produced in a drum containing earthworms, cattle dung, organic matter and sand. Materials that are used in vermicomposting beds are the same materials that are used to prepare a vermi-wash drum. The materials are farm waste, farmyard manure, earthworms, water, small stones and coconut coir or dry hay.

Figure-11. Ms. Madhuri describing a vermiwash unit

The vermi-wash tub is first layered with small stones up to 4 inches. The second layer has 2 inches of coconut coir of 4 inches of dry hay. The tub is them filled with farmyard manure, a mixture of farm waste mixture. The drum is watered daily for 4 to 5 days, and earthworms are released. The drum is watered regularly to keep the contents wet. A vermi-wash unit can be prepared in plastic drum or earthern pots of various sizes ranging from 10 to 100 litres. The drum has a tap at the bottom to facilitate collection of the vermi-wash liquid. Excess water is provided after 20 to 30 days and vermi-wash liquid is collected through the tap at weekly intervals. The vermi-wash liquid is diluted 10 times with water and sprayed over plants. The spray fluid is rich in microorganisms and has soluble nutrients and hormones that promote plant growth. The vermi-wash liquid has a near neutral pH. It contains less quantities of nutrients and carbon, but is rich in soil microorganisms such as Nitrosomonas, Nitrobacter and fungi that can be used to inoculate farm soils or composting units.

Composts and manures are important sources of nutrients for plants and organic matter for soils. Composts when prepared properly can serve as an inoculum of microorganisms to rejuvenate soil health on a long-term basis. The principles of regenerative agriculture include increasing organic matter in soils and maintaining live root systems of diverse crops to ensure microorganism diversity in soils. Composts not only inoculate soils with a diverse range of microorganisms, but they also provide good amount or organic matter for microorganisms to multiply and survive in soils to build soil health for good crop health and high yields.

ACKNOWLEDGEMENTS

The authors thank **Dr Uma Reddy,** Associate Director of Research, RARS Warangal, Telangana, India; **Ms. Madhuri,** Agrico, college of Agriculture, PJTSAU, Warangal and **Dr. Upender Mahesh** for facilitating our visit to their composting units, explaining the processes and for the images.

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OBITUARIES

Dr. Lastus Serunjogi
Cotton Scientist, Uganda

Dr. Lastus Serunjogi passed away on 30 June 2022. He worked all his life for the welfare of farmers in Uganda and left a huge void that will be felt forever. Dr. Serunjogi will be remembered as the finest cotton breeder that the country has ever produced. He doubled as a Cotton Breeder and Leader of the Cotton Research Programme at the National Semi-Arid Resources Research Institute (NaSARRI) in Uganda, during 1972 to 2005. During his tenure at the research institute, Dr. Serunjogi Lastus served as the Director of Research from 2001 to 2005. Dr Serunjogi and his team developed eleven varieties, from the Albar germplasm of the *Gossypium hirsutum* origin, which earned premium prices for Uganda's cotton. He was a member of the 8th Parliament of Uganda from 2006 to 2011. He served, for one year, as the Vice-chairperson of the Parliamentary Committee on Social Services (Education and Health), and three years as the Vice-chairperson of the Committee on Agriculture. From 2011 until recently, he served as the Technical Advisor at the Cotton Development Organisation (CDO), the Regulatory body of the Cotton sub-sector. Dr Serunjogi coordinated and harmonized the Cotton research activities of NaSARRI with CDO's programmes. He was a Member of the Uganda National Seed Board where he represented the Uganda Plant Breeders' Association.

Dr Serunjogi had a B.Sc. (Hons) in Chemistry and Botany with specialization in Genetics from the Makerere University in Uganda (1972). He received M.Phil. (Plant Breeding) from the Cambridge University U.K. (1987) and a Ph.D. (Plant Breeding, with a major in Seed Technology) from the Ohio State University, USA in 1993. Dr. Serunjogi published several peer reviewed research papers and book chapters in national and international publications. Some of his notable papers were published in the Uganda Journal of Agricultural Sciences (UJARS), the World Cotton Research Conferences' proceedings and in the proceedings of the Technical Seminars at the ICAC Plenary Meetings. His Chapter; "Cotton (Gossypium Sp) in the Book "Agriculture in Uganda Volume II" (Ed) Pof. J.K. Mikiibi, 2001: Fountain Publishers/CTA/NARO pp 322 – 375 is widely referred by researchers.

Dr Serunjogi was a keen cotton farmer, an outstanding plant breeder and a great human being. His passion in research was infectious and was a great source of inspiration and motivation to his peers and young researchers not only in Uganda but across the world. He would never give up on hope and always dreamt prosperity for the Ugandan cotton farmer.

Dr Serunjogi was humble, simple and down to earth in his demeanour. Those who knew him well, will vouch for his great sense of humour. He could laugh on small nuances of our daily lives.

Dr Serunjogi was a great friend of the ICAC. He presented talks at the ICAC plenary meetings, technical seminars and the World Cotton Conferences. His presence and critical insights elevated the technical level of meetings. Dr Serunjogi's loss leaves a huge void in cotton research. Dear Lastus, we will miss you.

Dr. Gopalakrishnan
Cotton Scientist, India

Dr. N. Gopalakrishnan passed away on 17th June 2022 in, Coimbatore India. He was an eminent cotton scientist and an efficient research administrator. Dr Gopalakrishnan served cotton science in various capacities. He joined the Central Institute for Cotton Research as a scientist and took over the regional research station as project coordinator and Head in 2007 and later joined the administrative headquarters of the Indian Council for Agricultural Research – ICAR, New Delhi in 2011 as the Assistant Director General – ADG (Commercial Crops).

Dr Gopalakrishnan was a meritorious student all through his academic career. He obtained his bachelors' degree in chemistry from St. Johns college, Masters in biochemistry from Mysore and Doctorate from the Indian Agricultural Research institute (IARI) New Delhi in 1988. He was fluent in English, Tamil, Hindi, Telugu, Kannada, and had working knowledge in Marathi, Bengali, and German.

Dr Gopalakrishnan was highly respected by his peers for his tremendous knowledge on cotton and for his immense scientific contributions. He had excellent skills of communication and leadership. He will be remembered as a kind-hearted person who was always ready to help anyone who approached him. He is survived by his wife Mrs. Gowri and son Mr. Pramod.

Dr. Sukumar Saha
Cotton Scientist, USA

Dr Sukumar Saha an outstanding cotton scientist passed away on 3 September 2021. Dr Saha was a Research Scientist with USDA, Starkville, MS, USA. He specialized in cotton genomics and cytogenetics; molecular marker development and mapping; interspecific chromosome substitution line development and international agricultural research.

He was the Founding Editor in Chief for American Journal of Plant Sciences, President of Mississippi Academy of Sciences (MAS), and was elected Chairman/Co-chairman of Germplasm and Genetic Stocks Work Group of International Cotton Genome Initiative 2002-2016. His consistent research productivity, its impact, and scientific leadership have been recognized with several awards from his peers. Dr Saha received the 2010 Cotton Geneticist award from the National Cotton Council. He was awarded with the prestigious ICAC Cotton Researcher of the Year Award in 2011 from the International Cotton Advisory Committee because of his leadership role in cotton research communities. He received the Crop Science Society of America (CSSA) International Service Award in 2016. He received the Crop Science Society of America Fellow Award in 2017. He also received Outstanding Senior Scientist Award in 2017 from the Association of Agriculture Scientists of Indian Origin (AASIO). He was recognized and awarded as Scientist of the Year in 2018 by the Mississippi Academy of Sciences (MAS) for his contribution to promote science in Mississippi.

Dr. Saha was prolific in his contributions of research publications and varietal development. His research productivity is well documented in over 114 peer reviewed journal papers, a co-edited book and one patent. Dr Saha in collaboration with the Uzbek scientists, developed for the first time a unique cotton plant with early flowering, early maturity, high yield and improved fiber qualities using *Phy A* gene silencing technology (RNAi technology). USDA/ARS patented this technology in collaboration with the scientists from Uzbekistan and Texas A&M University. Currently farmers are growing RNAi Porloq cotton varieties developed from this technology over 75,000 ha farming lands in Uzbekistan.

Dr. Saha is survived by his wife- Tripti Halder Saha, daughters- Sulagna (Kamal) Saha, Satabdi Saha and grandchild- Avik Lamichhane apart from his siblings.

Photo credit: Ms. Lorena Ruiz & Keshav Kranthi

www.wcrc7.org

4-7 October 2022

Steigenberger Hotel, El Tahrir, Cairo, Egypt

The World Cotton Research Conference (WCRC) is held once every four years in different cotton growing countries. The previous conferences were held in Australia (1994), Greece (1998), South Africa (2003), USA (2007), India (2011) and Brazil (2016). The WCRC serves as a global platform for researchers and experts to share the latest updates in cotton research and development. The 5-day technical programme will include invited plenary lectures and keynote talks that feature world-renowned cotton scientists. The conference provides an opportunity for researchers to present their work through oral and poster presentations and for the private and public sector institutions to showcase their latest technologies and products.

The WCRC is organised jointly by the International Cotton Advisory Committee (ICAC) and the International Cotton Researchers Association (ICRA). The ICAC was set up in 1939 in Washington, DC, as an intergovernmental agency to assist member governments with information and policies on cotton. The ICRA is a global association of researchers that was set up by the ICAC in 2012 to foster research collaboration amongst cotton researchers across the globe.

DATES TO REMEMBER

Fresh paper submission	30 July 2022
Paper acceptance	5 August 2022
Sponsorship booking	15 August 2022
Registration	15 August 2022

FRESH CALL FOR PAPERS

Researchers may submit new papers before 30 July 2022. Papers accepted previously will be presented as oral or posters at the conference. Fresh submissions if accepted will be included for presentation. The BOOK OF PAPERS will be released at the conference.

7 October 2022
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