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The ICAC Recorder

International Cotton Advisory Committee

Special Issue: Climate smart innovations as gamechangers for cotton production

Editorial

Climate change stands as the paramount challenge of our time, one that affects not only our current generation but also the well-being of generations to come. As we advance in our daily lives, our relentless exploitation of natural resources to meet our needs and enhance our comfort poses an ever-growing threat to the future of our planet and, in turn, to our own survival. Fascinatingly, recent findings indicate that regenerative agriculture holds promise not only in advancing the sustainability of our agricultural practices but also in combatting climate change. In this edition of the ICAC RECORDER, we delve into these transformative perspectives and explore the potential of regenerative agriculture as a vital solution to the climate crisis.

In 1958, Charles David Keeling recorded the first historical measurement, indicating that atmospheric CO_2 levels stood at 317 ppm at Mauna Loa in Hawaii. Over the ensuing decades, the concentration of CO_2 has steadily increased, reaching 420 ppm by December 2023. This alarming rise of over 103 ppm has occurred in just 62 years, contributing significantly to the global carbon load. To put this into perspective, each ppm of CO_2 equates to a mass of 7.821 billion metric tons, containing approximately 2.13 billion tonnes of carbon. Consequently, during this 62-year period, humanity has introduced a staggering 219 billion tonnes (corresponding to 103 ppm of CO_2) of carbon into the atmosphere.

On average, atmospheric CO_2 is currently increasing by at least 2 ppm annually, translating to the addition of more than 4 billion tonnes of carbon into the atmosphere each year. Given the ongoing growth of the global population, greenhouse gas (GHG) emissions are poised to continue their upward trajectory, indicating a potentially worsening situation. While reducing emissions is undeniably crucial, it constitutes only one facet of the solution. The more substantial challenge lies in capturing the excess 219 billion tonnes of carbon and permanently sequestering it back into the Earth's soils.

If any entity can accomplish this task, it is the plant kingdom. With approximately 1.5 billion hectares of arable land worldwide, there exists a significant potential to capture over 4.0 billion tonnes of carbon annually through biomass production, a portion of which can be effectively sequestered into the soil. The degree of success in achieving this permanent sequestration will largely depend on the development and implementation of climate-smart innovations that accelerate sequestration processes. Additionally, it will hinge on the collective determination of humanity to take action and persist until targeted sequestration goals are met.

Interestingly, even a relatively small fraction of global arable land can make a substantial difference. Currently, cotton cultivation occupies less than 2.3% of this available land. However, if all cotton farmers were to transition to regenerative agricultural practices and adopt carbon sequestration techniques such as converting cotton stalks into biochar, the cotton crop could emerge as a climate-positive contributor. By sequestering more greenhouse gases than it emits, cotton cultivation has the potential to play a pivotal role in mitigating climate change and promoting sustainable land use practices.

A Technical Seminar titled 'Climate-Smart Innovations: Transforming Cotton Production' took place as part of the ICAC Plenary meeting in Mumbai from December 2nd to December 5th, 2023. This seminar convened experts and thought leaders from around the world to explore climate-smart innovations poised to revolutionize cotton production. The seven distinguished experts delivered remarkable presentations, offering valuable insights into the various challenges and solutions within the realm of cotton production.

These experts collectively emphasized that in a world increasingly focused on mitigating greenhouse gas emissions, the cotton farming sector is faced with a unique set of challenges and opportunities. Recent research findings indicate that the adoption of climate-smart technologies not only contributes to emission reduction but also plays a pivotal role in enhancing carbon sequestration, improving soil health, and ultimately increasing crop productivity.

Carbon sequestration is a critical component of climate-smart agriculture (CSA). One particularly notable finding is that no-till cotton acreage can store more atmospheric carbon than it emits during production, establishing it as a net carbon sink. These innovations not only benefit the environment, biodiversity, and soil health but also enhance the profitability *of cotton farming. Climate change factors, including global warming, disrupted precipitation, and elevated CO_2 levels, significantly impact cotton yields. Rainfed cotton cultivation, reliant on monsoon rains, faces challenges due to delayed onset, dry spells, and rainfall deficits, all of which can result in significant yield losses. Climate-smart agriculture helps mitigate many of these climate-induced stress factors. Climate-smart cotton production technologies directly impact soil health, biodiversity, and yield. Climate-smart plant breeding is another avenue for addressing the challenges faced by cotton growers. Drought tolerance, a long-standing goal, presents complexity due to its quantitative nature. Traits associated with tolerance, such as stomatal conductance, transpiration, and photosynthesis, play pivotal roles in addressing this challenge. Integrating data from root system analysis and plant growth parameters is essential for identifying genotypes with advantageous traits for stable biomass accumulation under water deficit conditions.*

The world is facing unique challenges in cotton production, including factors like soil nutrients, pests, diseases, heat stress, aridity, and ozone. The IPCC has reported that temperature increases can have both positive and negative effects on cotton yields. Resilient cropping systems, regional assessments, and science policy engagement are essential for addressing the impact of climate change on cotton production and soil health. In sub-Saharan Africa, rainfed cotton farming is vital for livelihoods. Soil organic carbon plays a crucial role in maximizing soil health and crop production. Climate-smart practices for rainfed cotton farming encompass improving water retention, reducing soil compaction, enhancing water infiltration, increasing nutrient availability, and improving crop yield stability. Regenerative agriculture principles and practices, such as cover cropping and conservation tillage, promote soil health, carbon sequestration, and climate change mitigation while addressing challenges faced by smallholder farmers.

Regenerative agriculture, zero budget natural farming (ZBNF), and organic cotton farming are promising climate change mitigation strategies. Reducing chemical fertilizer usage, implementing cover crops, practicing conservation agriculture, and converting cotton stalks into biochar are key steps in reducing greenhouse gas emissions and enhancing soil health. Organic farming and ZBNF, with their reduced reliance on chemical fertilizers, can play pivotal roles in the global fight against climate change.

Emerging technologies now quantify soil carbon, translating it into measurable carbon credits to provide incentives for farmers effectively sequestering carbon on their farms. Digitizing carbon farming empowers smallholder farmers and promotes climate change mitigation. Practices like no-till, organic fertilizer application, intercropping, and optimized fertilizer usage can enhance carbon sequestration rates. Capacity building and knowledge transfer programs are essential for widespread adoption.

We are delighted to present the December 2023 special issue of the ICAC RECORDER, devoted to capturing the insightful presentations and discussions from the Technical Seminar on 'Climate smart innovations as gamechangers for cotton production'. This edition of the RECORDER features seven articles authored by the experts who delivered lead presentations at the Technical Seminar, along with an additional invited article by Dr. Marcelo Paytas, a renowned cotton scientist who, regrettably, couldn't attend the seminar.

The Technical Seminar underscored the urgent need to embrace climate-smart innovations in cotton production. These innovations not only mitigate climate change but also enhance soil health and boost yields. It is imperative that governments, organizations, and farmers work collaboratively to implement these practices, ensuring a sustainable and resilient future for cotton farming while contributing to global climate change mitigation efforts.

Against the backdrop of global efforts to combat climate change and reduce greenhouse gas emissions, the articles in this issue shed light on the transformative potential of these innovations. From regenerative agriculture practices that enhance soil health and carbon sequestration to climate-resilient technologies, our contributors have shared their expertise and insights on how cotton farming can not only adapt to a changing climate but also become a part of the solution to mitigate its effects. I earnestly hope this special issue serves as a valuable resource for cotton stakeholders and inspires continued progress in sustainable and climate-smart cotton production.

– Keshav Kranthi

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Climate-Smart Agronomy for Improved Soil Health and Biodiversity

Alexandra Perschau and Inka Sachse

The Aid by Trade Foundation (AbTF), Germany

Ms. Alexandra Perschau started her cotton career in 2001 and has since worked in various positions, always with a focus on sustainable cotton production in a small holder farming context across the African continent. Since 2017, she has served as Head of Standards and Outreach at the Aid by Trade Foundation, owner of the Cotton made in Africa Standard. The department is responsible for the standards and their continued development; their assurance and monitoring; evaluation, and learning; as well as supporting so-called Managing Entities to implement and continuously improve their performance. During her cotton career, Alexandra has worked on-site with civil society organisations, governmental institutions, and the private sector in Benin, Burkina Faso, Côte d'Ivoire, Ethiopia, Togo, Tanzania, Uganda, Zambia, and Zimbabwe. AbTF also cooperates with partners in Cameroon, Chad, Mozambique, and Nigeria.

Climate-Smart Agriculture (CSA)

Climate-smart agriculture (CSA) is a strategic approach designed to facilitate the transformation of agri-food systems towards environmentally sustainable and climate-resilient practices. CSA aligns with internationally agreed-upon objectives, such as the Sustainable Development Goals (SDGs) and the Paris Agreement. Its core objectives encompass enhancing agricultural productivity and income sustainability, fostering adaptability to climate change, and mitigating or eliminating greenhouse gas emissions when feasible, as defined by the Food and Agriculture Organization (FAO).

The Aid by Trade Foundation (AbTF) is a globally recognized non-profit organization dedicated to promoting sustainable raw materials in natural fibres. Its mission revolves around making a substantial and measurable impact on nature conservation, as well as improving the quality of life for people and animals. Guided by the principle of empowering communities through trade rather than relying solely on charity, AbTF fosters an innovative approach. The organization's extensive network includes partners throughout the global textile supply chains, as well as governmental and non-governmental organizations.

Recent Developments in Climate-Smart Agriculture

Over the past decade, its primary emphasis has been on adapting to climate change and exploring the potential for carbon sequestration. Carbon sequestration gained prominence as a means for companies to offset emissions originating from their products and operations. However, expanding the focus beyond carbon has proven challenging due to the lack of universally agreed-upon metrics and the substantial effort required for measuring the various interconnected impacts. With the emergence of more explicit requirements for companies, this limited perspective has begun to expand.

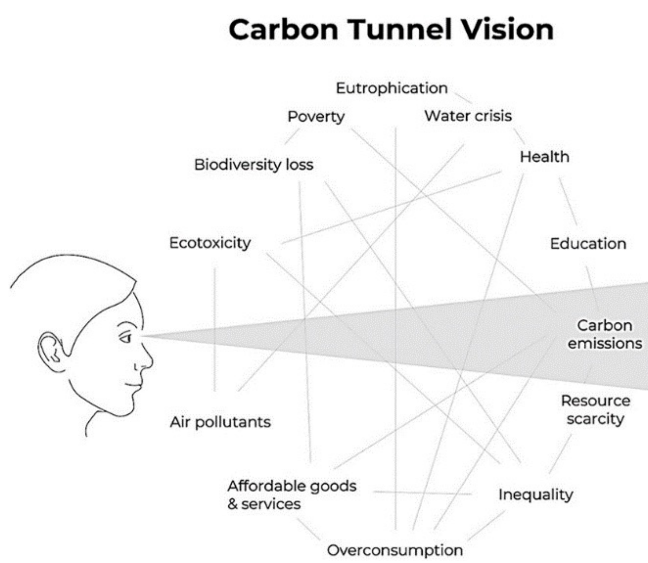


Figure-1. Graphical presentation of Carbon Tunnel Vision; Photo by Jan Konietzko from https://www.sei.org/perspectives/move-beyond-carbon-tunnel-vision/

CSA has become a widely discussed topic, as other terms like sustainable and regenerative agriculture. Nevertheless, despite the shared intention, individual interpretations of CSA may vary and, in single cases, offer opportunities for greenwashing as well. Recent developments have sharpened the requirements for companies selling products within the European Union (EU), particularly concerning claims and reporting related to carbon emission reductions, carbon removals and other environmental impacts. Scientific advancements in carbon removal modelling, remote sensing, and artificial intelligence have facilitated more accessible monitoring of land use changes, biomass variations, soil carbon removal, and biodiversity shifts.

Figure-2. Fungal filaments in Biochar and compost enriched soil. Image: CmiA

Table-1. Climate and biodiversity smart agricultural practices. (+++ high; ++ medium; + low).

Measure	Adaptation/ removal	Biodiversity/ Soil Health	C efficiency	Cost
Agroforestry	AD/RE	+++	+++	+++
Living soil cover	AD/RE	+++	+	+++
Reduced/no-till	AD/RE	+(+)	+	+
Organic fertilization	AD/RE	+++	++	++
Biochar application	AD/RE	+(+)	+++	+
Addition of bacteria, mycorrhiza etc.	AD/RE	+++	++(+)	++(+)
Intercropping	RE	++	+	+

Source: adapted from Soil & More Impacts

Requirements for Companies Regarding Climate and Biodiversity Impacts

Companies are facing increasingly stringent requirements related to their climate and biodiversity impacts and reporting formats. Notable regulations and reporting rules with international implications include the EU Corporate Sustainability Reporting Directive ("CSRD"). This directive applies to "large" EU companies and companies with substantial EU revenues, as well as those with an EU branch or subsidiary.

Under the CSRD, companies must disclose how sustainability-related factors affect their business operations, recognizing the concept of "double materiality." This entails environmental disclosures that encompass each of the EU Taxonomy's environmental objectives, which comprise:

1. Climate Change Mitigation: This includes reporting on Scope 1, Scope 2, and Scope 3 greenhouse gas emissions, addressing both direct and indirect emissions. Scope 1 emissions are direct emissions from sources owned or controlled by a company. Scope 2 emissions include indirect emissions from purchased electricity, steam, heat, and cooling and Scope 3 emissions are all other emissions associated with a company's activities.
2. Climate Change Adaptation: Companies are required to outline their strategies for adapting to the challenges posed by climate change.
3. Water and Marine Resources: Reporting on water resource management and conservation, as well as impacts on marine ecosystems, is essential.
4. Resource Use and Circular Economy: Disclosures should cover resource usage practices and efforts to transition towards a circular economy model.
5. Pollution: Companies must report on their measures to minimize pollution and environmental contamination.
6. Biodiversity and Ecosystems: The CSRD necessitates reporting on actions taken to protect and enhance biodiversity and ecosystems.

Additionally, within these disclosures, companies will need to articulate their plans for ensuring that their business models and strategies align with the goal of limiting global warming to 1.5°C, in accordance with the Paris Agreement. This objective aligns with the EU's European Climate Law, which aims to attain climate neutrality by 2050. Companies are also expected to provide insights into the due diligence processes they have implemented to address sustainability matters, encompassing actions taken to prevent or mitigate actual or potential adverse impacts related to their own operations and value chain.

Prominent Voluntary Initiatives

Several voluntary initiatives have gained prominence within the sustainability landscape, including:

1. Science-Based Targets Initiative (SBTi): This initiative is particularly focused on Scope 3 supply chains, with a significant emphasis on land use, especially addressing deforestation.
2. Science-based Targets for Nature (SBTN): SBTN provides valuable guidance on assessing impacts across various environmental dimensions, including Freshwater, Land, Biodiversity, Ocean, and Climate.
3. As these initiatives become more widely recognized, their significance in guiding sustainable practices across industries, including cotton trading, is on the rise. Textile brands are increasingly interested in understanding the condition of the land and engaging in improvement initiatives.

Recent Scientific Insights (1)

Recent scientific discoveries have shed light on crucial aspects of land and soil management:

1. Soil Organic Carbon (SOC) Dynamics: It has been revealed that Soil Organic Carbon (SOC) is not a stable carbon pool. Portions of SOC fluctuate over time, particularly during climate extremes. This finding holds significant implications for carbon projects that have traditionally relied on overly optimistic models regarding agricultural soil as a carbon storage medium.
2. Biologically Activated Charcoal: Given the dynamic nature of SOC, returning carbon in the form of biologically activated charcoal, utilizing high-temperature and low-emission technology, has emerged as an intriguing and relevant practice. This approach has the potential to play a pivotal role in carbon sequestration and land management strategies.

Recent Scientific Insights (2)

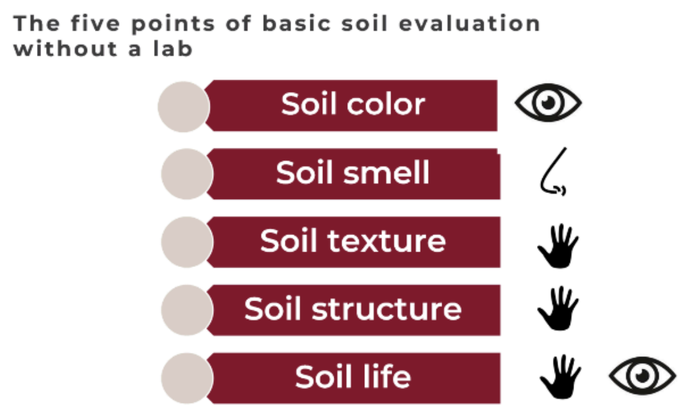
Recent scientific findings have uncovered the significant potential of mycorrhizal fungi in carbon removal from the soil. These fungi offer a promising avenue for enhancing carbon sequestration efforts.

Effective management strategies that promote increased fungal activity, coupled with a focus on achieving high functional diversity among fungi, can result in more stable carbon sources within the soil. However, it's crucial to recognize that these strategies can also impact the structure of the soil food web, extending their effects up to the ecosystem level (Hannula et al., 2023).

The AbTF Approach to Climate-Smart Agriculture

The AbTF approach to climate-smart agriculture encompasses a comprehensive journey, starting from an overview and progressing to a detailed assessment leading up to project development. Key components of this approach include:

1. Remote Sensing: Collaborative efforts with organizations such as Cotton made in Africa (CmiA), a German geospatial IT company, and one partner in Tanzania are initiating the implementation of remote sensing technologies for African Cotton.
2. In-Field Soil Analysis: CmiA partners are actively testing a infrared soil scanner device developed by a Dutch Ag-Tech company to facilitate in-field soil analysis.
3. Soil Health: Simple and manual field soil assessments are being conducted for CmiA and Regenerative Cotton Standard (RCS) partners to promote soil health.
4. Climate Projects: AbTF is actively involved in the development of guidelines that aim to facilitate the recognition of case-specific potential and the execution of cost-benefit analyses in conjunction with sustainable agriculture practices.



Basic Soil Evaluation

Incorporating in-field basic soil evaluation practices is fundamental to this approach, with a focus on assessing soil color, odor, texture, structure, and the presence of soil life. These foundational elements provide essential insights into soil health and suitability for various farmer-led agricultural and environmental initiatives on the ground.

Relevant links:

AbTF https://www.aidbytrade.org/

RCS https://regenerative-cotton.org/

Science based targets Initiative https://sciencebasedtargets.org/

CSRD: https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

Articles: Mycorrhizal mycelium as a global carbon pool https://www.sciencedirect.com/science/article/pii/S0960982223001677

Will fungi solve the carbon dilemma? https://www.sciencedirect.com/science/article/pii/S001670612200074X

Hannula, S.E., Jongen, R. and Morriën, E., 2023. Grazing by collembola controls fungal induced soil aggregation. Fungal Ecology, 65, p.101284.

Impact of Climate Change on Global Cotton

Michael Bange
Cotton Seed Distributors, Australia

Dr. Michael Bange has been a cotton systems agronomist for 30 years, delivering innovation and substantial impact for sustainable cotton production. He is currently the Commercial Research Manager with Cotton Seed Distributors in Australia, supporting investment in grower-facing research. Before that, he was a Chief Scientist with CSIRO Australia, where he led initiatives in cropping systems research; physiology and agronomy; into managing abiotic stress; fibre quality initiatives across the whole value chain; crop nutrition; climate change impacts; and water use efficiency.

His career has also involved delivery of decision support systems for assisting crop management and knowledge dissemination. Recognition of his contributions in cotton physiology and agronomy was acknowledged by receiving the prestigious USA Beltwide Cotton Award in 2017, and in 2019 with a Service to Cotton Science award from the Association of Australian Cotton Scientists. He is a Fulbright Scholar with longstanding international collaborations, especially in the USA.

Introduction

Worldwide, cotton is broadly adapted to growing in temperate, sub-tropical, and tropical environments, but global cotton production may be challenged by future climate change. It will be necessary to understand these impacts such that vulnerabilities and opportunities for adoption are recognized. Various global analyses of climate change impacts on crop productivity identify challenges with soil nutrition, pests and diseases, heat stress, aridity, flooding, and ozone.

The presentation (that is decidedly plant and crop focused) outlined worldwide specific research efforts that have generated understanding of climate change impacts on cotton production from a plant and soil perspective, including impacts of elevated atmospheric CO_2 concentrations; elevated temperatures; changes in water dynamics; integrated effects of CO_2 by temperature; waterlogging; ozone; soil health; and legacy effects. It was recognized that these impacts are already complex within a biological system.

Climate change

Climate change will have both positive and negative effects on cotton production. Increased CO_2 can increase yield in well-watered crops, and higher temperatures will extend the length of the growing season (especially in current short-season areas). However, higher temperatures also have the potential to cause significant fruit loss and lower yields, as well as alter fibre quality and reduce water use efficiencies. Extreme weather events such as droughts, heatwaves, and flooding also pose significant risks to improvements in cotton productivity.

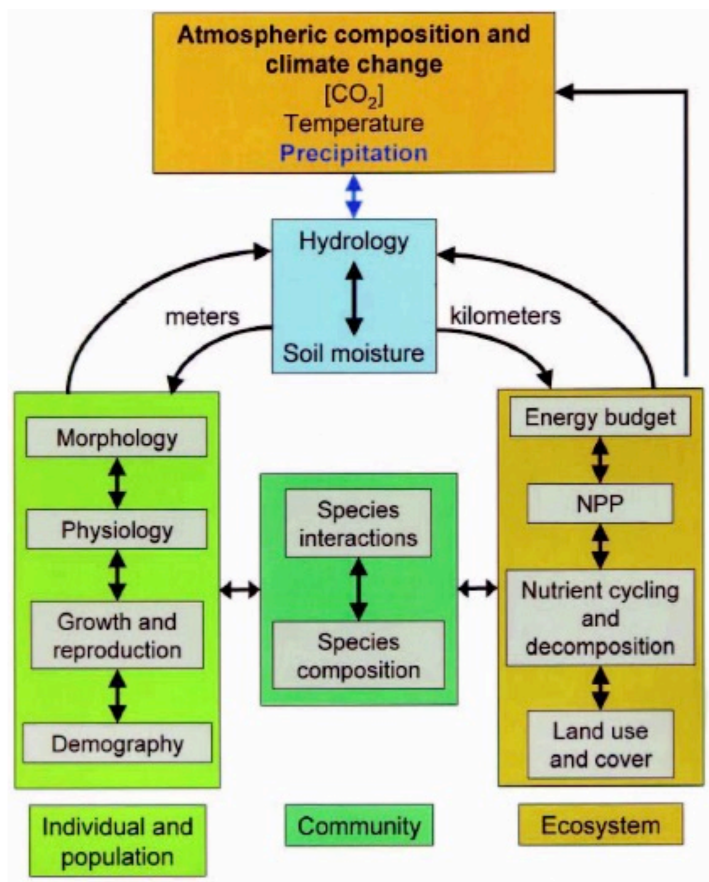


Figure-1. Complex responses of biological systems to increased atmospheric composition of CO2 and the associated climate change effects.

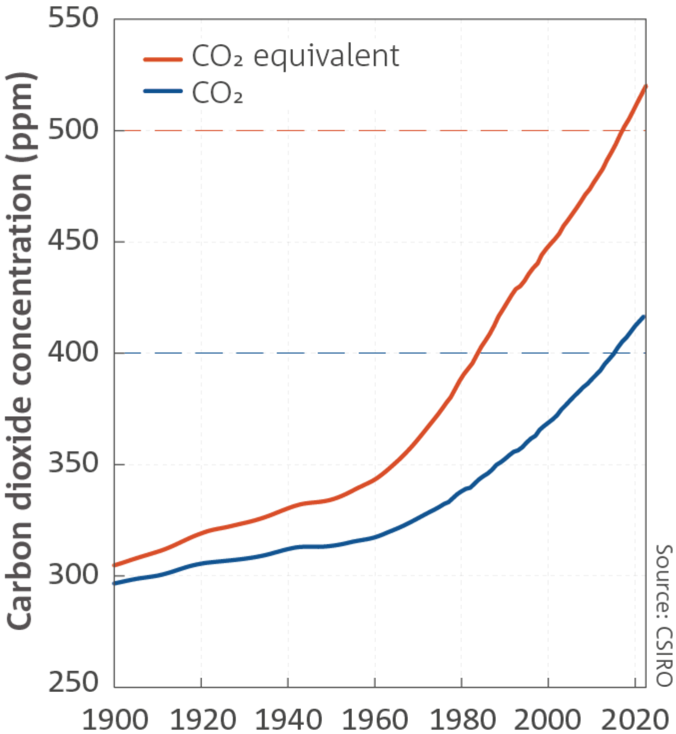


Figure-2. Historic increases in carbondioxide concentrations.

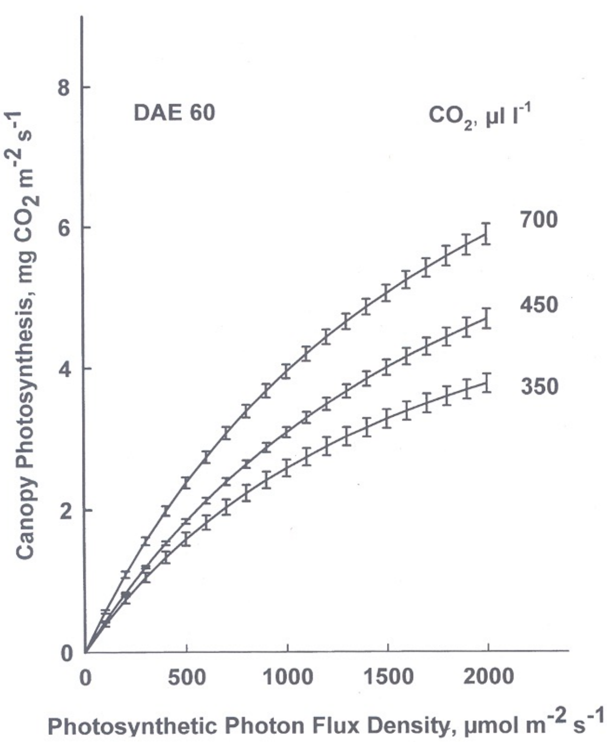


Figure-3. Canopy photosynthesis in response to elevated CO_2.

Of all the projected changes in climate, the ongoing rise in CO_2 is the best documented and forecasted climate variable known to impact plant growth. Elevated CO_2 can individually mitigate many of the negative impacts of environmental stresses on plants, although when the integrated effects of climate change are considered, this can substantially change outcomes. Examples are given of recent research where these outcomes are investigated.

Figure-4. Elevated carbondioxide levels resulted in 68% more growth while requiring 18.0% less water.

This research highlighted challenges with increasing canopy level photosynthesis, especially for cotton production environments considered high input (yields greater than 2,000kg/ha). Along with higher temperatures, this led to increased fruit loss and vegetative growth, resulting in lower lint yields and water use efficiencies.

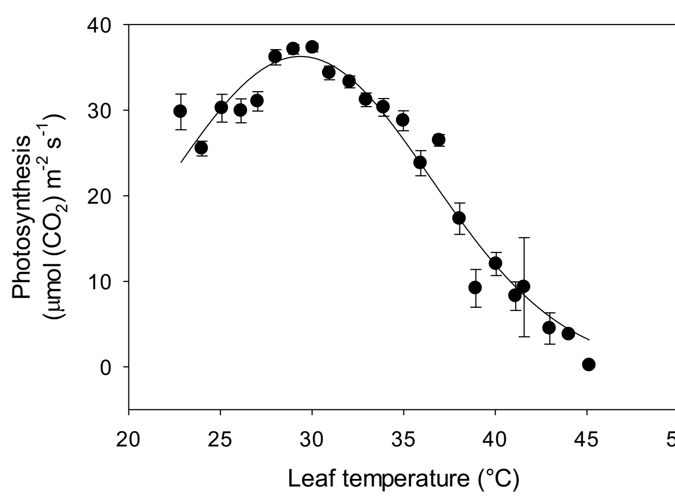


Figure-5. Effect of leaf temperature on photosynthesis

Higher temperatures and excessive shading caused by a dense canopy may require more aggressive management of early vegetative growth. It was also noted that the effects of ozone concentrations and increases in boll respiration from higher temperatures would potentially add to these effects.

Waterlogging is particularly challenging for cotton crops, from both a plant and soil perspective, particularly as cotton is naturally poorly adapted to this stress. Currently, one of the most effective means of insurance against waterlogging is utilizing raised beds in the cropping system.

Figure-6. A water-logged field.

Figure-7. A water-logged field.

Increasing atmospheric vapor pressure deficit resulting from low humidity can also increase crop stress despite adequate levels of soil moisture. This will require a need to better quantify plant water stress across environments by moving to plant-based sensing approaches.

Climate change also has the potential to affect cotton fibre quality due to limited access to water during boll filling (fibre length reductions) and increases in temperature (increases in micronaire). An integrated approach to fibre quality management across the production chain will substantially help manage fibre quality to help cotton compete with synthetics.

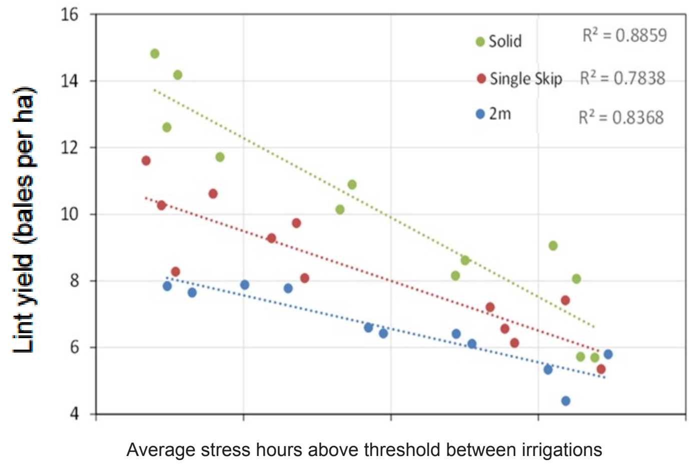


Figure-8. Impact of water-stress on lint yields

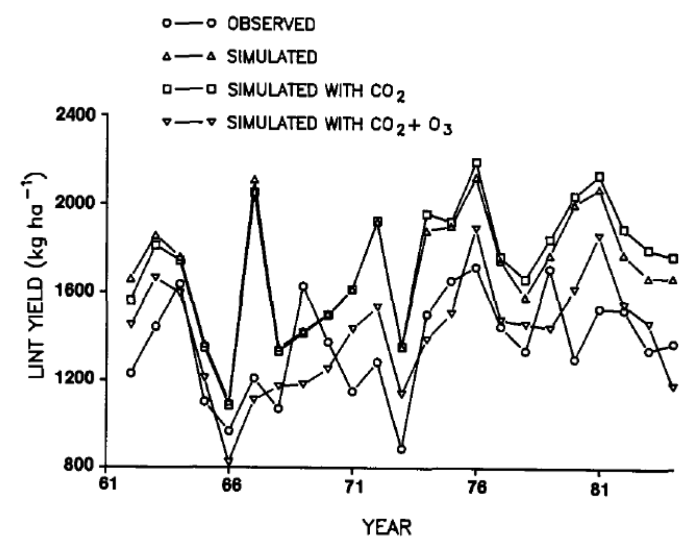


Figure-9. Lint yield influenced by simulated CO_2 and ozone.

In terms of belowground responses, climate change can affect soil microbial communities, especially those that mediate N transformations such as ammonia-oxidizing bacteria and archaea. This has consequences for soil N availability and plant N uptake. Coupled with these effects, elevated CO_2 and temperature can change the quality of plant material grown, which is subsequently incorporated into soil. Crop residue quality generated in these climate change conditions resulted in less soil N availability in the subsequent season (despite similar levels of fertilizer applied), which was reflected in the leaf N at flowering, and lint yield of this season. These results indicate the importance of legacy and feedback effects through soil biology and decomposition processes in understanding long-term responses to climate change factors.

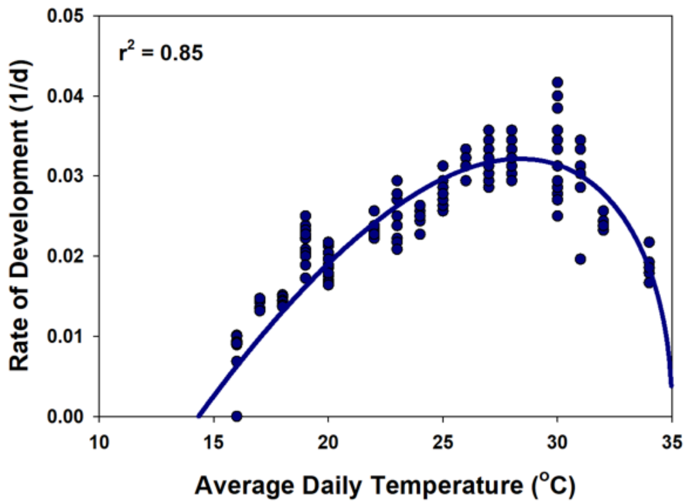


Figure-10. Impact of water-stress on lint yields

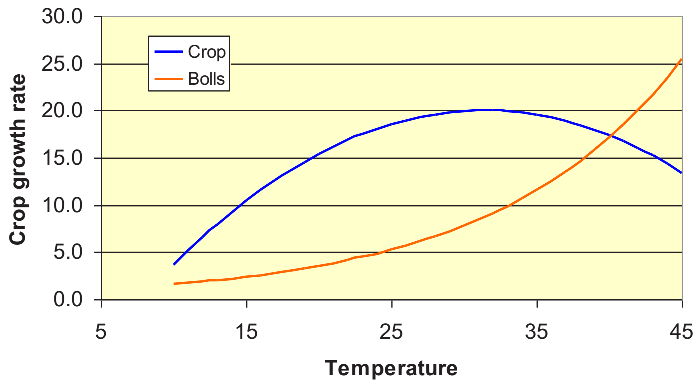


Figure-11. Impact of temperature on canopy growth rate.

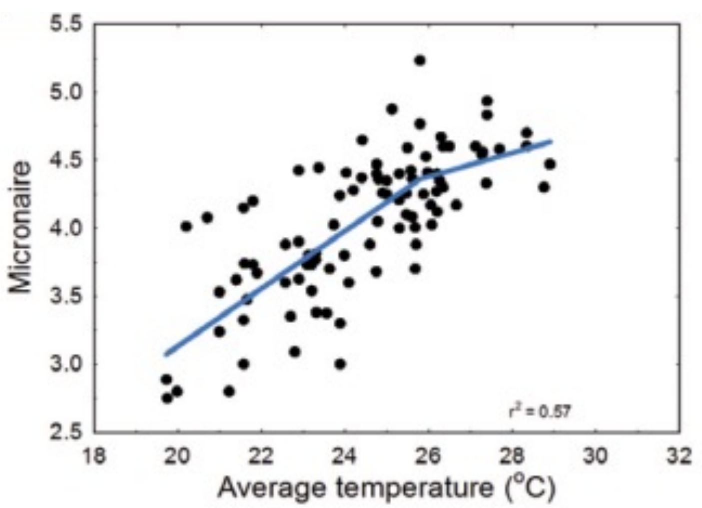


Figure-12. Impact of temperature on micronaire

In conclusion, the presentation outlines some key strategies for consideration in adaptation to the impacts of climate change. Key approaches to raising and maintaining yields are to develop and refine new technologies (such as precision agriculture, cultivars with both yield and fibre quality improvements, chemicals, etc), agronomic practices (including sowing time, plant population, crop nutrition, etc) and management systems (such as integrated weed and pest management) that enable cotton to grow healthier and become more tolerant to both abiotic (temperature and water stress, waterlogging) and biotic stresses (pests and diseases).

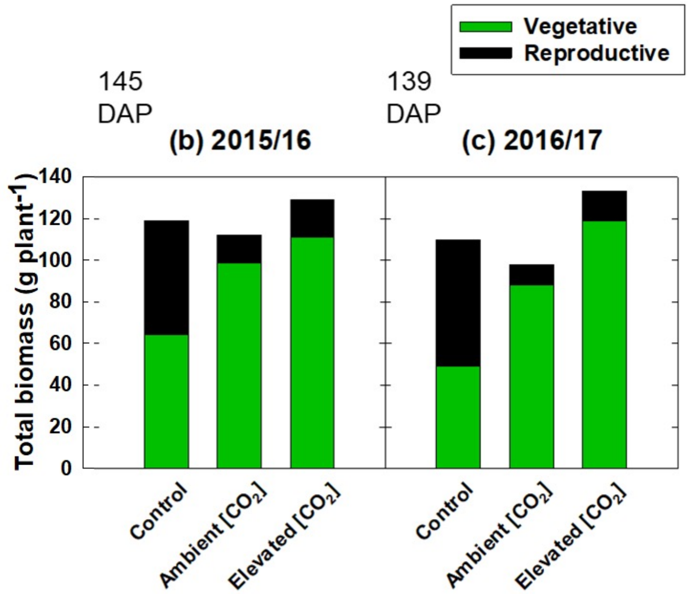


Figure-13. Integrated effects of CO_2 x temperatrure -biomass.

Overall, detailed, and integrative research over a greater range of environments and stresses is needed to properly assess impacts and adaptation options that translate into realized yield and quality improvements. Few studies have been conducted on any crop that deals with three-way interactions of changes in combinations of atmospheric CO_2, water, temperature, and atmospheric humidity.

Figure-14. Integrated effects of CO_2 x temperatrure on boll retention.

Future cotton research programs will need to ensure that knowledge and technologies respond to these impacts, and strategies are developed to both exploit and avoid maladaptation to climate change.

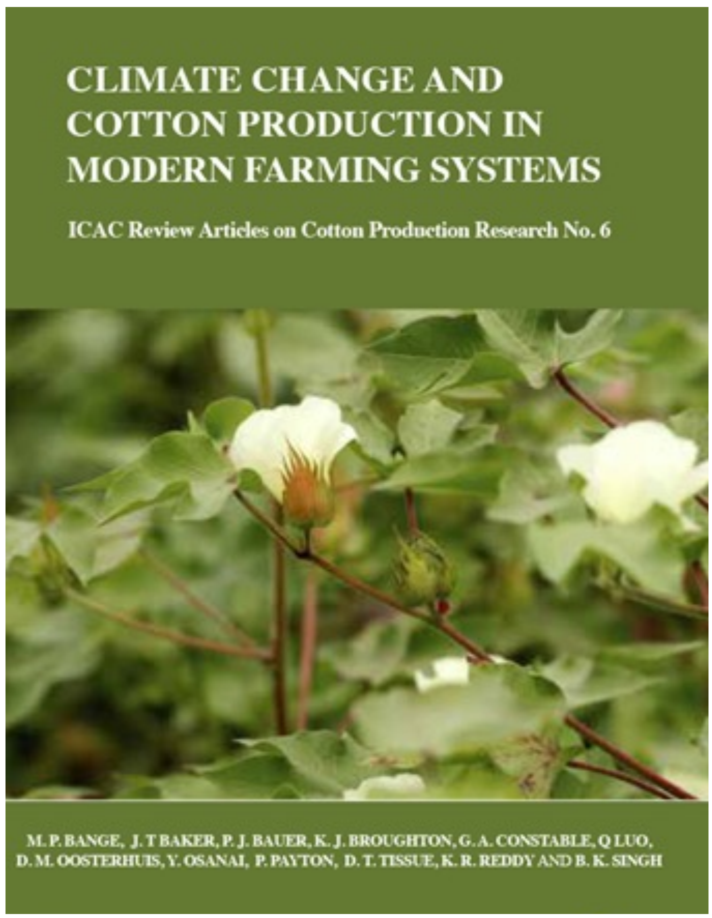
Figure-15. Australian National Cotton Climate Change Facility – Interactive effects of climate change in the field

Finally, it is acknowledged that most approaches discussed here are decidedly production focused, and therefore impacts on global production are by no means comprehensive. There are no doubt other significant efforts to combat the changing climate from other perspectives, scales, and policies. Ultimately, it is a multi-faceted, systems-based approach that combines all elements mentioned here — as well as others that provide the best insurance to harness the change that is occurring, and best allow cotton industries to adapt.

Figure-16. Canopy Evapotranspiration and Assimilation Chambers in Lubbock, Texas, USA.

Given that there will be no single solution for all the challenges raised by climate change and variability, the best adaptation strategy will be to develop more resilient systems. Early implementation of adaptation strategies — particularly those that enhance resilience — has the potential to significantly reduce the negative impacts of climate change.

Figure-17. Free Air CO_2 Enrichment (FACE) – Maricopa, Arizona.



Acknowledgements

To the various colleagues from around the world that have contributed to these discussions, thank you. This paper was adapted from the review sponsored by the International Cotton Advisory Committee in 2016.

Climate-Smart Cotton Production Technologies for Improved Yield

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Dr YG Prasad is currently working as Director, ICAR-Central Institute for Cotton Research (CICR), Nagpur, since 2020 and steering the All India Coordinated Research Project (AICRP) on Cotton implemented through 21 State Agricultural University centres. Current focus is on technology targeting to enhance cotton productivity across India through large scale demonstrations on HDPS cotton in suitable agro-ecology, adopting a cluster-based and value-chain approach in public-private partnership mode. An entomologist and IPM expert with diverse experience in frontline extension and climate change adaptation initiatives, Dr Prasad has coordinated country-wide efforts on preparation of district-level agricultural contingency plans and conduct of farmer participatory technology demonstrations for climate resilience in agriculture through 121 farm science centres. He did his doctoral studies at the Indian Agricultural Research Institute (IARI), New Delhi, and later worked at IIOR and CRIDA, Hyderabad. A recipient of NUFFIC fellowship, he has participated in international conferences/workshops in the USA, UK, Netherlands, France, Brazil, Indonesia, and Egypt, and has 150 publications to credit.

Introduction

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has highlighted the complex and varied impacts of climate change on cotton crops. These impacts have been observed to have both positive and negative effects. Negative consequences include disruptions in phenology, adverse effects on plant water status, increased incidence of cotton bollworm, and deterioration in fibre quality, as detailed by Bezner Kerr et al (2022). Conversely, rising temperatures are expected to have beneficial effects on cotton cultivation, given cotton's heat tolerance.

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A meta-analysis that examined the potential influence of climate change on global cotton yields utilizing crop simulation approaches demonstrated the significance of various factors.

These factors include temperature, precipitation patterns, CO_2 concentration, and the implementation of adaptation measures, as documented by Na-Li et al (2021).

In India, assessing the influence of a changing climate on crop production is a multifaceted endeavour, primarily due to the prevalence of a wide range of cropping systems and varying

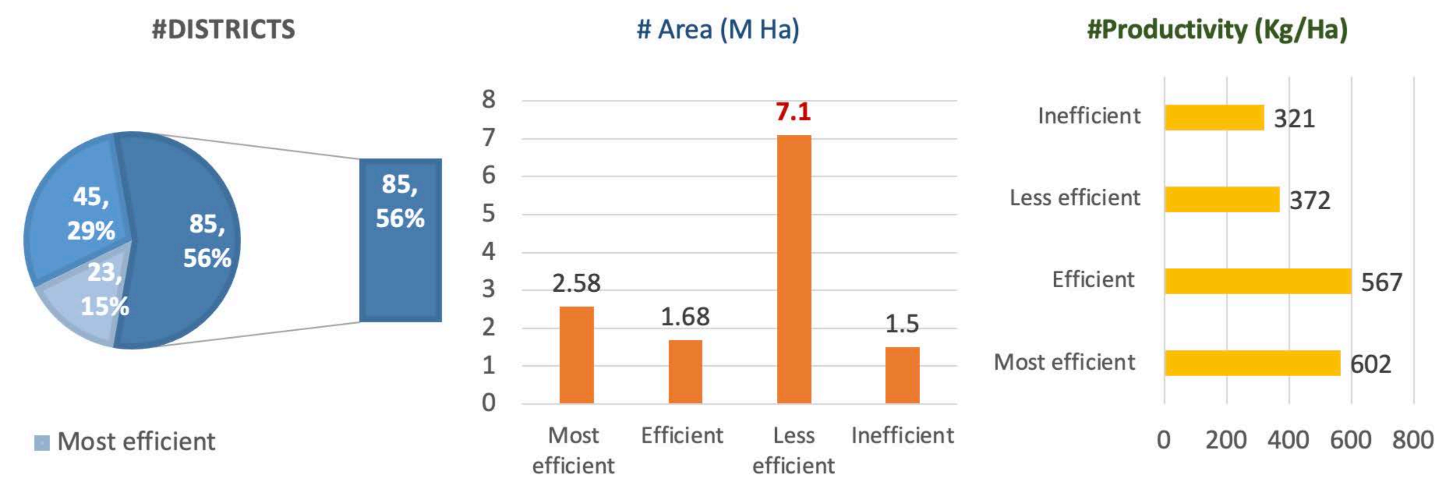

Figure-1. Area and yield of 153 districts in 10 States growing cotton in more than 5,000 ha. (https://eands.dacnet.nic.in/. Predominantly rainfed cultivation – prone to erratic rainfall levels of technology adoption, as highlighted by Hebbar et al in 2013.

Resilience to climatic variability holds particular significance in the context of the monsoon-dependent agriculture practiced across most parts of the Indian sub-continent. Approximately 75% of the annual rainfall, with an average of 868.6 mm, occurs during the Southwest Monsoon season from June to September.

Factors such as the onset delay, dry spells, and rainfall deficits within the crop season play a pivotal role in determining the productivity of rainfed crops, including cotton, where more than 60% of the cotton area relies on rainfed conditions. A dry spell index (DSI) has been developed to quantify the cumulative impact of dry spells on cotton grown in the kharif season that are cultivated and harvested during the monsoon season lasting between April and October in South Asia. This index has been used to analyse district-wise variability of DSI across rainfed regions in India, utilizing rainfall data from 1,636 weather stations.

The findings indicate that the impact of DSI on cotton yield loss ranges from 50% to 74% in approximately 44% of cotton-growing regions, as reported by Bal et al in 2022. These results underscore the critical role that climatic factors, particularly dry spells, play in the productivity of rainfed cotton crops in India.

Rainfed Cotton Production Prone to Erratic Rainfall

An attempt was made to classify major cotton-growing districts in India using a classification system based on the Relative Spread Index (RSI, as a percentage of normalized cotton area) and the Relative Yield Index (RYI, as a percentage of normalized yield) with a range for each, varying between <100 to >100.

This analysis was conducted using data for the triennium ending in 2020-21, as outlined in Table 1. Among the 153 districts in the study, it was observed that nearly 67% of the total area, equivalent to 8.5 million hectares, fell into the category classified as less efficient or less productive.

These districts are predominantly rainfed and are susceptible to the uncertainties associated with monsoon rainfall patterns.

Increasing Vulnerability of Cotton in the Irrigated North Zone

Significant and rather surprising changes have become evident in terms of area, production, and productivity in the irrigated northern zone states of Punjab and Haryana, as depicted in Figures 2 to 4. In the 2022/23 season, there was a noteworthy reduction in the cotton-growing area in these two states, ranging from 7% to 16%, compared to the 5-year average.

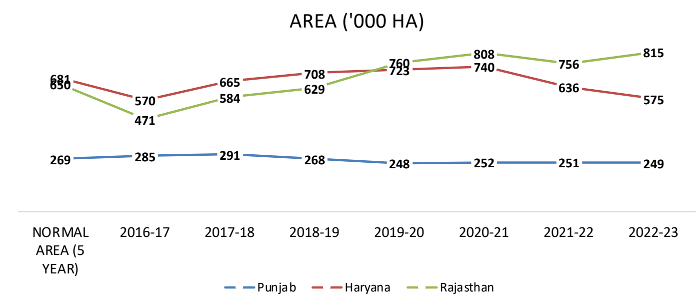

Figure-2. Trends in area (Ha) in north zone 2016-2022

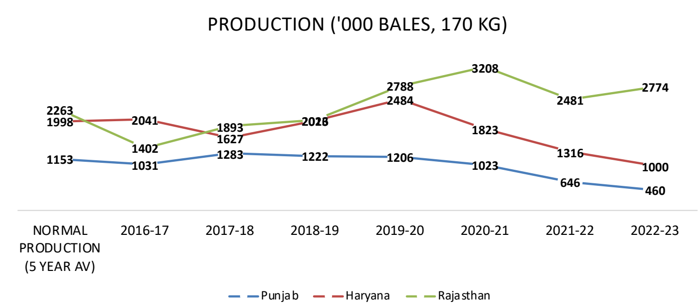

Figure-3. Trends in production ('000 bales, 170 Kg) in north zone 2016-2022

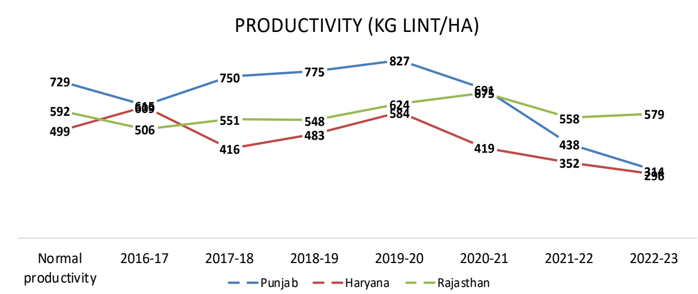

Figure-4. Trends in yield (Kg/Ha) in north zone 2016-2022

Table-1. Classification of districts based on relative area and productivity .

				Yield (kg lint/ha	
Classification	# Districts	Area (ha)	% of study area	Mean	Range
Most efficient (both RSI & RYI >100)	23	25,76,527	20.07	567	456-826
Efficient (RSI <100 & RYI >100)	45	16,82,100	13.10	602	459-904
Less efficient (RSI >100, RYI <100)	41	71,00,480	55.31	372	205-454
In-efficient (both RSI & RYI <100)	44	14,79,311	11.52	321	145-519
Total	153	1,28,38,418	100.00	466	-

Additionally, production witnessed a substantial decline, ranging from 50% to 60%, and productivity dropped by 41% to 57%. Several factors have been attributed to these declines.

One prominent factor is the spread of resistant populations of pink bollworm to the northern zone, facilitated by the import of infested seed and seed cotton by ginning and pressing units. Furthermore, the storage of infested crop residue for fuel purposes, coupled with the increasing incidence of whitefly and boll rot driven by weather conditions — as well as the prevalence of cotton leaf curl virus due to the cultivation of highly susceptible genotypes — has contributed to these challenges.

An exception to this trend is the cotton scenario in Rajasthan, which has shown a positive trajectory. However, recent field reports from the 2022/23 season have indicated significant crop losses in the two northern districts of Rajasthan, primarily due to instances of pink bollworm infestation and boll rot. Conversely, higher productivity has been reported from the southern districts of Rajasthan during the same period.

Selection of Suitable Genotypes

The potential for cotton genotypes to thrive is influenced by various factors, including biotic and abiotic stresses, which significantly impact production (Constable and Bange, 2015).

As cotton production systems intensify and climate patterns become more unpredictable, the challenges posed by pests and pathogens are on the rise. In rainfed agro-ecologies, it becomes crucial to select cotton genotypes with growth durations that align with the availability of soil moisture, also known as the length of the growing period.

Table-2. Breeding targets for developing cultivar product-profiles suitable for target areas.

	Central and South zones		North zone
	Rainfed light soils	Irrigated heavy soils	Irrigated loamy soils
	60% area	24% area	16% area
Maturity duration (days)	140-150	150-165	150-165
Plant height (cm)	100-140	140—160	140- 160
Plant Type	Compact	Open	Open
Boll weight (g)	4 - 5 g (medium)	5.5- 6 g (big)	3.8- 5 gm
Boll Number / plant	8-10	30-40	35-45
Sucking pest tolerance	Jassid	Jassid	Whitefly
Tobacco streak virus	Tolerant	Tolerant	-
Leaf curl virus	-	-	Resistant
Plant population / m row	3-7	1-3	2-3
Lint yield (kg/ha)	750	1000	1100
Abiotic stress tolerance	Drought, heat & salinity	Heat, water logging & salinity	Heat & salinity tolerance

Presently, a significant proportion of cotton growers (approximately 95%) cultivate Bollgard (BG) II cotton hybrids with a growth duration spanning 180 to 200 days. However, in many rainfed regions with shallow to medium-deep soils, the soil moisture availability may not be sufficient to meet the crop's demands during the peak boll load period following the cessation of monsoon rains, typically starting on October 1st.

To address this challenge and enhance productivity beyond the global average — and meet the increasing demands for fibre and the projected per capita clothing requirements by 2030 — it is imperative to develop product profiles for genotypes possessing desirable traits related to plant type, maturity, and stress tolerance (as outlined in Table 2). Making these genotypes readily available to growers is a key strategy.

In pursuit of this objective, recent provisions have been established for the early identification and release of cultivars with desired characteristics such as compact plant type, early maturity, higher ginning outturn, and resistance traits. These cultivars are developed through marker-assisted selection within the multi-location evaluation system of the All India Coordinated Research Project (AICRP) on Cotton.

Technology Targeted to Agro-ecology

A joint initiative on scaling of technologies for cotton was launched in 2023 by the Ministry of Agriculture and Farmers Welfare and Ministry of Textiles and was implemented by ICAR-Central Institute for Cotton Research (CICR), Nagpur. The project's primary objective is to conduct large-scale technology demonstrations in public-private-partnerships, involving collaborations with partners from the textile and seed industries.

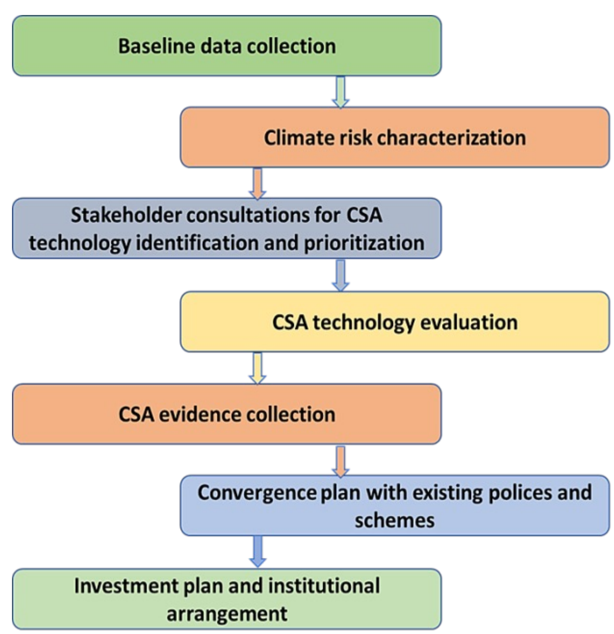

Figure-5. Scaling out Climate Smart Agriculture (CSA): case study of a cotton growing district (Adilabad, Telangana state). https://cgspace.cgiar.org/handle/10568/111203

Additionally, it aims to provide grassroots extension support through farm science centres. To enhance productivity, the project made early-maturing and compact-genotype seeds available to farmers for cultivation in rainfed, shallow to medium-deep soils. This involved adopting a high-density planting system (HDPS) with a spacing of 90 x 15 cm, resulting in approximately 74,000 plants per hectare, along with effective canopy management.

Figure-6. A cotton field under high density planting

Figure-7. A Demonstration field on high density planting

Efforts are also underway to implement best practices for boosting extra-long staple (ELS) cotton production in select niche areas. Notably, these initiatives have included geo-referenced farmer demonstrations, covering 61 cotton-growing districts across eight states. Despite the challenges posed by a difficult season characterized by erratic rainfall, these demonstrations have yielded positive outcomes.

To ensure technology assistance reaches registered farmers efficiently, a direct-benefit transfer (DBT) mechanism has been adopted, utilizing digital payment methods. This represents a pioneering approach in providing support to cotton farmers in the country.

Increasing In-field Crop Diversity, Local Innovations for Soil and Water Conservation Practices

Tailoring cotton-based intercropping to specific locations and ensuring it is financially rewarding has proven to be an effective climate-resilient agricultural practice. This approach optimizes the utilization of available space, nutrients, and water resources. For instance, in Gujarat, it is recommended to adopt an intercropping system consisting of cotton alongside peanut, blackgram, or sesame. Meanwhile, in Maharashtra, a cotton intercropping system with greengram, blackgram, soybean, groundnut, or cowpea is recommended, showcasing the added benefit of natural pest control.

Figure-8. Intercropping of cotton with blackgram

Figure-9. Intercropping of cotton with peanuts

Figure-10. Intercropping of cotton with soybean

In rainfed ecosystems, cotton crops often face both excess and deficit water stress. The implementation of location-specific, in-situ soil moisture conservation practices plays a vital role in maximizing soil water retention during deficit conditions and ensuring the safe disposal of excess rainfall during extreme weather events. Venugopalan and Prasad (2022) have extensively documented suitable soil moisture conservation practices tailored to different cotton-growing states, aiming to enhance resource use efficiency and overall productivity.

Figure-11. Earthing-up in dry soils.

Figure-12. Mulching with green manure crops

Figure-13. Mulching with dry crop residues

Figure-14. Bed planting and mulching

Many rainfed cotton-growing states in India possess significant potential for rainwater harvesting through the construction of farm ponds. The harvested rainwater can be efficiently utilized to provide supplemental irrigation during critical crop growth stages, contributing to climate resilience and increased productivity.

In irrigated conditions, the adoption of polymulch combined with drip fertigation has been shown to boost productivity while improving water- and nutrient-utilization efficiency.

Several straightforward methods for soil health restoration have been developed and demonstrated, though their widespread adoption remains an opportunity. Practices such as planting a legume green manure border crop like Sesbania sp. (Dhaincha) and utilizing it as green manure in organic cotton cultivation can enhance soil moisture conservation and weed suppression.

Additionally, repurposing leftover cotton stalks post-harvest can be an excellent source of carbon and nutrients for the soil. Practices such as returning shredded stalks to the soil or using them as organic mulch contribute to soil health improvement by increasing soil organic matter, stimulating microbial activity, enhancing soil moisture retention, and enriching crop nutrition over time. A simple yet highly beneficial practice in rainfed situations involves earthing-up the interspaces after the second weeding, which significantly enhances crop yields.

Value-added Agro-advisory Services at Finer Scale

The India Meteorological Department (IMD) operates an essential service known as the Agrometeorological Advisory Services (AAS), which furnishes medium-range weather forecasts at the district and block levels for the upcoming five days. This valuable information empowers 130 Agromet Field Units (AMFUs) within State Agricultural Universities and District Agromet Units (DAMUs) at Krishi Vigyan Kendras (KVKs) to issue agro-advisories to local farmers twice a week. You can access these advisories on the IMD's website.

The ICAR-Central Institute for Cotton Research (CICR) further extends its services through the 'e-kapas' (ICT) network, delivering voice messages in local languages to registered farmers on a weekly basis. These messages are designed to provide timely and relevant information. You can access additional weekly cotton advisories for all cotton-growing states in the country on the CICR website.

The Crop Pest Surveillance and Advisory Project (CROPSAP), a collaborative effort involving multiple stakeholders, has been also successfully implemented in the cotton sector for over a decade. Led by the State Department of Agriculture in Maharashtra, this initiative focuses on monitoring crop pests and offering advisories to manage them effectively. You can find more information about CROPSAP on its dedicated website.

Dissemination of Insect Resistance Management Strategies

In response to the emergence of pink bollworm resistance to Bt cotton (Kranthi, 2015), ICAR-CICR and AICRP initiated an outreach program aimed at disseminating insect resistance management strategies in cotton-growing states.

Since 2018, approximately 1,000 cotton farmers in 100 villages across 21 cotton-growing districts in the North, Central, and South zones have been selected to participate in this outreach program. Through collaborative efforts, the program has achieved a notable reduction of 30%-40% in pink bollworm infestations within the demonstration plots (Nagrare et al, 2023).

Similar strategies are now essential in the northern zone states to raise awareness and monitor the incidence of resistant pest populations, which have expanded into this region. Off-season crop residue management has been identified as a pivotal intervention for mitigating the pink bollworm menace in the northern zone (Prasad, 2021).

The Way Forward

Cotton productivity in India has encountered challenges, with yields remaining below approximately 500 kg lint/ha for nearly a decade following the initial peak in area and production back in the 2013/14 season.

The widespread cultivation of *Bt* cotton, covering more than 95% of the cotton-growing area, now faces susceptibility to pink bollworm. This susceptibility has led to widespread outbreaks of this destructive pest in central and southern states, such as Gujarat in 2015, Maharashtra, Telangana, Andhra Pradesh, and Karnataka in 2017/18, and eventually extending to previously unaffected areas in the northern zone states of Punjab and Haryana in 2021/22.

The increased frequency of whitefly infestations and boll rot, driven by weather conditions, has further disrupted the cotton supply chain and contributed to price volatility.

Given these challenges, adapting to, and building resilience against climate change and variability have assumed paramount importance in efforts to improve yield and foster growth in cotton production in India.

Key measures include the careful selection of suitable cotton cultivars, efficient management of abiotic stresses (such as soil and water resources), and proactive strategies for addressing biotic stresses, encompassing insect pests, diseases, nematodes, and weeds.

Furthermore, raising awareness, extending support and information to farmers, and implementing supportive policies for the adoption of productivity-enhancing technologies are essential steps to achieving sustainability and growth in India's cotton industry.

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The ICAC Recorder

Climate-Smart Plant Breeding of Cotton: Enhancing Resilience in the Face of Climate Change

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He worked for 13 years in Brazil with Embrapa's Cotton Research Center (Campina Grande, 2005-2010; Goiânia, 2010-2018), and currently works in cooperation with cotton improvement programs in Africa (Cameroon, Benin, and Côte d'Ivoire). His areas of expertise include cotton breeding and molecular genetics, and he presently is working mainly in pre-breeding and breeding. He currently serves as CIRAD's Cotton Supply Chain Correspondent.publications to credit.

Introduction

Cotton production faces significant challenges due to the impacts of climate change, particularly in rainfed areas. Our research focuses on the urgent need to address three major climate-related challenges: disrupted rainfall patterns affecting water availability, rising temperatures, and increased atmospheric CO_2 concentrations.

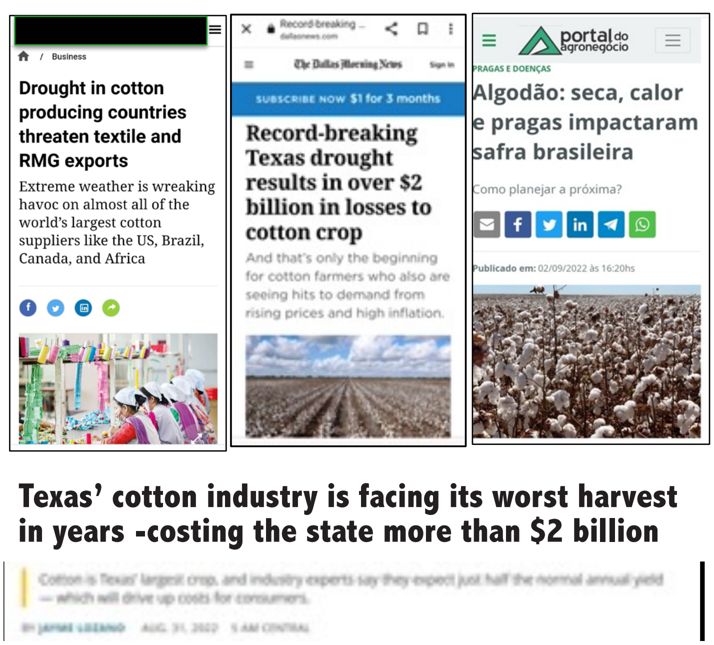

Figure-1. Climate change threatens cotton crop across the world.

Water Availability and Climate Change

Cotton cultivation relies heavily on sufficient water availability during critical stages of its growth, making it vulnerable to the erratic distribution and irregular rainfall patterns associated with climate change (Monfreda et al., 2008). Disrupted monsoons can severely impact water availability for crops, jeopardizing cotton production. Furthermore, the rise in global temperatures and climate variations lead to increased evapotranspiration, which in turn, places higher demands on water resources for agriculture (Hatfield & Prueger, 2015).

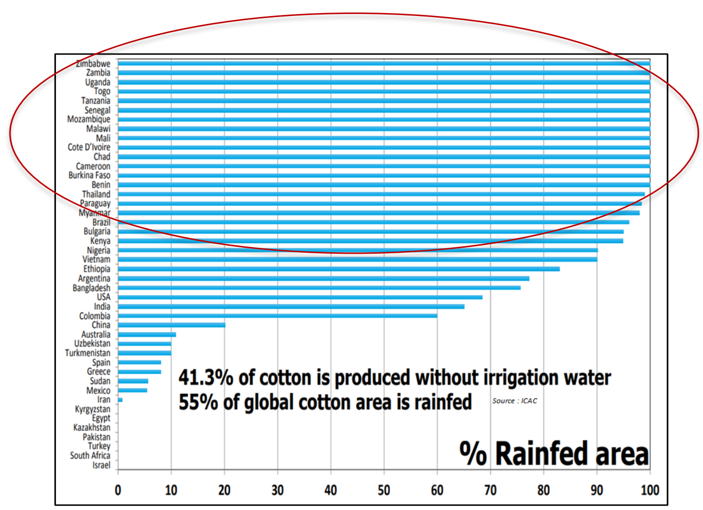

Figure-2. More than 55% of the global cotton area is dependent on rainwater. More than 95% of the area in Africa is rain dependent. Source: ICAC Databook 2021.

Elevated temperatures and changing climate conditions have far-reaching effects on cotton plants (Dhankher and Foyer, 2018; Thompson et al., 1996). High temperatures, prolonged periods of above-optimal temperatures, and warmer night temperatures can result in several detrimental outcomes. These include pollen sterility, poor formation of squares, flowers, and bolls, as well as fruit shedding (Echer et al., 2014). Such effects can significantly reduce cotton yields and quality.

The increase in atmospheric CO_2 concentrations, another hallmark of climate change, can affect cotton in both positive and negative ways. While elevated CO_2 levels may stimulate photosynthesis, potentially increasing crop productivity (Osborne et al., 2014), the benefits are often constrained by the accompanying rise in temperatures (Suzuki et al., 2014). Thus, the overall impact of increased CO_2 on cotton yields remains a complex interplay of various factors.

Impact of Water Deficit:

Water deficit during critical growth stages has been well-documented as a significant threat to cotton production (Ul-Allah et al., 2021). Early-stage water deficits can lead to poor seedling emergence, hinder root development, and result in an insufficient plant stand, often necessitating re-sowing (Reddy et al., 2020). However, there is evidence (McMichael and Quisenberry, 1991; Ball et al., 1994; Pace et al., 1999) to show that water stressed cotton seedlings produced longer roots accompanied with a reduced root diameter.

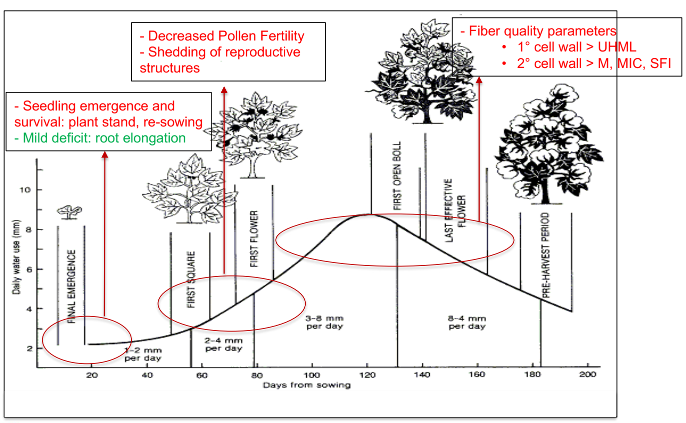

Figure-3. Effects of water deficit on cotton development are well documented.

However, a mild water stress at early stages can also increase root length. Water deficits during the squaring stage can reduce pollen fertility and lead to the shedding of reproductive structures (Oosterhuis and Snider., 2011). Subsequent water deficits during flowering and green boll development stages can cause severe yield losses (Bange et al., 2016).

Even slight changes in temperature can have a profound impact on cotton fiber quality (Reddy et al., 2017). A one-degree Celsius change can significantly affect fiber length, while a two-degree Celsius change can negatively impact micronaire and fiber strength (Lokhande and Reddy, 2014). These temperature-induced variations in fiber properties can have implications for the textile industry's final product quality.

Breeding for Drought Tolerance

Addressing these climate-related challenges through plant breeding is a daunting task, given the complex nature of "drought tolerance" and the quantitative traits associated with it (Furlow et al., 2011; Mollaee et al., 2019). Drought tolerance is a multifaceted trait influenced by various genetic factors, making it challenging to characterize and breed for (Magwanga et al., 2020). Moreover, such traits generally suffer from low heritability, adding to the complexity of breeding efforts (Boopathi, et al., 2015).

Figure-4. Climate-Smart Plant Breeding of Cotton – Generate phenotypic data for roots system architecture (RSA) and aerial parts

Figure-4a. Climate-Smart Plant Breeding of Cotton – CAWaS. Panel of 269 genotypes: main cotton breeding pools; modern and obsolete varieties, advanced breeding lines.

Efforts to breed for drought tolerance have been ongoing for several years, and researchers are exploring various morphological, physiological and biochemical traits associated with tolerance. These traits include stomatal conductance, transpiration, canopy temperature, osmotic adjustment, water-use efficiency (WUE), specific leaf area (SLA), fluorescence, and photosynthetic rate (Aboukheir al., 2011).

Despite the challenges, there is a ray of hope in the high level of genetic variability observed for traits associated with drought tolerance in cultivated cotton and related species. This genetic diversity provides an opportunity for plant breeders to develop cotton varieties that can withstand water deficits and climate-related stresses (Banga and Kang, 2014).

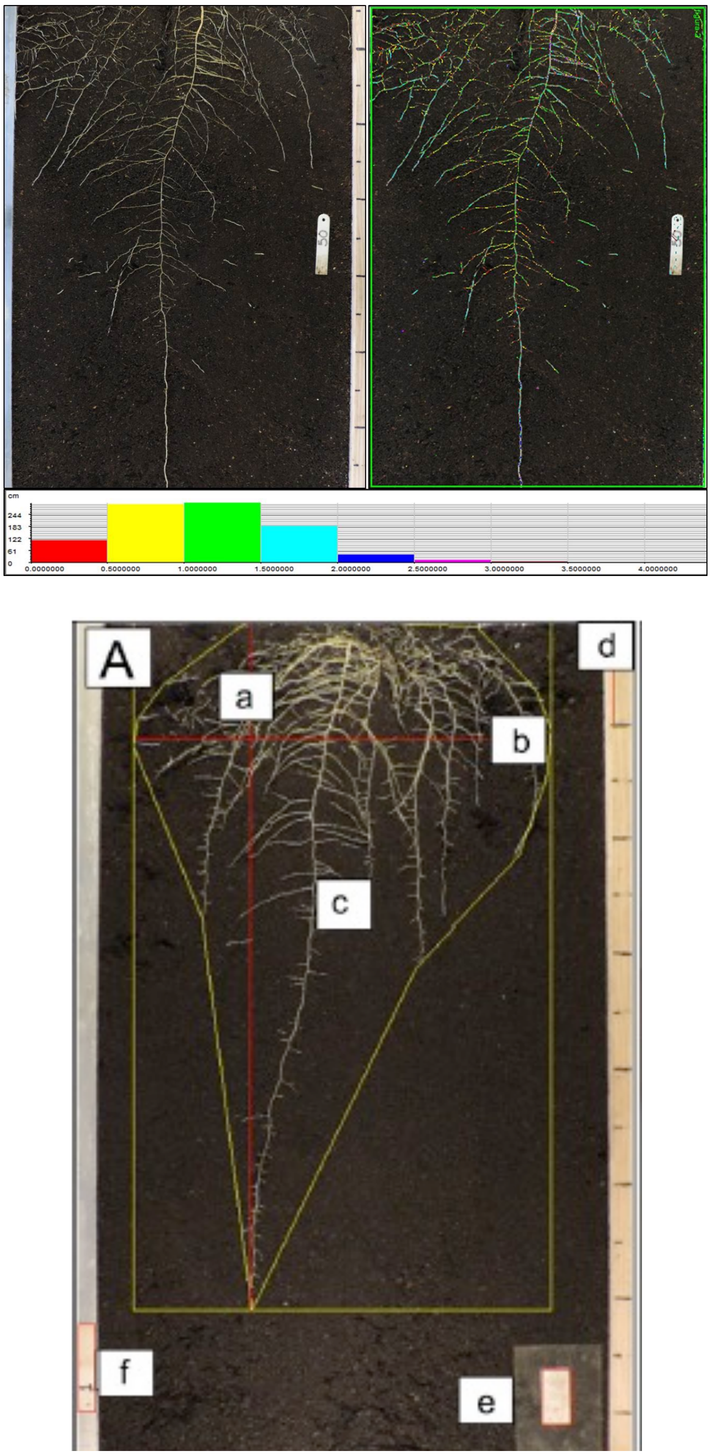

Figure-5. Pheno-Roots an inexpensive non-ivasive phenotyping system to assess the variability of root architecture.

The Role of Phenotyping in Cotton Breeding

One of the pivotal approaches to address these challenges is the use of advanced phenotyping techniques (Pandey et al., 2017). Our research emphasizes the importance of accurately characterizing root system architecture (RSA) and aerial parts to enhance cotton adaptation to water stress (Martins et al., 2019). The Cotton Adaptation to Water Stress (CaWaS) project primarily focuses on root phenotyping to determine the genetic and morphological characteristics related to drought stress response during the vegetative phase of plant development.

An innovative system known as 'PhenoRoots' has been developed for this purpose (Martins et al., 2019). The 'PhenoRoots' system is cost-effective and non-invasive, enabling real-time visual assessment of variability in root growth and architecture. This system provides valuable insights into parameters such as total root length, average root diameter, maximum root depth, root area explored at different soil depths, root surface area, root volume, and root density (Martins et al., 2019).

Research shows that there is a high degree of variability in root traits among cotton genotypes, and this variability typically follows a normal distribution (Klueva et al., 2000). Additionally, there is low to moderate heritability (ranging from 13% to 44%) for key traits associated with drought tolerance (Martin et al., 2019).

Table-1. Determining root traits through PhenoRoots.

Trait	Abbreviation	Unit	Means of determination
Total root length	trl	cm	WinRHIZO
Average diameter of roots	adr	mm	WinRHIZO
Maximum root depth	mrd	cm	Measuring tape
Total area explored by roots	ea	cm^2	ImageJ toolset
Area explored by roots 0-40cm profile	ea_0_40	cm^2	ImageJ toolset
Area explored by roots 40-75cm profile	ea_40_75	cm^2	Calculation
Maximum width reached by roots	mrw	cm	ImageJ toolset
Projected area	pa	cm^2	WinRHIZO
Root surface area	rsa	cm^2	WinRHIZO
Root volume	rv	cm^3	WinRHIZO
Ratio maximum root depth to maximum root width	mrd_mrw	-	-
Density of roots (ratio trl:ea)	trl_ea	cm/cm^2	-

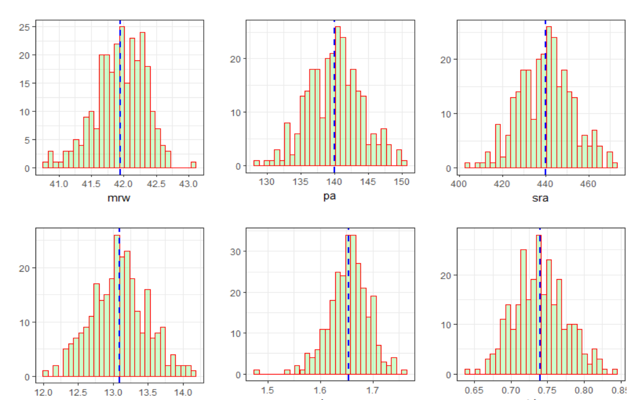

Figure-6. Root traits and parameters. High levels of variability for all roots traits – Normal distribution.

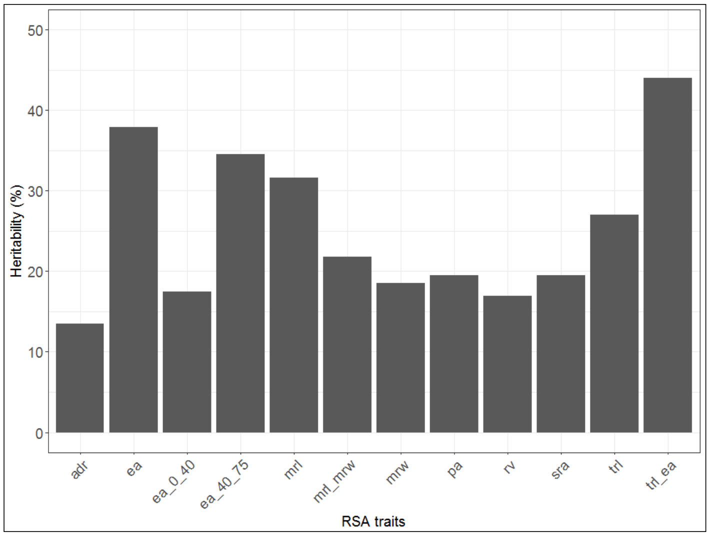

Figure-7. Root traits and parameters. Low to moderate heritability (13-44%): trl_ea = 44% ; ea, ea_40_75, trl > 30%

PhenoArch for Comprehensive Phenotyping

In addition to root phenotyping, comprehensive phenotyping is crucial for understanding cotton's response to water stress. The PhenoArch High-Throughput Phenotyping Platform (HTPP), utilized in our research, characterizes various plant growth parameters and physiological indices under contrasting water regimes (Martins et al., 2022). These parameters include relative reduction, biomass, leaf area, plant height, transpiration, WUE, SLA, carbon isotope discrimination, osmotic adjustment, and leaf water content.

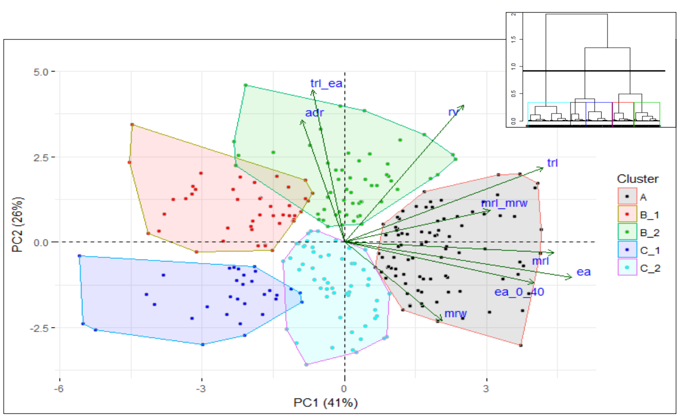

Figure-8. Root traits and parameters. Hierarchical Clustering on Principle Components: 5 groups.

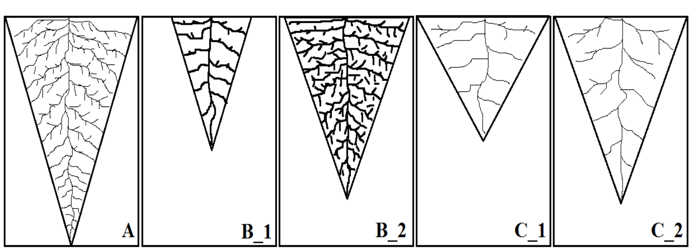

Figure-9. Root traits and parameters. >5 root system architecture morphotypes.

Endpoint measurements reveal high levels of variability for all parameters, with most exhibiting a normal distribution (Bruno et al., 2017). Under conditions of water limitation, values for most parameters decrease significantly, except for water-use efficiency (WUE), which shows a notable increase (Martins et al., 2022).

Figure-10. Traits and Parameters: PhenoArch HTPP (LEPSE, Montpellier, France)

Figure-11. Characterization of plant growth parameters and relevant physiological parameters/indices under contrasting water regimes: 80% Field Capacity vs. 30% Field Capacity.

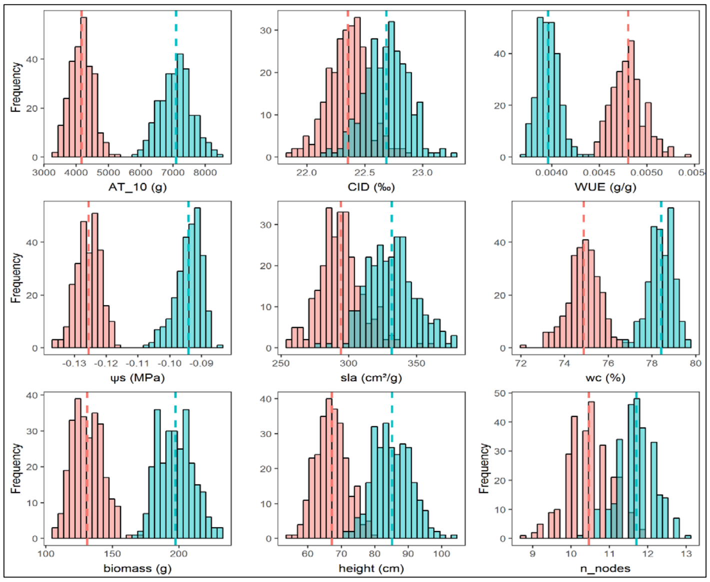

Figure-12. Traits and Parameters: PhenoArch HTPP, Endpoint measurements. High levels of variability for all parameters – Normal distribution.- Decreased values under water limitation – except for WUE

Table-2. Traits and Parameters: PhenoArch HTPP, Endpoint measurements. Effects of Genotype and of Scenario for all parameters. No GxS interaction in most cases.

Charactere[1]	Scenario (S)				Genotype (G)				G x S			
	MS	F	p-value		D	LRT	p-value		D	LRT	p-value	
oa	-	-	-	-	-670,04	13,04	0,0003	***	-	-	-	-
AT_10	1597364421	3977	0,0000	***	26420	25,64	0,0000	***	26398	3,74	0,0531	ns
biomass	1454282	3583	0,0000	***	15798	34,40	0,0000	***	15767	3,41	0,0650	ns
CID	38	176,51	0,0000	***	2815	31,871	0,0000	***	2785	1,965	1,0000	ns
height	96951	3178	0,0000	***	11510	116,29	0,0000	***	11402	7,87	0,0050	**
n_nodes	462	1207	0,0000	***	4182	120,37	0,0000	***	4186	4,27	0,0387	*
ψs	0,329	2768,4	0,0000	***	-9461,4	32,54	0,0000	***	-9491	2,98	0,0843	ns
sla	556353	505	0,0000	***	16632	70,42	0,0000	***	16562	1,00	0,9060	ns
wc	4495	1261	0,0000	***	7535	19,58	0,0000	***	7516	0,71	0,3996	ns
WUE	0,0002	2337	0,0000	***	-20251	35,08	0,0000	***	-20247	3,26	0,0709	ns

Genotype and Scenario Effects

Our research also delves into genotype and scenario effects on cotton's response to water stress. This exploration reveals distinct responses among genotypes, differentiating between optimistic and pessimistic genotypes. Notably, the dynamics of biomass accumulation demonstrate significant variations among individual genotypes. These findings raise critical questions about the relevance of endpoint values, the importance of trait dynamics, and the potential role of phenotypic plasticity in cotton breeding (Martins et al., 2022).

Integration for Resilient Cropping Systems

As climate change continues to exert pressure on cotton production, it becomes imperative to integrate climate-resilient cotton varieties into more sustainable cropping systems. This integration should consider various aspects, including life cycle duration, competition with other crops (such as row cropping), adapted architectural traits (e.g., increased plant density), improved harvest index, and enhanced water use efficiency (WUE), evapotranspiration use efficiency (EUW), and nutrient use efficiency (NUE).

By incorporating climate-resilient cotton varieties into sustainable cropping systems, we can enhance cotton's adaptability to changing environmental conditions and ensure more stable yields. This approach represents a transition from merely focusing on Climate-Smart Plant Breeding of Cotton to a broader perspective of Breeding Cotton for Resilient Cropping Systems.

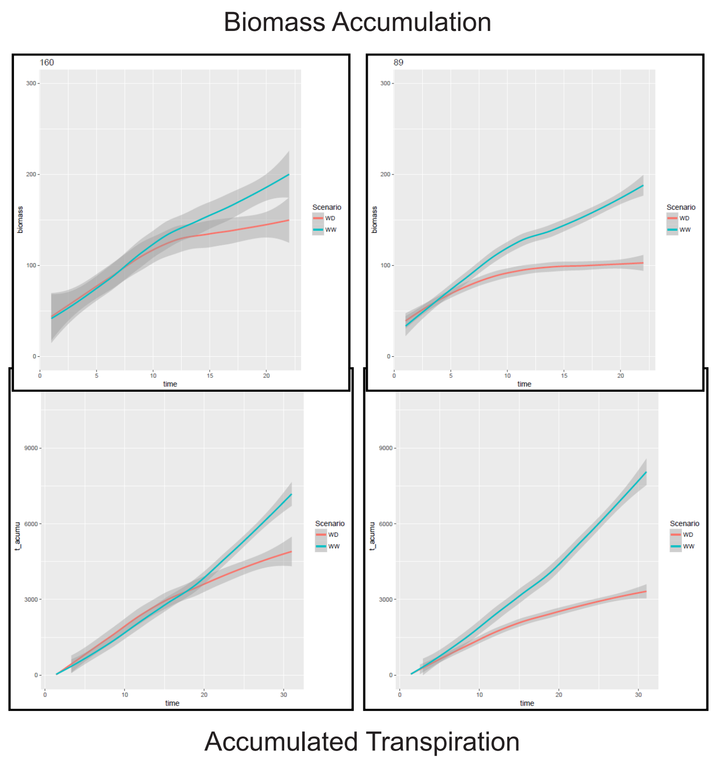

Figure-13. Traits and Parameters: PhenoArch HTPP (LEPSE, Montpellier, France). Dynamics of Biomass Accumulation show clear differences between individual genotypes. Two contrasting behaviors: optimistic vs. pessimistic genotypes.

Figure-14. Traits and Parameters: PhenoArch HTPP (LEPSE, Montpellier, France). No correlations between root traits and aboveground characters measured on PhenoArch.

Conclusion

Our research underscores the urgency of developing climate-resilient cotton varieties to mitigate the adverse impacts of climate change on cotton production.

Utilizing innovative phenotyping techniques such as the 'PhenoRoots' system and integrating cotton into sustainable cropping systems offers promising pathways toward a more secure cotton supply chain in the face of evolving climatic challenges.

As cotton growers face increasingly unpredictable weather patterns and rising temperatures, the quest for climate-smart cotton varieties remains paramount for ensuring global cotton sustainability.

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The ICAC Recorder

Implementing Climate-Resilient Innovations in Cotton Farms in Sub-Saharan Africa

Mahesh Ramakrishnan
Vice President – Cotton Agronomy & Sustainability (WAF), Olam Agri, Abidjan, Cote d'Ivoire

Mr. Mahesh Ramakrishnan has 25 years of experience in sustainable cotton sourcing for textile value chains. He has been involved in the design and implementation of sustainable cotton farming standards (Organic/Fairtrade/Better Cotton/CmiA/ Regenagri/Atsource plus) and collaborating with small holder harmers in different cotton growing regions of Southeast Asia and Africa, with a focus on climate resilient farming practices, soil health, improving livelihood through improved yields, and reducing the cost of production for cotton farmers.

Since September 2020, Mahesh has been working with Olam Agri in West Africa as Vice President of Sustainability for Cotton BU, based out of Abidjan, Cote d'Ivoire. He has specialised in organic cotton and has a deep knowledge of the sector. He also has co-authored the boo, 'Organic Cotton Crop Guide – A Manual for Practitioners in the Tropics'. He represented Arvind Limited in the first governing council of BCI, and served as a board member of the Textile Exchange – Europe.

Introduction

Cotton farming under rainfed conditions is highly vulnerable to climate change. As climate change intensifies and land degradation accelerates, there is a need to evaluate how rainfed cotton is cultivated. The role of healthy, biodiverse soils is crucial in mitigating the risk of water scarcity, especially in the arid regions of sub-Saharan Africa. Soil isn't just dirt; it is a living treasure trove of biodiversity that fuels sustainable agriculture and helps mitigate climate change.

Soil Organic Carbon

Soil organic carbon is an important aspect of crop production and the long-term sustainability of the soil. Carbon makes up approximately 58% of the organic matter in soil, revealing just how significant it is for maximizing soil health and crop production. Without adequate amounts of soil organic carbon, crops cannot reach their genetic potential resulting in lower yields, tighter margins, and a higher cost of production for the farmer. Having a healthy amount of soil organic carbon is beneficial because it improves fertility, reduces erosion, and increases the land's resistance to drought and flooding. When erosion occurs, the soil is exposed, and carbon is released into the atmosphere and converted into carbon dioxide (CO_2). Reducing erosion allows the carbon to be utilized for soil and plant health, while also reducing unnecessary greenhouse gas emissions. When soil organic carbon is managed properly, it will benefit the land and farmers for years to come.

Managing the soil organic carbon is fundamental in rainfed cotton farming systems to ensure crop production and long-term sustainability of the soil. Benefits include:

1. **Improving water holding capacity in soils:** This builds drought resistance, as the crop can survive an extended dry spell in rainfed conditions. Every 1% increase in organic matter results in as much as 232,000 litres of available soil water per hectare.
2. **Reducing soil compaction:** Adding organic matter (in form of enriched compost), helps to increase carbon in the soil, minimizing compaction because organic matter is less dense than soil minerals. When soil is less dense, the movement of root systems in the soil becomes easy and crops can scavenge for nutrients and moisture more easily.
3. **Increasing water infiltration:** Soil organic carbon helps to form soil aggregates, where organic molecules produced by microorganisms bind mineral particles together. This makes the soil porous and helps rainwater infiltrate into the ground — especially important under rainfed conditions.
4. **Increased nutrient availability:** When microbes feed on soil organic carbon, they release the essential macro and micronutrients that were tied to that carbon, thereby providing more nutrients for the plant.
5. **Improving crop yield:** Farmers who adopt soil health improvement practices to improve soil organic carbon with those farmers who don't enjoy benefits such as more stable yields on a year-to-year basis.

In the context of smallholder rainfed cotton farming regions of sub-Saharan Africa, regenerative agriculture offers a promising solution to mitigate the climate change challenges. By adopting regenerative agriculture principles and practices, farmers can regenerate the soil, which will contribute to more CO2 storage and sequestration.

Integrating biochar from harvested cotton stalks, especially in acidic soils, contributes to soil amendment. Farmers can see immediate yield improvements of 20% against baseline yields for acidic soils, thus improving overall productivity.

Figure-1. Biochar.

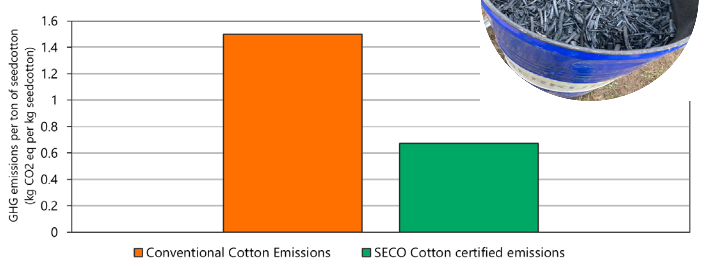

Figure-2. Impact of Regenerative Agricultural practices on GHG emissions.

CERTIFICATE N.: CU-895516-F
COMPANY N.: 437865

regenagri

CERTIFICATE

Issued to:
. SECO - Societe d'Exploitation Cotonniere Olam
QUARTIER USINE,BP 129
FERKE,OUANGOLODOUGO,
COTE D'IVOIRE

Control Union declares that the practices adopted by the farms listed on this certificate have been found to be compliant with the regenagri® Standard Criteria.

Address	No. of Certified Farms	Type of farms	Total Area (hectares)
QUARTIER USINE,BP 129 FERKE,OUANGOLODOUGOU , COTE D'IVOIRE	20374	Arable (cotton, maize, soybean, and beans) and top fruits (mango, peanut, cashewnut)	256,915.00 ha

Valid from: 10/11/2023
Valid to: 09/11/2026

On behalf of the Managing Director
Authorized by:
Marina Mérola

Certifier
Control Union (UK) Limited
2nd Floor, 56 High Street, Lymington, SO41 9AH, United Kingdom
http://www.controlunion.com
tel.: +44(0)20-7488-2210

Date of Certification decision: 10/11/2023

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Figure-3. Regenerative Agricultural Certification.

Biochar derived from cotton stalks can play a significant role in sustainable cotton production and soil management. When incorporated into the soil, biochar acts as a carbon-rich, porous material that enhances soil structure, promoting better aeration and drainage, water retention, and nutrient availability. This is particularly beneficial in rainfed cotton farming. Biochar helps sequester carbon in the soil, contributing to climate change mitigation by locking carbon in a stable form.

Biochar has a high cation exchange capacity, which means it can retain and exchange essential nutrients with plant roots, reducing nutrient leaching and making nutrients more available to crops. Biochar provides a habitat for beneficial soil microbes, fostering a healthy ecosystem that supports plant growth and resilience.

Enriched compost like bokashi, which is produced by the fermentation of organic materials with a microbial inoculant that helps to convert the harvested crop biomass and weeds. It takes a shorter period to make — no more than four weeks, as opposed to a typical three-month or longer period for regular composting. The initial process also requires less labour, as continual turning of the bokashi is not required as it is in regular composting. The benefits of composting are numerous, like increased supply of nutrients and fertilization of crops, improvement of the soil structure, and better biological activity. Crop protection is enhanced by beneficial microorganisms, which increase the humus and humic acid content and improve soil moisture retention, among other advantages.

Planting cover crops during fallow periods protects the soil from erosion by creating ground cover, helps increase water infiltration, slows evaporation, improves soil carbon, adds organic matter, improves soil fertility, and enhances microbial activity. Cover crops work as green manure because they are mowed back into the soil rather than grown for harvest. Nature always keeps the ground covered, so we are learning from nature and controlling what we cultivate to ultimately increase our yield through improvements to our soil and our crops' root systems.

Similarly, conservation tillage helps preserve soil structure, reduce erosion, and promote the accumulation of organic matter. The adaptation of conservation tillage systems, especially minimum tillage, improves crop growth and cotton crop productivity in the long run by reducing soil erosion and carbon emissions.

Smallholder farmers face various problems that prevent them from adopting climate change adaptation practices. As a result, the smallholder farmers continue to experience multiple challenges, including low agricultural production, poor infrastructure, food insecurity, and income challenges.

Conclusion

Understanding the impacts of climate change is fundamental in improving adaptation practices. Smallholder farmers in sub-Saharan Africa with limited resources are trying different ways to cope with climate change. Nonetheless, farm extension services, knowledge transfer, and capacity building of field staff have helped to bridge the gap by identifying the key challenges that growers face. Finding innovative solutions through partnership and collaboration on climate-smart agricultural farming techniques will help farmers better respond to changing climatic conditions.

The ICAC Recorder

Implementing Climate-smart Agronomy

Marcelo Paytas
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Dr. Marcelo Paytas graduated as an Agricultural Engineer from the National Northeast University, Corrientes, Argentina, and obtained a PhD at the University of Queensland, Australia, in Cotton Physiology and Agronomy. He currently serves as Director of INTA (National Institute of Agricultural Research), Reconquista Santa Fe, Argentina, where he is a researcher and project leader of the cotton team with a focus on crop physiology and agronomy, biotechnology, and genetic improvement.

A member of APPA (the Association for the Promotion of Cotton Production), which associates all representatives of the cotton chain of Santa Fe, Argentina, he also serves a coordinator of academic and technical agreements between INTA and other national and international organisations. A member of the ICAC's SEEP Committee and ICRA, Mr Paytas's main interest is to link and promote research and development together with the cotton industry through public and private interaction for sustainable production.

The Current State of Cotton: Addressing Dynamic Challenges

Agriculture and ecosystems worldwide are increasingly affected by the escalating severity of climate change. Within this shifting landscape, cotton cultivation confronts a multitude of agronomical challenges. These are not only a consequence of climate change but also stem from the competition between natural and synthetic fibres. Additionally, sustainability in cotton production remains a central concern, encompassing three fundamental pillars: social, environmental, and economic.

Defining Climate-smart Agriculture: An Overview

Climate-smart agriculture (CSA) is a multifaceted approach crafted by the United Nations Food and Agriculture Organization (FAO) to guide farmers' decision-making processes, foster environmentally sustainable agri-food systems, and implement resilient methods that can withstand the challenges posed by a changing climate.

CSA, in essence, constitutes an integrated strategy encompassing the management of diverse landscapes, croplands, livestock, forests, and fisheries. It seeks to effectively address the intertwined concerns of food security and climate change. This comprehensive concept is designed to achieve three core objectives:

1. **Sustainably Increase Agricultural Productivity:** By adopting CSA practices and technologies, the agricultural sector aims to enhance productivity while ensuring the sustainable use of resources.
2. **Enhance Resilience to Climate Change:** CSA strategies and approaches are geared toward making agriculture more robust and adaptable in the face of evolving climatic conditions.
3. **Mitigate Greenhouse Gas Emissions:** CSA endeavours to reduce the environmental footprint of agriculture by curbing greenhouse gas emissions associated with the sector.

The application of CSA practices and technologies holds the potential to mitigate the adverse effects of climate change on cotton production, both at the farm level and within regional contexts. Nevertheless, the adoption of CSA is contingent upon numerous factors, including institutional arrangements, landscape governance, resource availability, and the prevailing economic, social, and climatic conditions. Therefore, the pursuit of climate-smart agriculture necessitates the active participation and collaboration of a diverse array of stakeholders, including farmers, researchers, representatives from the public and private sectors, and civil society.

Implementing Climate-smart Agronomy Strategies for Cotton, Emphasizing Soil Health, Biodiversity, and Other Agronomical Aspects

Long-term studies conducted in the cotton regions of Argentina have revealed common soil limitations across zones. Predominantly, these limitations include low organic matter content, resulting in reduced water retention and increased susceptibility to water erosion. Additional challenges involve inadequate availability of essential nutrients such as phosphorous, nitrogen, potassium, and magnesium, with some areas experiencing elevated levels of exchangeable sodium. Incorporating service crops, crop rotations involving grain crops and pastures, and adopting zero-tillage practices are all integral components of a comprehensive soil conservation approach.

Biodiversity, Conservation Technologies, and Land Use

Biodiversity, conservation technologies, and land use play pivotal roles in climate-smart agronomy for cotton cultivation. Key agronomic practices such as zero tillage systems, crop rotation, and cover crops are fundamental for soil conservation. To ensure soil health, routine soil analysis should be implemented by both producers and research programs. This analysis aids in adjusting nutrient doses and critical application timings. It also includes encouraging and assisting farmers in conserving and enhancing biodiversity on their land and implementing practices that minimize negative impacts, such as habitat preservation and sustainable farming methods that protect native flora and fauna. Promoting biodiversity and employing conservation technologies are critical components of climate-smart agronomy in cotton production. Key practices include:

- **Zero Tillage Systems or No-Tillage:** These practices reduce soil disturbance, promote soil health, and enhance carbon sequestration.A dopting zero tillage practices further supports soil conservation by minimizing soil disruption.
- **Crop Rotation and Cover Crops:** Implementing crop rotation and cover cropping helps maintain soil fertility, reduce erosion, and improve overall soil structure.
- **Soil Health Data:** Routine soil analysis conducted by producers and research programs is essential. This process informs nutrient management, guiding decisions on nutrient dosages and critical application timings.
- **Service Crops and Rotations:** Incorporating service crops, grain crop rotations, and pastures within the agricultural system contributes to soil conservation.

Land Management Strategies

It is also imperative to develop land management strategies that encompass changes in crop and livestock placement, efficient drainage and rainwater management, flexible production shifts between livestock and crops, and tailored fertilizer and pesticide application intensities. Utilizing nutrient sources can further enhance sustainability. Consider implementing land management approaches that enhance soil health and sustainability. Specific actions may include:

- **Changes in Crop and Livestock Production Locations:** Assess opportunities for relocating crops and livestock production to optimize resource utilization and reduce environmental impact.
- **Drainage and Rainfall Water Management:** Efficiently manage drainage and rainfall water to prevent soil erosion and improve water-use efficiency.
- **Crop Rotation and Shifting Production:** Rotate crops and shift production between livestock and crops to diversify the agricultural system and reduce soil degradation.
- **Optimized Fertilizer and Pesticide Application:** Vary the intensity and timing of fertilizer and pesticide applications based on specific crop and soil requirements.
- **Use of Agro-Industrial Sector Resources:** Explore alternative nutrient sources from the agro-industrial sector to reduce reliance on synthetic fertilizers.

The implementation of these climate-smart agronomy strategies — with a focus on soil health, biodiversity, and other agronomical aspects — can contribute to sustainable cotton production while mitigating the impact of climate change. These practices aim to enhance soil fertility, reduce erosion, improve water management, and promote biodiversity conservation, ultimately fostering a more resilient and sustainable cotton farming system. Crucially, supporting farmers in conserving and enhancing biodiversity on their land is essential. Encouraging the adoption of practices that minimize negative environmental impacts is also imperative.

Sowing Dates and Cotton-Critical Periods

Selecting optimal sowing dates is a critical factor in cotton cultivation, especially in Argentinean conditions. Ideally, sowing should commence in October and conclude in November to ensure that the crucial flowering stage aligns with the most favourable environmental conditions, resulting in higher cotton yields and higher-quality production.

It is equally important to embrace the concept of integrated fibre management, which encompasses various physiological processes influenced by meteorological conditions. To mitigate the adverse effects of increased climate variations commonly observed in semi-arid tropics and arid regions worldwide, strategies may include adjusting sowing dates to capitalize on water availability and sunshine periods during critical stages while avoiding unfavourable weather events throughout the growing season.

In addition to optimizing sowing dates, it is imperative to propose and evaluate a range of agronomic practices tailored to specific environmental limitations. These practices may encompass fertilization at both sowing and pre-flowering stages, crop configuration, crop management techniques, and other innovative approaches to enhance overall crop production.

Integrated Pest Management for Cotton Crops in the Face of Climate Change

Climate change, characterized by shifts in temperature and rainfall patterns, significantly affects insect pests, weeds, and disease dynamics in cotton crops. To address these challenges, the adoption of integrated pest management (IPM) is crucial,

Figure-1. Implementing Regenerative agricultural practices in cotton farms in Argentina.

emphasizing a greater reliance on biological control and cultural practices. This approach should be complemented with the introduction of new cotton cultivars resistant to diseases and pests, as well as the implementation of other crop protection measures.

Supporting farmers in developing a deeper understanding of IPM is essential to reducing their reliance on synthetic pesticides, which can have detrimental impacts on both the environment and the health of farming communities. It's important to transition away from highly hazardous pesticides.

Additionally, the availability and adoption of alternative organic products are on the rise, providing sustainable alternatives to conventional pest control methods.

Weather Monitoring, Prediction, and Modelling

Collecting meteorological information, including historical and daily data, is indispensable for effective agricultural planning. Investment in meteorological stations is essential to obtain accurate and real-time regional weather data. Weather forecasts and early warning systems are invaluable for mitigating the potential risks associated with climate-related crop losses.

Crop modelling emerges as a valuable tool for managing agricultural risks. Modelling plays a pivotal role in developing techniques that provide crop management insights and yield forecasts. Simulation models significantly contribute to the improvement of crop development practices and offer practical recommendations for effective crop management.

The Role of Stakeholders in Climate-Smart Cotton Agronomy

Addressing the multifaceted challenge of climate-smart cotton agronomy requires collaborative efforts from a diverse range of stakeholders, including producers, researchers, and the public and private sectors. Together, they must implement strategies that enhance agricultural productivity, bolster climate change resilience, and minimize greenhouse gas emissions.

It is crucial to underscore that producers require comprehensive support, including training, technical guidance, financing, and investments throughout the entire cotton supply chain, especially in countries heavily reliant on agriculture for their economies. Public investments can play a pivotal role in incentivizing farmers to embrace climate-smart agricultural practices.

Cotton production worldwide faces significant challenges related to sustainability but there are ample opportunities for improvement. Climate-smart agronomy offers a promising alternative to address these issues. To further this cause, additional initiatives and programs should be developed at the regional and national levels, as they align with government agendas and priorities.

Regenerative Agriculture, Zero Budget Natural Farming, and Organic Cotton: Do They Combat Climate Change?

Rajeev Baruah
Global Agronomic Lead, Sustainable Cotton Program, Primark

Mr Rajeev Baruah has been a cotton professional since 1992, a journey of three decades that involved pioneering the organic cotton movement and helping sustainable cotton initiatives expand its footprint in India. He is driven by his passion to work with farmers, especially education about global best practices (sustainable & regenerative). Rajeev has very close links with the global cotton research community to understand challenges and find solutions. Rajeev believes that this is the decade for action, and the responsibilities rest on the shoulders of organisations engaged with farmers. It Is the moment for collaboration between academia, research institutions, scientists, and civil society to bring real change in farming. Rajeev is currently the Global Agronomic lead for the Primark Sustainable Cotton Program.

Introduction

The profound consequences of climate change have become increasingly evident over the past few years. According to the European Union's Copernicus Climate Change Service, global temperature will surpass 2016 as the hottest year on record with temperatures 1.4 degrees Celsius warmer than pre-industrial levels. In May, the World Meteorological Organization (WMO) issued a report that projected a significant likelihood (66 percent) that the world would exceed the 1.5 degrees Celsius threshold in the next four years.

Considering these developments and agriculture's role in climate change, it is imperative to examine the connectivity to agriculture.

The Role of Carbon

Carbon is the fundamental building block of all living organisms. It serves as the primary constituent of life, comprising approximately half of the dry biomass in organic matter. To illustrate, if one were to eliminate all water from living organisms and measure their dry weight, roughly half of that weight would consist of carbon.

Photosynthesis

Photosynthesis is a fundamental process that many of us learn about in secondary school but may not think much about afterward. It's how plants create their own food, requiring sunlight, carbon dioxide from the air, water absorbed from the soil, and chloroplasts found in green leaf cells. These chloroplasts act like solar panels, capturing light energy. Photosynthesis is the process that transforms atmospheric CO2 into biomass, which includes roots, trunks, branches, stems, leaves, flowers, and seeds.

The Crisis

In recent years, the atmosphere has been accumulating four gigatons (billion tonnes) of carbon annually. Of these, nine gigatons come from human activities, with soils sequestering three gigatons and the oceans sequestering two. To move toward net-zero emissions, we must find ways to capture and sequester those four gigatons of carbon every year.

Mitigation Measures

1. Enhancing carbon sequestration mechanisms involves capturing excess CO_2 from the atmosphere and storing it in the soil.
2. Curtailing greenhouse gas emissions (GHGs) requires actions across various sectors, including energy, transportation, agriculture, and industry, aimed at reducing the release of GHGs into the atmosphere.

Can We Reach Zero Emissions?

Although agriculture generates approximately 18% of global greenhouse emissions, it also holds the potential to save the planet. The world's soils contain two to three times more carbon than the atmosphere. By increasing carbon storage in the top 30 to 40 centimetres of soil from 0.4% to 4% annually, we could significantly reduce the annual increase of carbon dioxide in the atmosphere.

Agriculture can combat climate change by adopting multifaceted approaches that reduce GHGs and enhance CO2 sequestration through innovative land management practices. With 1.5 billion hectares of global arable land, sequestering 2.67 tons of carbon per hectare equals four gigatons of carbon.

Exploring Organic, ZBNF, and Regenerative Agriculture

Let us examine the key principles of organic, zero budget natural farming (ZBNF), and regenerative agriculture to assess their potential in addressing climate change.

Regenerative Agriculture

Regenerative agriculture has garnered significant attention from producers, retailers, researchers, consumers, politicians, and the mainstream media. It encompasses practices such as cover cropping, integrating livestock, and reducing tillage to improve soil health and sequester carbon. Despite this widespread interest, there is no established legal or regulatory definition for the term "regenerative agriculture," and a widely accepted definition has yet to emerge in common usage.

A review conducted by Newton in 2020, which analysed 229 journal articles and 25 practitioner websites, aimed to define what regenerative agriculture is. The review revealed that there are numerous definitions and descriptions currently in use. These definitions are often based on various processes, including the utilization of cover crops, the integration of livestock, and the reduction or elimination of tillage. These practices are pursued with the ultimate goals of improving soil health, sequestering carbon, or a combination of both.

Key pillars include:

- Avoidance of harmful chemicals.
- Zero or minimum tillage.
- Diverse cropping systems.
- Live cover crops and crop rotation.
- Integration of crops and livestock.

Zero Budget Natural Farming (ZBNF)

Zero Budget Natural Farming (ZBNF) is an agricultural approach that originated in India, aimed at reducing production costs and minimizing environmental impact. Introduced by Subhash Palekar and supported by NGOs in Karnataka, India, it is primarily adopted by small and marginal farmers. ZBNF promotes self-reliance and indigenous sustainable farming practices, rooted in Neo-Gandhian philosophy. Originating in Karnataka in 2002, this movement has spread across India with Andhra Pradesh taking a lead by formulating policies and other states following suit. The central government also allocated funds for ZBNF in the 2019 budget, recognizing its significance in sustainable agriculture. ZBNF is characterized by practices like seed treatment, bio-inoculants, bio-mulching, and soil aeration. It emphasizes a natural and holistic approach to farming without external inputs.

Key pillars include:

1. **Beejamrut (Seed Treatment):** Beejamrut is a seed treatment technique used in Zero Budget Natural Farming (ZBNF) and organic farming. It involves soaking seeds in a mixture of beneficial microorganisms, organic materials, and water. This treatment helps protect seeds from diseases, enhances germination, and improves the overall health of the seedlings. Beejamrut is a natural alternative to chemical seed treatments.
2. **Jeevamrut (Bio-inoculant):** Jeevamrut is a bio-inoculant used in ZBNF and organic farming practices. It is a liquid fertilizer made by fermenting cow dung, cow urine, jaggery (sugar), and specific biological materials. Jeevamrut contains beneficial microorganisms that promote soil health and plant growth. When applied to crops, it enriches the soil with essential nutrients, enhances nutrient uptake by plants, and suppresses harmful pathogens.
3. **Achadana (Bio-mulch):** Achadana is a farming technique in ZBNF where organic mulch is spread on the soil surface around crop plants. This mulch can consist of materials like straw, leaves, or crop residues. Achadana serves multiple purposes, including conserving soil moisture, regulating soil temperature, suppressing weed growth, and improving soil structure. It helps create a favorable environment for crop growth while reducing the need for synthetic mulching materials.
4. **Whapsa (Soil Aeration):** Whapsa is a term used in ZBNF to describe the practice of creating soil aeration using farm residues. Soil aeration is essential for promoting root health, improving water infiltration, and increasing oxygen availability to plant roots. It enhances soil structure and overall soil fertility, which benefits crop growth and productivity.

Organic Agriculture

Organic agriculture is a well-defined farming approach with a comprehensive scientific definition, regulated by various authorities worldwide, including the European Commission, the United States Department of Agriculture (USDA), and the National Program for Organic Production (NPOP) in India, among others. Organic agriculture focuses on intercrops, cover crops, biological pest control, green manure, minimal tillage, and soil organic matter enhancement.

Key pillars include:

- Intercrops and cover crops.
- Biological pest control.
- Improved soil fertility through green manure and compost.

- Minimal tillage to retain soil carbon.
- Emphasis on building soil organic matter.

Now that we've explored the key principles of these three farming systems, let's examine their common aspects .

Table-1. Common Practices between RA, ZBNF and Organic. Green denotes explicit in the pillars. Yellow denotes that it is not explicit.

	ZBNF	RA	Organic
Avoidance of Chemicals	Green	Yellow	Green
Zero or Minimum Tillage	Yellow	Green	Green
Organic Mulch/ Manures	Yellow	Green	Green
Diversity of Cropping Systems	Yellow	Green	Green
Live Cover Crops & Crop Rotation	Yellow	Green	Yellow
Integration of Animal Husbandry	Yellow	Yellow	Green

It is worth noting (without any bias) that the term "regenerative agriculture" has been gaining significant traction. Let's examine this through a bibliometric analysis:

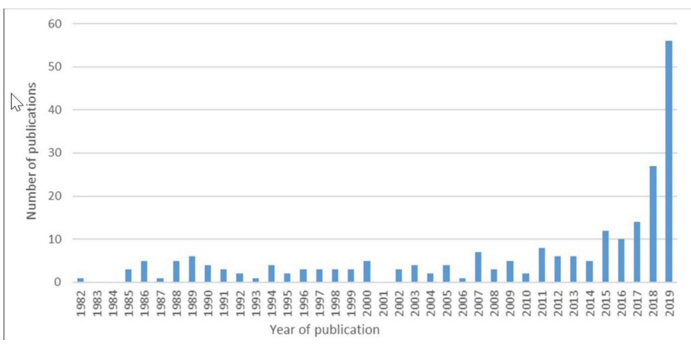

Figure-1. Number of research articles that use the term "regenerative agriculture" from 1982 -2019 (source: Newton et al, 2020)

Let's now look at the carbon sequestration potential of different agricultural practices:

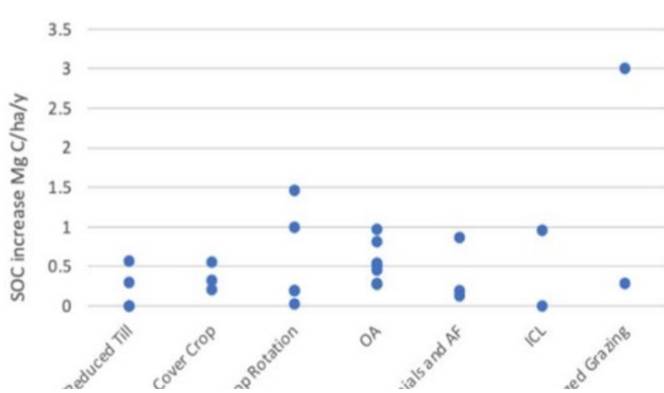

Figure-2. Studies and meta-analyses that indicate the SOC accumulation rates for individual farming practices. Each point represents one study (Rehberger et al, 2023)

Let's look at four practices, and their ability to reduce GHG/ sequester carbon:

1. Reduction in the use of chemical fertilizers
2. Cover crops
3. Conservation agriculture and carbon sequestration
4. Conversion of cotton stalks into biochar

Reduction on the Use of Chemical Fertilizers

Reducing the use of chemical fertilizers offers a significant opportunity to mitigate GHGs associated with agricultural production. These emissions stem from both the extensive use of chemical fertilizers and the GHGs generated during their production and application.

Currently, the global demand for fertilizers stands at approximately 200 million metric tons (FAO 2019), with nearly half of this demand attributed to nitrogen fertilizers, resulting in 2,300 kilo tonnes of nitrous oxide emissions. N_2O accounts for 22% of total emissions from agriculture. A complete substitution of chemical fertilizers could potentially reduce GHGs by 0.203 Mg CO_2 eq/ha, while partial substitution could still yield a reduction of 0.0672 Mg CO_2 eq/ha (Rehberger et al).

Based on these calculations, it becomes evident that organic cotton and ZBNF hold the highest potential to combat climate change. Currently, the global area under organic cotton (including Cotton made in Africa – CmiA) encompasses approximately 4% of the total cotton cultivation area (Textile Exchange Preferred Fiber and Materials Market Report, October 2022).

Cover Crops

This practice has been hailed as the "powerhouse of carbon capture" (Kranthi and Kranthi, 2023). It offers a highly promising strategy for carbon sequestration, boasting an annual accumulation rate of 320 kg/ha. To put this into perspective, that's equivalent to capturing and fixing 1,174.4 kg/ha of CO_2 from the atmosphere per year.

Conservation Agriculture and Carbon Sequestration

The three core principles of conservation agriculture — minimal or zero tillage, the implementation of intercropping and crop rotation, and the maintenance of live crops throughout the year — play a substantial impact on carbon sequestration. A quantitative analysis of 20 studies conducted in the USA indicates an average increase of 481 kg/ha of soil organic carbon per year. Data from these studies also suggest that no-tillage practices combined with cover crops can sequester as much as 672 kg/ha of carbon annually.

Conversion of Cotton Stalks to Biochar

This practice represents a long-term solution for carbon removal and is applicable not only to organic, ZBNF, and regenerative cotton farming, but also to conventional agriculture. On average, cotton farms yield three tons of cotton stalks. Taking

India as an example, with nearly 12 million ha of land devoted to cotton cultivation, this amounts to a substantial 36 million tons of stalks (a conservative estimate, as hybrid cotton could yield even more). Approximately 50% of this biomass consists of carbon, totalling around 18 million tons. Assuming a 50% efficiency in carbon retention during the conversion process, we could effectively capture and securely sequester 9 million tons of carbon, which equates to an impressive 33 million tons of CO_2 removed from the atmosphere.

Approximately 55 years ago, Dr Wim Sombroek became intrigued by the Terra Preta soils in the Amazon basin. What fascinated him was the soil's exceptional nutrient retention capabilities without the need for synthetic fertilizers. Later, another scientist, Dr Bruno Glaser, confirmed that charcoal played a pivotal role in stabilizing soil organic carbon.

This leads us to a critical question: How can we scale up these practices now that we have scientific backing, research, and some readily available opportunities?

Two essential components hold the key:

1. **Measurement of Soil Organic Carbon:** One of the major challenges in implementation is the monitoring, reporting, and verification (MRV) platforms for assessing soil carbon changes. While several MRV components exist, they are not globally integrated and often are unevenly distributed. FAO's RECSOIL program, which is designed to improve the national and regional greenhouse gases (GHG) mitigation and carbon sequestration initiatives, presents an opportunity to consolidate these efforts, particularly in developing countries. There's significant potential for leveraging robotics, AI, machine learning, and data assimilation to support carbon sequestration.
2. **Encouraging Farmers to Embrace These Practices:** Understanding the barriers and impediments to adopting outlined practices is crucial. How can we incentivize farmers to embrace them? Is there potential for treating soil organic carbon as a farm commodity that can be traded and sold, creating an additional income stream for farmers?

Conclusion

In conclusion, it's evident that organic farming, ZBNF, and regenerative agriculture — all three forms of agriculture — have the potential to combat climate change. The time has come to move beyond labels and create supportive environments that empower farmers to adopt these beneficial practices.

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Digitizing Carbon Farming: Empowering Smallholder Farmers through Carbon Markets

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Mr. Ganesh Babu Krishnappa is an INSEAD alumni with 20+ years' experience in P&L Management, Sustainable Agriculture, Carbon Market Development, Business Turnaround, Sales, Business Development, Business Planning, Global S&OP, Supply Chain Planning, and International Business. Mr Ganesh has worked in the agri-food business, technology, as well as business transformation and turnarounds across India and Europe. He is currently working at Boomitra, building the technology centre in India and is responsible for APAC and Africa SBUs. Has successfully onboarded more than 110,000 mostly small holder farmers on to Boomitra's Carbon Platform in the last year across both India and Africa.

Introduction

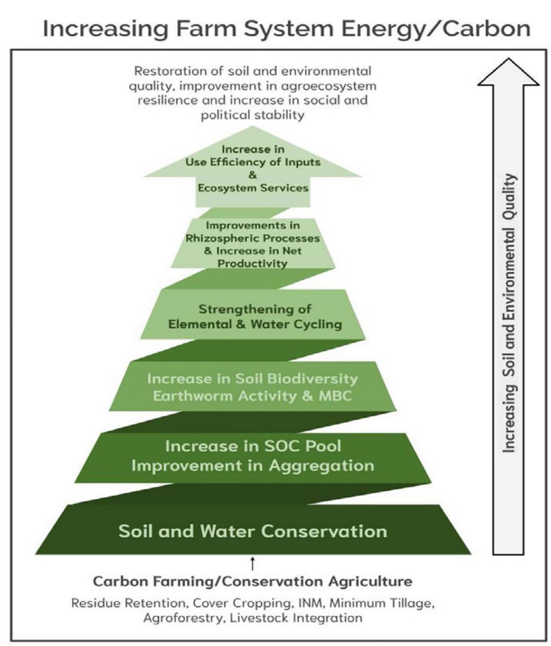
Agriculture is critical for global food security but faces significant challenges in carbon management and climate change mitigation. This abstract emphasizes the role of remote sensing technologies and an inclusive carbon market in promoting transformative behaviour among smallholder farmers.

The carbon farming approach is the cornerstone of empowering small-scale farmers across cropping systems and adopting practices including, but not limited to, no-till, conservation tillage, organic fertilizer application (manure, compost, vermicompost), optimized fertilizer usage, specialized fertilizers/biological amendments, intercropping, cover cropping, crop rotations, and improved water management/irrigation. Effective carbon management practices, such as in-situ crop residue management among others as listed above, enable farmers to enhance carbon sequestration to rates of 0.5-2 tonnes/acre/year, depending on the crop and practices adopted.

Leveraging remote sensing technologies can reduce risk and improve compliance as farmers seek to access a carbon market supported by payments for ecosystems services. Remote sensing can provide a cost-effective mechanism for monitoring and managing vast agricultural landscapes more effectively to meet standards set by the world's leading third-party carbon trading entities. Through this platform that pays to provide an ecological service, smallholder farmers can also gain valuable insights from participating into plant health, growth patterns, soil moisture, nutrient levels, and carbon sequestration potential.

Capacity-building initiatives are crucial for the widespread adoption of carbon farming, equipping farmers with the necessary knowledge and skills in agriculture, natural resource management, and other basic skills such digital/basic literacy, numeracy, and business skills. Knowledge transfer programs facilitate the dissemination of best practices and offer financial incentives to support sustainable practices without a financial burden. Carbon market empowers small-scale farmers by providing critical information and a sustainable funding mechanism.

In conclusion, the integration of innovative and scalable measurement techniques, local partnerships, and policy enhances the success of nature-based solutions such as carbon farming, leading to reduced input costs, increased crop productivity, improved livelihoods, and greater food security. If tied to payments for ecosystems services, these approaches can further boost farm incomes and reinforce the adoption of climate friendly practices.



The ICAC Recorder

ICAC RESEARCHER OF THE YEAR 2023

Dr. Michael Peter Bange

Winner of the ICAC RESEARCHER OF THE YEAR AWARD-2023

It is with great admiration and respect that we honor Dr. Mike Bange, a cotton systems agronomist of exceptional international reputation, with over three decades of innovative work, and a significant contributor to sustainable management practices. Dr Bange is widely acknowledged as as a global research leader on climate change, its impact on cotton and management. His illustrious tenure as a chief scientist at CSIRO Australia stands testament to his exceptional capability and dedication in the field of science. Dr. Bange's innovative approach has consistently enabled him to meld comprehensive understanding of farm-scale requirements with an in-depth analysis of key biological processes. His profound insights into productivity under varied and shifting climates have distinguished his career. He is known for addressing challenges throughout the entire value chain, from seed to shirts, with an innate ability to engage farmers, advisors, and stakeholders in his research. In addition to his extensive collaborations with universities and international cotton industry stakeholders, Dr. Bange has attracted and managed complex projects, leading teams of up to 50 people. As a Fulbright Scholar with active collaborations in the USA and China, his influence extends far beyond Australian borders.

Dr. Bange's pioneering work in sustainable crop management, water use efficiency, cotton agronomy, harvest and postharvest management, and climate change impacts and adaptation are notable. His impactful development of computerized decision support systems for cotton management further highlights his contribution to the field. Dr. Bange has been acknowledged with an impressive tally of awards for his contributions to the field. His recognitions include four prestigious international accolades and a substantial seventeen national awards from esteemed institutions such as the CSIRO, CRC Association of Australia, Australian Museum, Cotton Australia, and the Australian Cotton Cooperative Research Centre, among others. The prestigious USA Beltwide cotton award in 2017 recognized Dr. Bange's significant contributions to physiology and agronomy. In 2016, he graced the World Cotton Research Conference as a keynote speaker, discussing 'Cotton Physiology as the Cornerstone of Cotton Science', further affirming his esteemed standing in the cotton science community. Dr. Bange's leadership extends beyond his research. He has held executive roles within the Association of the Australian Cotton Scientists (AACS) and with ICRA. In 2019, the AACS acknowledged his remarkable contribution to cotton science with the prestigious service to cotton science award.