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SAFEGUARDING HARVESTS

In the face of escalating climate volatility, pest resurgence, and trade pressures, crop protection stands as the unbreakable shield for India's agrarian backbone. From paddy fields to pulse belts, our farmers confront an evolving arsenal of threats—fall armyworms devouring maize, pink bollworms targeting cotton, fungal blights ravaging wheat, and now herbicide-resistant weeds like Phalaris minor choking wheat fields. Yet, protection isn't merely about reaction; it's a proactive symphony of science, sustainability, and strategy to secure yields, cut losses, and bolster farmer incomes nationwide.

Integrated Pest Management (IPM) remains the cornerstone, blending biological controls like Trichogramma wasps against stem borers with cultural practices such as crop rotation and resistant varieties. Chemical pesticides, while potent, demand judicious use—over-reliance has bred resistance in 50+ pest species. We also witness the success of bio-pesticides like neem-based azadirachtin, which have curbed lepidopteran pests in vegetables without residue risks. Digital tools amplify this: AI-driven apps like those from ICAR forecast outbreaks, enabling precision spraying that slashes input costs by 20-30%. Community-led pest surveillance via farmer WhatsApp groups has detected early infestations, saving crops worth Rs 5,000 crore annually.

Climate-smart innovations shine brightly. Drought-tolerant Bt cotton hybrids fend off bollworms while conserving water, while nano-encapsulated fungicides offer targeted delivery, minimizing environmental runoff. Beneficial insects and microbial agents, such as Pseudomonas fluorescens for sheath blight in rice, foster ecological balance, reducing chemical dependency by up to 50% in trials.

Policy plays a pivotal role. The government's push for low-budget natural farming, subsidies on biopesticides, and new regulations on pesticide registration align with the National Mission on Sustainable Agriculture. Extension services must evolve—training 10 crore farmers in IPM via KVKs, digital platforms, and drone demos ensures adoption.

The payoff is profound: protected crops mean resilient farms, enhanced exports meeting global MRL standards (boosting agri-exports to $100 billion), and soil health for future generations. IPM adopters report 15-25% higher net profits. As India eyes a $50 lakh crore agri-economy, let us champion holistic protection—merging tradition with technology. Farmers, researchers, and policymakers must unite to transform threats into triumphs.

Protect today, harvest tomorrow.

Rajni Shaleen Chopra

CONTENT

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From the CEO's desk

Fortifying India's Fields With Crop Protection

India's vast and vibrant agro-ecosystems sustain over 1.4 billion lives. Yet, they face relentless threats—pests, diseases, nutrient gaps, and climate vagaries—that demand a holistic defense strategy. Crop protection today transcends reactive measures, embracing precision tech, biotech, organics, and balanced inputs like chemical fertilizers. This integrated approach boosts yields, cuts losses, slashes costs, and empowers farmers toward resilient, profitable farming, securing India's food sovereignty amid global challenges.

Judicious use of chemical fertilizers stands as a cornerstone, delivering major gains when applied smartly. Balanced NPK formulations, guided by soil testing, replenish essentials depleted by intensive cropping, boosting yields by 20-30% in staples like rice and wheat. Slow-release urea variants minimize leaching, enhancing nitrogen use efficiency to 60-70% and saving farmers Rs 5,000-10,000 per hectare on inputs. They fortify crop resilience against stresses, reducing pest susceptibility—vibrant, nutrient-rich plants better withstand pest attacks.

Environmentally sound practices, like split dosing and foliar sprays, curb overuse, aligning with soil health while unlocking economic windfalls: higher outputs fetch premium prices, lifting smallholder incomes by 15-25% and enabling diversification into high-value crops.

India's diverse agro-ecosystems pulse with renewed vigour, outsmarting nature's challenges through innovation, resilience, and collective resolve for bountiful harvests.

Precision agriculture leads the charge. Drone-mounted hyperspectral imaging detects nutrient deficiencies and early pest signatures, triggering site-specific interventions that cut pesticide use by 40%. Coupled with IoT soil sensors, farmers receive real-time alerts, optimizing protectants like pheromone traps for fruit borers in orchards.

Biotech breakthroughs offer enduring shields. Gene-edited crops with stacked traits resist multiple viruses, while RNAi sprays silence pest genes at the molecular level without harming pollinators. Organic farmers thrive with entomopathogenic fungi like Beauveria bassiana, decimating whiteflies in brinjal with 80% efficacy.

Water and soil guardians emerge too. Mulching suppresses nematodes in tuber crops, while mycorrhizal fungi enhance root vigor against wilt pathogens. Post-harvest, hermetic storage bags and ozone fumigation preserve grains from storage mites, slashing losses from 10-15% to under 2%.

FPOs amplify impact, pooling resources for bulk biopesticide procurement and shared machinery. Regulatory strides, like faster approvals for indigenous formulations, bridge lab-to-land gaps.

Economically, robust protection unlocks potential: a 1% yield gain translates to Rs 20,000 crore in value. It fortifies climate adaptation. As stewards of the soil, let us embrace this renaissance—fusing genomics, data, community wisdom, and balanced fertilizers. The call is clear: innovate relentlessly, protect proactively. India's fields will not just endure; they will flourish, feeding generations with pride.

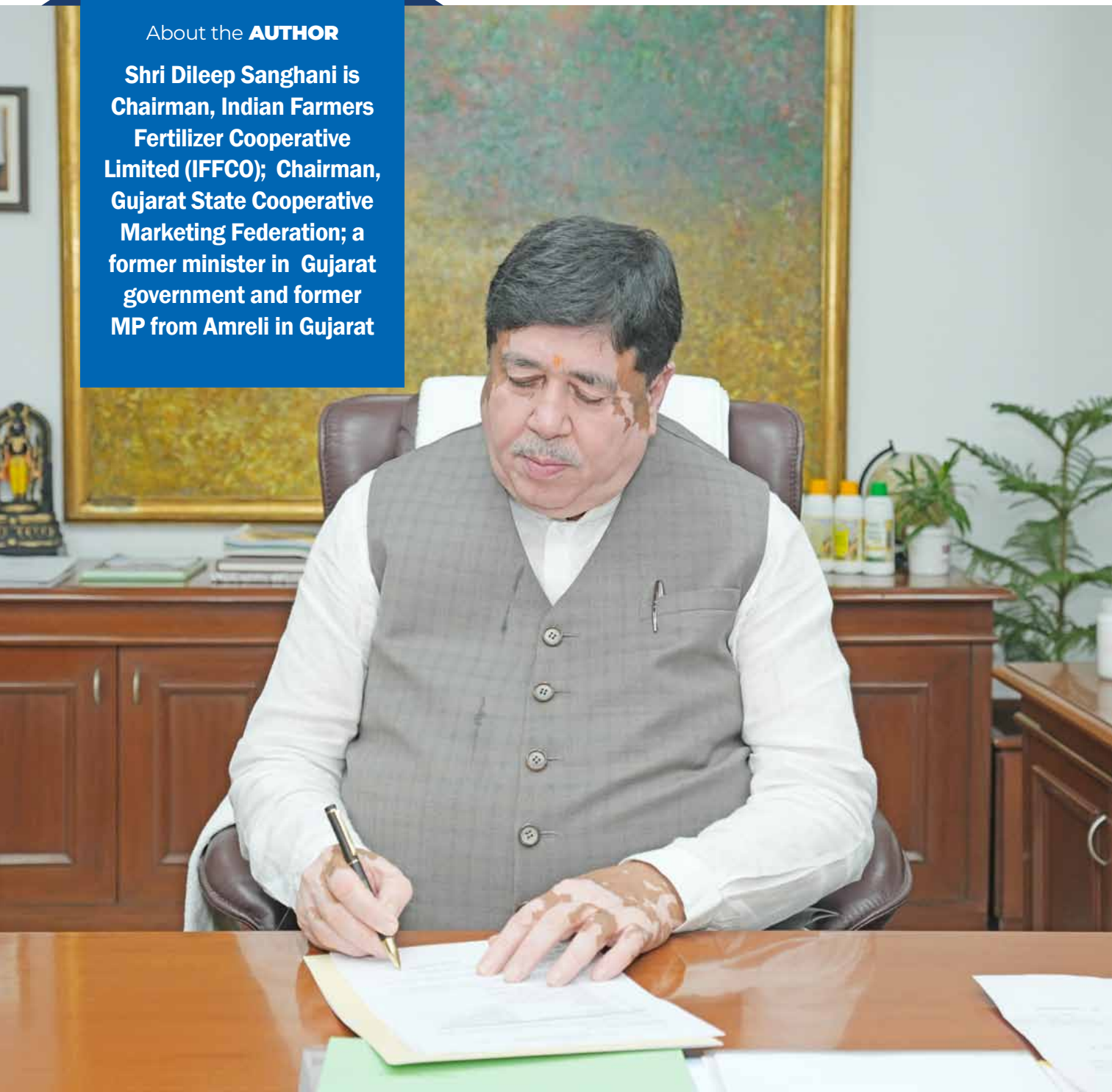
Haris Khan

NANO FERTILIZERS

IFFCO'S REVOLUTION FOR A SELF-RELIANT INDIA AND PROSPEROUS FARMS

About the **AUTHOR**

Shri Dileep Sanghani is Chairman, Indian Farmers Fertilizer Cooperative Limited (IFFCO); Chairman, Gujarat State Cooperative Marketing Federation; a former minister in Gujarat government and former MP from Amreli in Gujarat



Farmers' hard work, their hopes, and the future of their land can only be secured if they have access to high-quality, affordable, and future-proof soil nutrients—solutions that not only increase production but also enhance soil health and make farming sustainable. Our annadatas are the true architects of India's progress. They deserve tools that multiply their yields without burdening the earth.

India's agriculture isn't just our economy—it's our heart, our pride, and the foundation of a self-reliant India. Our farmers have been transforming soil into life for generations with their tireless hard work and dedication, feeding over a billion people and contributing nearly 18% to our GDP.

Challenges Faced by our Farmers

But today, farmers face numerous challenges—erratic monsoons, declining soil fertility due to overuse of chemicals, rising input costs, fragmented landholdings, and increasing global demand for food. At this critical juncture, we must move beyond reliance on traditional fertilizers and embrace innovations that are better for both the soil and the environment. Small changes are no longer enough. We need a vision and technology that makes farming more profitable, sustainable, and future-ready—where farmer incomes double, costs decrease by half, and India scales new heights in agriculture, aligning perfectly with Prime Minister Narendra Modi's "Viksit Bharat 2047" dream.

Nano Fertilizers - The Game-Changer

Nano fertilizers are not a glitzy phenomenon; they are a game-changer for global agriculture at the molecular level. Conventional urea and DAP often lose approximately 60-70% of their nutrients through leaching, evaporation, or runoff, leaving crops starved, soils poisoned by chemicals, and groundwater contaminated with nitrates. This inefficiency costs our farmers dearly—think of the lakhs of rupees washed away in the first rains. IFFCO's Nano Urea liquid, with particles just 20-50 nanometers across—smaller than a virus—penetrates directly into the plant's stomata and roots via foliar spray or soil application. Crops instantly absorb 80-90% of the nutrients, boosting growth, chlorophyll content, and photosynthesis by up to 20-30%, as proven in over 15,000 farmer trials across 13 states.

Produced at IFFCO's state-of-the-art plants in Kalol, Aonla, and Phulpur, a single 500 ml bottle of nano fertilizers replaces a full 45 kg bag of urea. We've scaled production to 44 crore bottles annually by 2026, with plans for 200 crore by 2027, including new R&D for Nano Zinc and Multi-Nutrient blends

This is nothing less than a masterstroke by IFFCO for a self-reliant India. Imported urea ate up approximately Rs 2.5 lakh crore of our foreign exchange reserves last year alone, making us slaves to global prices and supply chains. Nano fertilizers change the narrative entirely: Produced at IFFCO's state-of-the-art plants in Kalol, Aonla, and Phulpur, a single 500 ml bottle replaces a full 45 kg bag of urea. We've scaled production to 44 crore bottles annually by 2026, with plans for 200 crore by 2027, including new R&D for Nano Zinc and Multi-Nutrient blends. The lighter load—mere half-kilo bottles—puts less strain on our farmers' backs, reduces logistics costs by 50%, and eases railway and truck burdens. Costs decrease by approximately 30-50% per hectare; a farmer spraying Nano Urea on paddy saves Rs

500-700 per acre compared to granular urea. This isn't just savings—it's money for children's education, better healthcare, and realizing farmers' dreams of prosperous lives.

The Cooperative Powerhouse Driving Change

When the world comes to our doorstep in the era of "Viksit Bharat 2047," we will showcase fields lush with bountiful harvests—golden wheat, vibrant paddy, resilient cotton—proving that India is feeding itself and leading the world. No longer need to beg at foreign tables; we decorate our own tables with homegrown abundance. IFFCO Nano Urea is Atmanirbhar Bharat in a bottle—saving Rs 1.5 lakh crore in imports over five years.

Cooperatives are the backbone of India's economy. It's an invisible economy, unlike any corporation—powered by trust, not stocks. IFFCO is the strength of 36,000 cooperatives, owned by approximately 50 million farmers across every district, including empowering 15 million women through self-help groups. This people-power has given birth to IFFCO Nano fertilizers. We marketed over 30 million bottles across the country in fiscal year 2025-26, reaching from the arid farms of Rajasthan to the humid deltas of Kerala. Remember the Green Revolution of the 1960s? Cooperatives made it possible through timely supply of HYV seeds and fertilizers. Now, the Nano Revolution is its next chapter, democratizing cutting-edge technology so that every small farmer—from the cotton belt of Gujarat to the rice bowl of Bengal, the sugarcane fields of Maharashtra to the spice gardens of Kerala—can prosper. Marginal farmers have doubled their tomato yield with just four sprays, fetching Rs 2 lakh extra income. Farmers reported 25% higher wheat yields and healthier stubble, reducing burning incidents.

Globally, nano fertilizers position India as an exporter, not an importer. We've exported technology to Nepal, Sri Lanka, and the US, with trials in Africa (Kenya, Zambia) and Southeast Asia (Vietnam, Indonesia) showing 15-25% yield jumps in maize and rice

Environmental Triumph and Soil Revival

Environmentally, this is a victory for Mother India. Excessive use of chemical fertilizers has nearly destroyed our soil—reducing organic carbon by 30-50% in many regions, choking sacred rivers like the Ganges with phosphatic runoff, and spiking greenhouse gas emissions from denitrification. Nano fertilizers prevent this catastrophe. Their targeted delivery minimizes residue, restores microbial life, and improves soil structure. Healthy soil retains water better—up to 20% more—fights drought, and sequesters carbon, aiding India's net-zero goals by 2070. Field trials show 40% less water usage and zero nitrate pollution, turning barren patches green again.

Global Leadership and Soft Agri Power

Globally, nano fertilizers position India as an exporter, not an importer. We've exported technology to Nepal, Sri Lanka, and the US, with trials in Africa (Kenya, Zambia) and Southeast Asia (Vietnam, Indonesia) showing 15-25% yield jumps in maize and rice. In "Viksit Bharat 2047," we will export not just bottles, but the cooperative model—training African unions in Nano Urea production. This is Soft Agri Power 2.0: India eradicating global hunger.

Challenges remain: farmer awareness, last-mile supply chains, and counterfeit risks. But cooperatives, with their vast network of 1 lakh villages, will overcome them through demos, Krishi Melas, and digital apps. Government support via DBT, 100% subsidies on trials, and ICAR validations make us unstoppable. IFFCO Nano fertilizers—now including Nano DAP and beyond—are not just science; they are the spirit of Swadeshi, empowering 50 million farmers, ensuring food security for 1.4 billion people, and paving the way for an agricultural economy worth nearly Rs 50 lakh crore by 2030.

A Pledge for Tomorrow

As we prepare for "Viksit Bharat 2047," let's pledge: nano-powered farms will attract global delegates, from UN envoys to WTO leaders, proving that a self-reliant India is blossoming. Join this nationwide movement of the IFFCO cooperative family—spray Nano Urea, share your story, and watch your fields thrive. Together, we will reap the harvest of a stronger, greener, self-reliant tomorrow. Jai Kisan! Jai Hind! Jai Sahakar!

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NANO FERTILISERS

THE SILENT REVOLUTION

THAT COULD REDEFINE GLOBAL AGRICULTURE

India's agriculture has never been just about crops and commodities; it is about identity, dignity, and an unbreakable bond between the farmer and the soil. For generations, this relationship has sustained not only livelihoods but the very soul of the nation. At IFFCO, we have had the privilege of being a part of this journey, walking alongside millions of farmers who place their trust in us not merely as a cooperative, but as a partner in their dreams.

Today, that journey stands at a defining crossroads. The pressures of a growing global population, shrinking natural resources, climate uncertainty, and declining soil health are no longer distant concerns, they are urgent realities knocking at our doors. In such a moment, incremental change is not enough. What agriculture needs is a breakthrough. A transformation. A leap of faith powered by science and guided by purpose to serve the humanity.

This is where Nano Fertilisers enter the story; not as just another product, but as a bold promise for the future.

Nano Fertilisers represent a

About the **AUTHOR**

Mr KJ Patel is Managing Director, Indian Farmers Fertiliser Cooperative Limited (IFFCO)

profound shift in the way we nourish our crops. Unlike traditional fertilisers, which often lose much of their value to the environment through leaching or volatilization, nano fertilisers work with precision at the molecular level. Their tiny nano size allows plants to absorb nutrients more efficiently, almost as if the crops themselves are finally being heard and understood. The result is not only improved productivity, but healthier plants and more resilient harvests.

But beyond laboratories and scientific breakthroughs lies a far more powerful narrative; the human impact.

Picture a farmer, who once struggled under the weight of heavy fertiliser bags, now holding a small 500 ml bottle of Nano Urea. It reduces costs, eases physical strain, and restores a sense of control and dignity to the farmer's daily life. In a country where farming is often an act of endurance, such change is nothing short of transformative.

This is the heartbeat of innovation at IFFCO. Progress, for us, is not measured in metrics alone; it is measured in the smiles of farmers, in their renewed hope, and in their confidence to dream again.

Developed through rigorous research on Indian soil, Nano Fertilisers are also a powerful symbol of national pride. They embody the spirit of *AtmaNirbhar Bharat* and *Make in India*, proving that India is not just a consumer of agricultural technology, but a global leader in creating it. These innovations are born from the trust of lakhs of farmers who see IFFCO not as an institution, but as their own cooperative family.

Equally compelling is the environmental promise that Nano Fertilisers bring. For decades, excessive use of chemical fertilisers has silently eroded soil health and polluted water bodies. Nano technology offers a way out of this cycle. By dramatically improving nutrient efficiency, it reduces the overall quantity of fertilisers needed, protecting the land that feeds us and the water that sustains us. It is not just a technological advancement, but it is a step toward healing the earth.

What makes this revolution even more remarkable is the spirit with which it is being embraced. Indian farmers,

By dramatically improving nutrient efficiency, nano fertilizers reduce the overall quantity of fertilisers needed, protecting the land that feeds us and the water that sustains us

often underestimated in their openness to change, have shown extraordinary courage and curiosity. They are questioning, experimenting, learning and leading. The adoption of over 3 crore bottles of Nano Fertilisers during the FY 2025-26 is not just a statistic; it is a testament to their faith in innovation and their determination to move forward.

At IFFCO, we understand that innovation does not end with invention. It must be nurtured through knowledge, guidance, and constant engagement. Through field demonstrations, training initiatives, and on-ground support, we are ensuring that farmers are not just users of Nano Fertilisers, but informed partners in this transformation.

The road ahead is filled with promise. With a clear vision to replace a significant portion of conventional fertilisers like urea and DAP with Nano alternatives in the coming years, India is setting the stage for a new agricultural paradigm, one that is efficient, sustainable, and globally relevant. Alongside nano fertilisers, our focus on biofertilizers and bio-stimulants will further rejuvenate soil health and align with national sustainability goals. Yet, this is only the beginning.

The true potential of Nano Fertilisers lies in their ability to transcend borders. The challenges faced by Indian agriculture are shared by farmers across the world. And the solution we are nurturing today has the power to become a global movement tomorrow; a comprehensive movement where technology serves humanity, and innovation restores balance to nature.

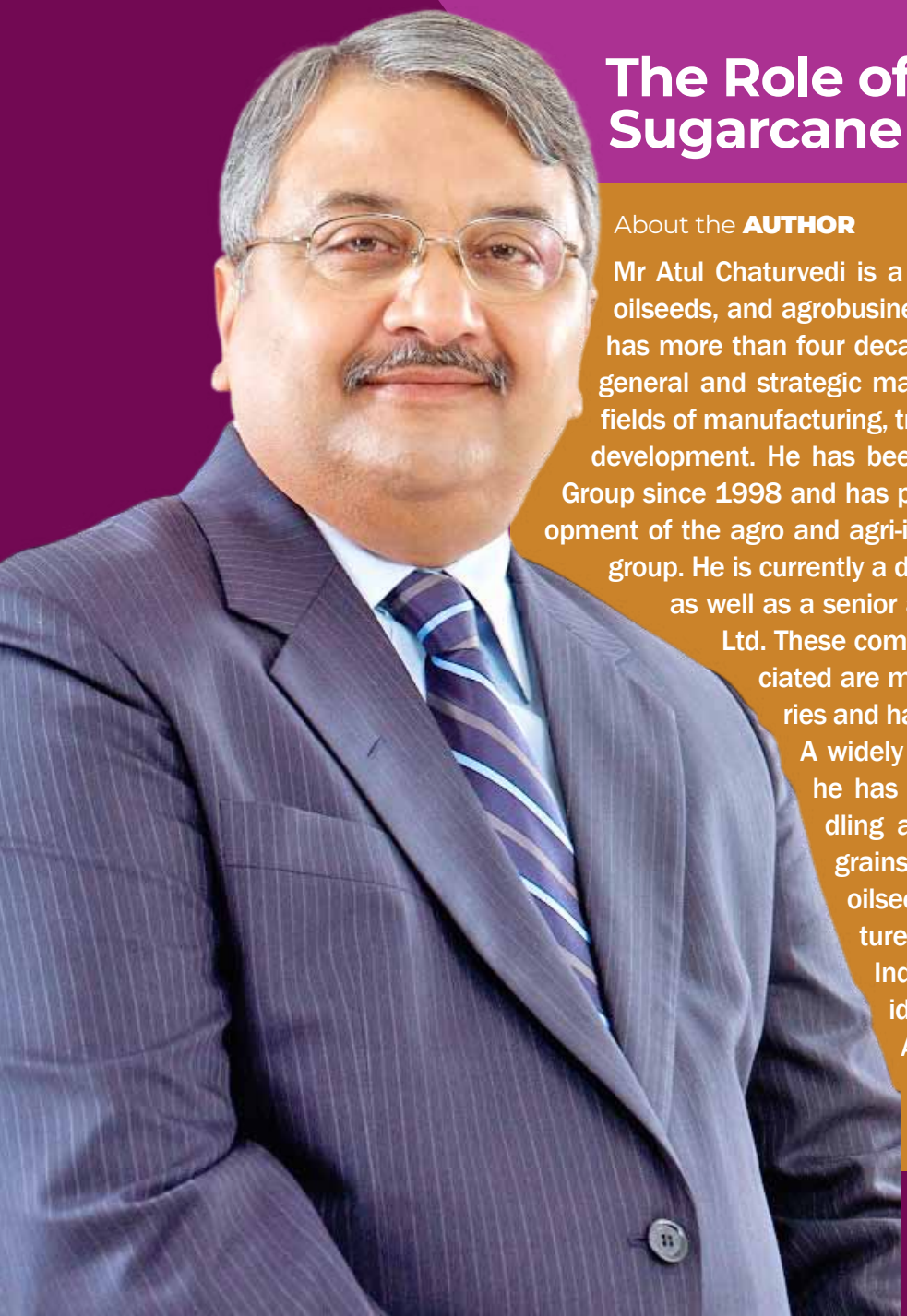
As we look to the future, one truth becomes clear: the destiny of agriculture will be shaped by how well we balance productivity with sustainability. Nano Fertilisers offer us that balance. They offer us hope.

This is more than a technological evolution, it is an emotional revolution. A quiet, determined shift that empowers farmers, protects the planet, and positions India as a torchbearer of agricultural innovation on the global stage.

And as we move forward, hand in hand with our farmers, we do so with conviction that every drop of innovation we create today will nourish a stronger, greener, and more self-reliant tomorrow.

CROP PROTECTION IS KEY TO INDIA'S ATMANIRBHARTA IN OILSEEDS

The Role of IPM in Sugarcane Sustainability



About the **AUTHOR**

Mr Atul Chaturvedi is a veteran in the vegetable oil, oilseeds, and agrobusiness sectors of the country. He has more than four decades of successful and varied general and strategic management experience in the fields of manufacturing, trading, and agri-infrastructure development. He has been associated with the Adani Group since 1998 and has played a key role in the development of the agro and agri-infrastructure business of the group. He is currently a director of Renuka Sugars Ltd. as well as a senior advisor of AWL Agri Business Ltd. These companies with which he is associated are market leaders in their categories and have done pioneering work.

A widely traveled international trader, he has hands-on experience in handling agro-products, vegetable oils, grains, sugar, ethanol distilleries, oilseeds, apples, agri-infrastructure, etc., both within and outside India. Recently, he was the President of the Solvent Extractors Association of India (SEA), a leading trade body of the vegetable oil industry.

Let me confess right at the beginning that I am no expert in agricultural science. However, during my long career spanning more than four decades, I have handled many agri-commodities like oilseeds, pulses, and grains, as well as sugarcane, and I understand the importance of crop protection not only for ensuring good yields but also for safeguarding the wellbeing of the tiller (farmer) of the soil.

Over the years, I have seen crops blossoming and then wilting before harvest, leaving the poor farmer in serious distress. Nature definitely plays an important role in the development of the crop, but improper crop protection can also play havoc with the final outcome in the form of low yields.

Having been closely associated with oilseeds as CEO of Adani Wilmar and later with sugarcane as Executive Chairman of Renuka Sugars, I will confine my comments to only these two agri-commodities.

Crop Protection - Oilseeds

Crop protection in oilseeds focuses essentially on protecting plants from pests, diseases, and weeds to ensure yields and quality are not compromised.

The global crop protection market is expected to grow to around USD 106 billion by 2030

The main approaches include chemical, biological, cultural, and integrated pest management practices.

Major Threats

Mustard: Aphids, Alternaria blight.
Groundnut: Leaf spots, stem rot, termites.
Soybean: Stem fly, rust.
Sunflower: Head borer.

Protection Measures

Listed below are commonly recommended protection measures for oilseeds in general:

- Proper seed treatment and the use of fungicides.
- Biopesticides like neem-based for-

mulations.

- Maintaining proper spacing and drainage to reduce fungal diseases.
- Last but not least, Integrated Pest Management (IPM) practices.

A widely recommended approach for Integrated Pest Management includes the following:

- Regular field monitoring.
- Biological control (natural predators).
- Cultural practices like crop rotation and planting resistant varieties.
- Judicious pesticide usage only when needed.

In a nutshell, effective crop protection combines resistant varieties, agronomic practices, biological control, and limited chemical usage to protect oilseed crops and maintain sustainability.

Sugarcane

Crop protection in sugarcane is mainly aimed at preventing losses from borers, sucking pests, fungal diseases, and weeds, particularly during the 120–150 days after planting.

Protection measures:

*Use healthy pest free seed cane
*Avoid ratooning heavily infested fields
*Remove and destroy affected shoots and install pheromone traps for borers.

Release biological control agents such as Trichogramma chilonis

Maintain proper irrigation and nutrition.

Overall, the Indian crop protection sector is moving from being insecticide-driven to a more balanced structure where herbicides, fungicides, and biologicals grow faster, especially in crops like oilseeds and sugarcane.

Use insecticides only when infestation crosses threshold level.

Major insect and pests which harm sugarcane are:

- Early shoot borer
- Top borer
- Internode borer
- Pyrilla and whitefly
- Termites and root grubs

Summing up, the most effective system is Integrated Pest Management (IPM), which includes the usage of resistant varieties, clean seed cane, timely monitoring, biological controls, and limited, need-based pesticide use.

This approach goes a long way in maintaining cane yield and sugar recovery.

Indian Crop Protection Scenario

India's crop protection sector is one of the largest globally and is becoming more and more important as we are witnessing labour shortages, climate changes, and an increase in pest resistance, which is contributing to reduced farm productivity.

The Indian crop protection chemicals market was estimated at around USD 6.4 billion in 2024 and is expected to grow closer to USD 10 billion in the next few years. The annual growth is estimated at around 5%.

India remains heavily skewed towards insecticides as crops face high insect pressure. Herbicides are also growing, as labour for manual weeding is not only becoming scarce but also expensive.

Emerging Trends

We are witnessing some interesting developments in crop protection in India:

- A shift towards biopesticides.
- The usage of drones for spraying.
- Precision farming and digital advisory.
- Increased regulation and a ban on old molecules.

Key Challenges

India's crop protection industry still faces several issues:

- Counterfeit and spurious products.
- Excessive dependence on older chemistries.
- Low awareness of safe application.
- A fragmented distribution network.
- Increasing pressure to reduce chemical residues in food.

Overall, the Indian crop protection sector is moving from being insecticide-driven to a more balanced structure where herbicides, fungicides, and biologicals grow faster, especially in crops like oilseeds and sugarcane.

The global crop protection market is expected to grow to around USD 106 billion by 2030. This reflects the importance of crop protection, which cannot be taken lightly if India is to achieve a semblance of Atmanirbharta in oilseeds and attain global yields in sugarcane.

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Reimagining PLANT PROTECTION

Plant protection has traditionally been associated with the application of pesticides, fungicides, and herbicides to safeguard crops against biotic stresses. However, as agriculture evolves toward sustainability, resilience, and efficiency, it is becoming increasingly clear that plant protection cannot be viewed in isolation. Instead, it must be integrated with plant nutrition and physiological enhancement strategies. This is where advanced nutritional technologies such as MAC (Micronutrient Activated Complexes) and NUE (Nutrient Use Efficiency) are redefining the paradigm of crop protection.

Modern agriculture faces a dual challenge: increasing productivity while reducing environmental impact. Excessive dependence on crop protection chemicals often leads to resistance development, residue concerns, and ecological imbalance. Therefore, enhancing the effectiveness of these chemicals while reducing their required doses has become a critical goal. Nutritional innovations, particularly those developed by companies like Verdesian Life Sciences, are playing a transformative role in achieving this balance.

Bridging Nutrition and Protection

Plants are inherently equipped with defence mechanisms to combat pathogens and pests. However, these systems require optimal nutrition to function effectively. Deficiencies or imbalances in nutrients can weaken plant immunity, making crops more susceptible to diseases and infestations. MAC and NUE technologies address this gap by ensuring that plants receive nutrients in highly efficient and bioavailable forms, thereby strengthening their natural defence systems.

MAC technology focuses on delivering micronutrients in a stabilized and plant-available format, ensuring rapid uptake and utilization. Micronutrients such as zinc, manganese, and copper play crucial roles in enzyme activation, cell wall strengthening, and metabolic pathways linked to plant defense. When delivered through advanced complexes, these nutrients not only correct deficien-

About the **AUTHOR**

Mr R K Goyal is Managing Director, APAC Region, Verdesian Life Sciences, USA

cies but also enhance physiological resilience.

On the other hand, NUE technology ensures that applied nutrients are utilized more efficiently by the plant, minimizing losses due to leaching, volatilization, or fixation. By improving nutrient uptake efficiency, NUE technologies support robust plant growth, which directly correlates with improved tolerance to stress conditions and reduced vulnerability to pests and diseases.

CPST: Enhancing the Performance of Crop Protection Chemicals

One of the most significant contributions of modern nutritional technologies to plant protection is through Crop Protection Support Technology (CPST). This innovative approach enables nutritional products to act synergistically with crop protection chemicals, enhancing their performance.

CPST works by improving spray solution characteristics, nutrient assimilation, and plant receptivity. When nutritional formulations are applied alongside pesticides or fungicides, they can enhance the penetration and translocation of active ingredients within plant tissues. This ensures that crop protection chemicals reach their target sites more effectively, leading to improved efficacy.

Moreover, CPST helps in reducing spray drift and improving adhesion on leaf surfaces, ensuring better coverage and longer persistence. This not only maximizes the effectiveness of the applied chemicals but also reduces the need for repeated applications. As a result, farmers can achieve better control of pests and diseases with optimized input usage, contributing to both economic and environmental sustainability.

Elicitation: Activating the Plant's Internal Defence System

Beyond supporting external crop protection measures, MAC and NUE-based products also possess elicitation capacity—an equally powerful tool in plant protection. Elicitors are compounds that stimulate a plant's innate defence mechanisms, triggering biochemical pathways that enhance resistance against pathogens and pests.

The role of advanced nutritional technologies in plant protection will continue to grow, offering new opportunities to safeguard crops while preserving the health of our ecosystems

When plants are exposed to elicitor molecules, they activate defence responses such as the production of phytoalexins, strengthening of cell walls, and synthesis of protective proteins. These responses create a hostile environment for invading organisms, effectively reducing disease incidence and severity.

Nutritional products with elicitation properties act as both a shield and a stimulant. They prepare the plant to respond more rapidly and effectively to stress, thereby reducing dependency on chemical interventions. This proactive approach to plant protection aligns with integrated pest management (IPM) strategies, where prevention and resilience are prioritized over reactive treatments.

A Sustainable Path Forward

The integration of MAC and NUE technologies into plant protection strategies represents a significant step toward sustainable agriculture. By enhancing nutrient efficiency and supporting the performance of crop protection chemicals, these technologies help reduce overall chemical load on the environment. At the same time, their elicitation capacity empowers plants to defend themselves, reducing reliance on external inputs.

Farmers adopting such integrated approaches benefit from improved crop health, higher yields, and better return on investment. Reduced input costs, minimized environmental impact, and improved produce quality further add to the value proposition.

Bridging The Gap Between Nutrition And Protection

Plant protection is no longer just about controlling pests and diseases—it is about building resilient cropping systems that can withstand challenges while maintaining productivity and sustainability. Technologies like MAC and NUE are at the forefront of this transformation, bridging the gap between nutrition and protection.

Through innovations such as CPST and elicitation capacity, these technologies not only enhance the effectiveness of traditional crop protection measures but also unlock the plant's inherent potential to defend itself. As agriculture moves toward a more integrated and sustainable future, the role of advanced nutritional technologies in plant protection will continue to grow, offering new opportunities to safeguard crops while preserving the health of our ecosystems.

INDIA'S EXPORT AMBITION WILL DEPEND ON WINNING THE BATTLE AGAINST PEST-LED CROP LOSSES

India's agricultural progress today hinges less on how much land is brought under cultivation and more on whether the quality of produce can be safeguarded right at the point of harvest.

The scale of the challenge is stark. Annual crop losses from pest incidence are estimated at nearly INR 2 lakh crore, making pest damage one of the most significant yet underaddressed drags on farm profitability and national agricultural competitiveness. In high-value crops such as vegetables, biotic stress can erode yields by as much as 20 to 40 per cent. The implications extend far beyond farm output. They directly influence farmer incomes, food inflation, export readiness, and India's credibility in premium global markets.

At a time when India is seeking to deepen its presence in global agri trade, the issue of preventive crop protection must move from an input decision to a national competitiveness imperative.

The export opportunity is expanding, but so are quality risks

India's farm exports are on a roll, keeping the country high on the list of top global agri-exporters. In FY26, agricultural exports reached US$ 16.9 billion, which shows there's strong and steady demand worldwide for Indian produce. What's even more interesting is that more buyers are looking for value-added products from India. That points to the country moving up the value chain and sets up the sector for even better exports down the road.

Vegetables, spices, and certain horticultural products that are sensitive to residues have all seen growing interest from buyers in West Asia, Europe, Southeast Asia, and North America. Demand from these regions just keeps climbing. India's diverse agro-climatic advantage and skilled cultivation base position it strongly to capture this demand.

Yet this opportunity is increasingly vulnerable to one critical fault line: quality degradation caused by pest damage and delayed intervention.

Scarring, discoloration, bore damage, surface feeding marks, and misshapen produce materially reduce grade realization in both domestic mandis and export channels. Even when yield loss remains manageable, visual defects alone can push produce into lower-value categories, undermining price realization for farmers and exporters alike.

The challenge intensifies when infestations are addressed too late. Curative overuse of pesticides near harvest often complicates adherence to stringent Maximum Residue Level compliance norms, increasing the risk of shipment rejections, container detentions, and market-access disruptions. Recent global scrutiny on residue management in Indian

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agri exports has reinforced the need for stronger upstream crop stewardship.

The farmer income equation begins with early protection

For Indian farmers, pests aren't just a headache- they hit the wallet hard. When pests show up, they can slash crop yields by 20 to 40 percent, sometimes even more. Vegetables, chilli, cotton, pulses, and fruits take the worst hits, especially during seasons when pests are everywhere. The economic impact compounds because quality deterioration often leads to steeper price discounts than the physical loss itself.

A partially damaged harvest does not merely weigh less. It sells for less.

In severe infestations, produce may become unsuitable for fresh consumption or processing-grade acceptance, effectively erasing the value of the crop. This weakens farm cash flows, disrupts reinvestment into the next sowing cycle, and heightens vulnerability to indebtedness.

From a broader market perspective, repeated pest-led losses tighten supply, contribute to price volatility, and affect food system stability, particularly in perishables where demand elasticity is low.

Preventive Pest Management is the new sustainability lever

The sector must therefore reframe pest control from a reactive spray model to a preventive crop health architecture.

Early-stage intervention delivers multiple advantages. It suppresses pest populations before they cross economic threshold levels, protects crop vigour from the root and vegetative stages, and materially reduces the need for repeated late-cycle rescue applications.

From a sustainability lens, this is where preventive agronomy and environmental stewardship converge. A single timely intervention, embedded within an integrated pest management framework, is often more resource-efficient than multiple curative sprays that increase cost, resistance pressure, and ecological stress.

For a country balancing food security, export ambition, and sustainability goals, early pest management is emerging as one of the most effective levers of value creation.

Every pest attack you prevent doesn't just mean healthier crops- it means farmers keep more of their income, exports build a stronger reputation, and the country becomes more competitive

The role of New-Age Chemistry in building resilience

This transition will also require continued adoption of advanced crop protection molecules with differentiated modes of action. New-generation insecticidal chemistries such as fluxametamide represent the kind of innovation that modern Indian agriculture increasingly needs. Belonging to the isoxazoline class, it offers targeted and rapid control across economically significant pests such as caterpillars, thrips, beetles, and flies. Its value lies not only in spectrum, but in strategic fit. In practice, how this chemistry is deployed across crops is equally important. For instance, combination formulations such as Rashinban by Godrej Agrovet, designed for crops like chilli, tomato, brinjal, okra, and cucurbits, integrate fluxametamide (3.8% SC) with pyridaben (9.5% SC) to address both sucking and chewing pests through complementary modes of action. In contrast, Gracia, a fluxametamide 10% EC formulation from the same portfolio, is positioned for crops such as chilli, cabbage, tomato, and brinjal, where targeted intervention against key pest complexes is critical.

Whether through combination formulations for broader control or single-active solutions for targeted use, these approaches align well with IPM frameworks and can enhance both farm economics and export-quality outcomes when used judiciously.

From Farm protection to trade competitiveness

India's next phase of agricultural export growth will depend on quality consistency, traceability, and compliance discipline.

That journey begins with protecting the crop before the damage becomes visible.

Moving ahead, farmers, policymakers, agri-scientists, exporters, and the crop care industry need to work together more closely. The thinking is simple: every pest attack you prevent doesn't just mean healthier crops- it means farmers keep more of their income, exports build a stronger reputation, and the country becomes more competitive. For India to fully realize its agricultural export potential, crop protection must be viewed not as an input cost, but as a foundational investment in economic resilience.

IS D2C THE FUTURE OF CROP PROTECTION OR JUST AN ADDED LAYER?

Crop protection products in India have always moved through a familiar chain. Manufacturers supply distributors, distributors supply retailers, and retailers finally reach farmers. It is an old system, but it has held because it runs on proximity and relationships. The village retailer is not just a seller, he is an advisor, an informal credit provider, and often the first call when something goes wrong in the field.

That structure is now being reshaped by D2C platforms. Not replaced. Reshaped.

Farmers with smartphones can now browse products, compare options, and order inputs without being limited to what is stocked at the nearest shop. What was once a supply-driven system is slowly becoming demand-responsive. Research confirms what practitioners are already seeing on the ground, digital platforms are improving access, transparency, and efficiency across agricultural value chains.

Policy Has Opened the Door

In 2022, Regulatory acceptance of Pesticide Sales through compliant e-Commerce channels has been a meaningful enabler. Combine that with rising smartphone penetration in rural India, and the conditions for D2C to scale are no longer theoretical. Farmer buying behaviour is changing. Studies now show that digital ac-

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cess is influencing how farmers search and purchase agri-inputs.

What Actually Changes for the Farmer

The biggest shift D2C brings is access, not just to more products, but to more information. Farmers can compare specifications, check pricing, and evaluate alternatives before buying. In a traditional channel, the retailer largely controlled that decision. That is changing.

Advisory Is Becoming Part of the Transaction

Crop protection is never a simple purchase. It requires correct problem identification, the right product choice, and the right timing. Several D2C platforms are now integrating agronomic advisory into the buying flow, farmers can diagnose a pest or disease issue and access recommended products in the same session. When diagnosis and purchase are connected, outcomes improve.

Logistics Is Still the Bottleneck

Technology enables D2C. Logistics decide whether it actually works. Rural supply chains are complex, demand is scattered, delivery conditions are inconsistent, and last-mile infrastructure is weak in many geographies. Platforms are responding with localized warehouses and cluster-based delivery models. The evidence shows a clear pattern: when delivery becomes reliable, farmer behaviour shifts from reactive last-minute purchases to planned buying.

Trust Remains the Hardest Problem

In rural markets, trust is personal and earned over years. The local retailer offers familiarity, accountability, and physical presence. D2C platforms have to earn that differently, through product authenticity, consistent service quality, and credible advisory. One bad recommendation or a counterfeit product can undo that trust quickly. This is not a small challenge.

Disruptive? Not Quite.

D2C is frequently called Disruptive. That overstates it. Traditional retail still plays a critical role, particularly for immediate availability and informal credit, both of which matter enormously to small and marginal farmers.

What is emerging is a hybrid system: digital platforms handle discovery, comparison, and advisory; physical networks handle fulfillment, trust building, and credit.

The data supports this. Digital agriculture complements existing systems more often than it replaces them.

How D2C Changes the Farmer's Buying Experience-Traditional vs. Digital Model

Factor	Traditional Channel	D2C Model
Product Availability	Limited to local inventory	Wide Digital Catalogue
Decision Basis	Retailer advice	Data + Advisory + Comparison
Purchase Trigger	Immediate need	Planned Purchase
Transparency	Low	High
Accessibility	Physical Proximity	Digital + Doorstep Delivery

Key Enablers of D2C Adoption in Indian Agriculture and their Impact

Enabler	Impact on Farmers
Smartphone penetration	Enables digital discovery and ordering
Last-mile delivery	Ensures timely input availability
Advisory integration	Improves decision quality
Policy support	Legitimizes digital channels
Digital payments	Simplifies transactions

D2C is not replacing the traditional channel. But it is becoming a permanent part of how the ecosystem functions, and the players who adapt to that reality early will have the advantage

Where This Is Heading

The long-term impact of D2C in Crop Protection rests on three things: Regulatory strength, Logistics reliability, and Advisory quality. If those three come together, D2C can meaningfully change how farmers access and use crop protection products. If they do not, it becomes just another layer in an already complex system.

For now, D2C is not replacing the traditional channel. But it is becoming a permanent part of how the ecosystem functions, and the players who adapt to that reality early will have the advantage.

THE FUTURE OF CROP PROTECTION

BIOLOGICAL SOLUTIONS AS A BALANCING FACTOR

Crop protection is at a pivotal crossroads. Conventional chemical interventions have powered yield gains for decades, but rising resistance, environmental concerns, and regulatory pressures are driving a fundamental shift. The future of crop protection will likely hinge on a balanced integration of diverse strategies, with biological solutions playing a central, stabilizing role.

1. The evolving landscape of threats and tools

Pests, diseases, and weeds continually adapt, rendering single-mode solutions less effective over time.

Chemical paradigms—once the default—face diminishing returns as resistance spreads and non-target impacts accumulate.

Climate change intensifies abiotic stress and expands the geographic range of many pests, demanding more resilient and adaptable protection systems.

2. Why biologicals are uniquely positioned to balance progress

Targeted action with lower non-target risk: Biologicals, including

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beneficial microbes, biopesticides, and bio stimulants, can offer specificity that reduces collateral damage and ensure quality, regulation, and stewardship to ecosystems and pollinators.

Systemic resilience rather than one-off suppression Living products can interact with plant physiology, enhancing innate defences and promoting healthier microbiomes that contribute to sustained vigour.

Compatibility and synergy: Biologicals often complement conventional chemistries, enabling reduced chemical loads and delaying resistance by diversifying the modes of action in a protection program.

Adaptability to local contexts: Microbial consortia and natural antagonists can be tailored to regional pest complexes and soil types, supporting more precise and context-aware protection strategies.

3. A framework for integrating biology into crop protection

Diversified toolkit: Combine biologicals with approved synthetic pesticides, cultural practices, and resistant varieties to create layered defenses. Diversification slows resistance development and preserves efficacy across seasons.

Lifecycle and rotation planning: Design protection programs that rotate mechanisms of action, integrate bio stimulants at key growth stages, and align with planting calendars and crop calendars.

Data-driven decision making: Leverage digital agronomy, remote sensing, and field diagnostics to time interventions precisely, maximizing biological performance and minimizing inputs.: Invest in robust validation, transparent labelling, and clear stewardship guidelines to ensure safety, efficacy, and farmer confidence. Regulatory frameworks Variability and performance consistency are evolving to accommodate novel biology; proactive engagement accelerates adoption while upholding standards.

4. Impacts on farmers, supply chains, and ecosystems

Economic viability: Although initial costs for some biologics can be higher,

Biological solutions will not replace chemicals entirely but will function as balancing factors that enhance sustainability, resilience, and productivity

total cost of ownership may decrease through reduced chemical use, yield protection, and premium markets for sustainably produced crops. Economies of scale and improved formulation stability are expected to bring price parity over time.

Supply chain resilience: Local production of microbial products and region-specific formulations can reduce dependence on geographically concentrated chemistries, buffering against shortages.

Environmental and social benefits: Lower chemical residues, improved soil health, and preserved pollinator populations support long-term agroecosystem sustainability and public perception of farming practices.

5. Challenges to overcome

Biological products can be more sensitive to temperature, UV exposure, and field conditions. Advancements in formulation, encapsulation, and delivery systems are essential to ensure stable performance.

Shelf life and logistics: Longer shelf life and easier to-handle products will ease adoption, particularly in smallholder contexts.

Regulatory harmonization: Streamlined approvals without compromising safety will accelerate market access for novel biologicals. International alignment helps farmers operate across borders.

Knowledge gaps: Farmers need accessible guidance on integration, compatibility with existing practices, and evidence-based return on investment. Extension services and farmer education must evolve in tandem with product innovation.

6. Enabling technologies and research directions

Microbiome engineering and consortia development: Designing robust microbial communities that support plant health and suppress pathogens.

Biopesticide discovery and optimized delivery**: Metagenomics, high-throughput screening, and smart formulations improve efficacy and user experience.

Bio stimulants and plant immunity: Compounds and microbes that prime plant defences can reduce the need for external inputs while maintaining productivity.

Precision application and digital farming: Sensor networks, AI-driven scouting, and decision-support tools enable targeted, timely biological interventions.

7. A resilient crop protection future

Biological solutions will not replace chemicals entirely but will function as balancing factors that enhance sustainability, resilience, and productivity. The most successful crop protection systems will blend biology with conventional practices in a principled, data-informed framework. This balance minimizes environmental impact, mitigates resistance risks, and supports farmers in delivering reliable yields under increasingly complex growing conditions.

As we look ahead, the shift toward biologically informed protection strategies represents a convergence of science, stewardship, and farmer ingenuity. The future of crop protection will be defined by how well we harmonize living solutions with established technologies to create resilient agricultural systems that thrive in a changing world.

PLANT PROTECTION AND AGRICULTURAL MARKETING

WHY HEALTHY CROPS CREATE WEALTH

The price of your food is decided long before it reaches the market—right in the farmer's field. In India, we often discuss production, procurement, and prices. But one crucial link quietly determines whether a farmer earns a premium or suffers a loss—Plant Protection. In my experience of working across agricultural value chains and markets, I have seen that the journey of a successful product does not begin at the mandi or supermarket—it begins with a healthy, well-protected crop.

Agriculture remains the backbone of our economy, supporting millions of farmers and feeding a vast population. Yet, every season, crops face relentless attacks from pests, diseases, weeds, and unpredictable weather. These challenges don't just reduce yield; they reduce quality, shorten shelf life, and ultimately affect what consumers see, choose, and pay for.

Globally, up to 40% of crops are lost due to such factors. For India, reducing these losses is not just an agricultural priority; it is a market and income imperative.

From Field Health to Market Value

Plant protection today is not just about spraying pesticides. It is about ensuring that crops remain healthy, safe, and market-ready from seed to shelf. It includes preventive practices, timely monitoring, biological control, and responsible use of chemicals.

Why does this matter to consumers and markets?

Because a well-protected crop means:

- Better-looking fruits and vegetables
- Safer food with lower chemical residues
- Longer shelf life and less wastage
- Consistent quality across batches

Plant protection is no longer farm practice; it is the engine that drives safe food, stronger markets, and sustainable farmer incomes. In simple terms, good plant protection transforms farm produce into marketable products.

Short-Term Impact: Better Prices, Better Choices

In the short term, the impact of plant protection is immediate and visible.

When crops are healthy:

- Farmers get higher prices due to better quality
- Traders prefer such produce for quick sale
- Consumers get fresher and more appealing food

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Think about a tomato or apple you pick at a store. If it has spots, pest damage, or uneven size, you are less likely to buy it—or you expect a lower price. This is exactly what happens in markets every day.

On the other hand, clean, uniform produce commands a premium. For farmers, this can mean 20–30% higher income in the same season, simply by protecting the crop effectively.

At the same time, healthier crops suffer less damage during transport and storage, reducing wastage and ensuring more food reaches consumers.

Medium-Term Impact: Stronger Value Chains, Reliable Supply

Over time, consistent plant protection practices help build trust and reliability in agricultural markets. When farmers or Farmer Producer Organisations (FPOs) supply uniform, high-quality produce:

- Retailers and processors are willing to engage regularly
- Bulk buyers prefer long-term sourcing relationships
- Farmers gain access to better and more stable markets

This is where value chains become stronger. Instead of distress sales, farmers move toward planned marketing and better price discovery.

Integrated Pest Management (IPM) plays a key role here. By combining biological, cultural, and minimal chemical methods, it ensures safer produce with fewer residues. This is increasingly important as consumers become more conscious about food safety.

For FPOs, plant protection also creates new opportunities:

- Providing advisory and pest monitoring services
- Offering drone-based spraying
- Ensuring quality consistency across member farms

Such services reduce costs and improve outcomes, making FPOs more competitive in the market.

Long-Term Impact: Safer Food, Stronger Markets, Sustainable Growth

In the long run, plant protection shapes the future of agriculture and food systems.

Plant protection is often seen as a technical aspect of farming, but in reality, it is a powerful economic and marketing tool

Sustained crop health leads to:

- Stable production and consistent supply
- Reduced environmental damage through balanced input use
- Lower risk of pest resistance and recurring outbreaks

From a market perspective, this builds:

- Consumer trust in food quality and safety
- Stronger branding for regions and farmer groups
- Access to premium and export markets

Today's consumers are not just asking "What am I buying?" but also "How was it produced?"

Residue-free, responsibly grown produce is gaining preference. Farmers who adopt scientific and sustainable plant protection practices are better positioned to tap into these evolving markets.

Technology is accelerating this transformation. From mobile advisories and AI-based disease detection to drone spraying and smart pest monitoring, farmers now have tools to protect crops more efficiently than ever before. This ensures that what reaches the market meets modern expectations.

Responsible Practices: Key to Market Acceptance

While plant protection is essential, how it is done matters even more.

Excessive or incorrect use of pesticides can lead to residue issues, making produce unacceptable in many markets, especially exports. This directly affects farmer income and market credibility.

Following simple principles—Right Product, Right Dose, Right Time, and Right Method—ensures that crops are not only protected but also safe for consumers and compliant with market standards

Protecting Crops, Powering Markets

Plant protection is often seen as a technical aspect of farming, but in reality, it is a powerful economic and marketing tool. In the short term, it improves prices and reduces losses. In the medium term, it strengthens value chains and market linkages. In the long term, it builds sustainability, trust, and competitiveness. For consumers, it means safer, better-quality food. For farmers, it means higher and more stable incomes. For the nation, it means a stronger and more resilient agricultural economy.

As someone closely associated with agricultural value chains, I strongly believe: The future of Indian agriculture will not be decided only by how much we grow, but by how well we protect what we grow—and how effectively we take it to the market.

PRECISION TECHNOLOGY
BUILDING THE NEXT CHAPTER OF INDIAN FARM MECHANIZATION

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Agriculture at the Cusp of Transformation

Agriculture has always been more than an occupation for India. It is the nation's enduring strength and the foundation of its progress. For decades, it has nourished millions, powered rural economies, and ensured food security. Yet today, the sector stands at a turning point.

Challenges such as water scarcity, declining soil fertility, and unpredictable weather are testing productivity. Meanwhile, a growing population and evolving consumption patterns are driving higher demand for food. To ensure sustainability and profitability, India must shift from input-intensive, conventional farming to data-driven, intelligent, and sustainable agricultural practices.

Precision Farming: The Smart Way Forward

Precision farming marks a fundamental shift in how agriculture is practiced. Technologies like sensors, drones, GPS-guided machinery, and data analytics help farmers make informed decisions at every stage of cultivation. This enables field-level management, adjusting water, seeds, and fertilizer as per specific needs, resulting in higher productivity, optimized costs, and reduced environmental impact.

While common in advanced economies, adoption in India is still emerging but gaining pace. Supported by government initiatives, affordable sensors, and agri-tech startups, India's precision agriculture market, valued at around USD 304 million in 2024 is projected to nearly double within a decade.

Pilot projects in states such as Ma-

harashtra, Tamil Nadu, and Punjab are showing promising results. In Tamil Nadu, crop yields rose 30–200% compared to traditional methods, and orchard productivity increased up to 60%. Even small interventions, like nitrogen sensors on tractors in northern India, boosted wheat yields by about 3%. These examples highlight the tangible benefits of precision technologies.

Smart Machines and Connected Ecosystems

At the heart of precision farming lies smart machinery and networked devices. GPS and auto-steering systems allow farmers to plant, spray, and harvest with precision, minimizing wastage. Soil sensors help tailor fertilizer use, while drones and satellites detect pest infections and water stress early.

Farm management software consolidates these insights into actionable intelligence. With AI and machine learning, farmers can forecast weather patterns, pest attacks, and yield outcomes, transforming agriculture into a data-driven profession.

Policy Support and Sustainability

The government is actively promoting innovation through initiatives such as the ☐550 crore allocation for "profitable farming" in Uttar Pradesh, focusing on digital agriculture and advanced mechanization. Such initiatives, if scaled effectively, can accelerate adoption across states through collaboration between technology providers, researchers, and policymakers.

Precision farming also supports India's climate goals. It improves water efficiency, reduces fertilizer misuse, and helps restore soil health. As agriculture contributes nearly 18% of India's emissions, technology-led efficiency will play a vital role in building a sustainable future.

CNH India: Driving the Next Wave of Mechanization

As a leader in agricultural and construction equipment, CNH India recognizes the transformative power of precision technology. Our global portfolio includes advanced solutions such as GPS guidance, telematics, and data-driven farm management systems, now being localized for Indian conditions.

With continued policy encouragement, industry collaboration, and farmer awareness, precision agriculture can redefine Indian farming, transforming it from a weather-dependent vocation into a knowledge-based, sustainable enterprise

Our flagship products including sugarcane harvesters, combines, forage harvesters, cotton pickers, and large balers, represent the next level of mechanization. These machines enhance yield, address labor shortages, and make farming more efficient. The strong response to these introductions reaffirms the vast potential for growth in this market.

Building Skills, Capabilities, and Collaboration

Meeting the diverse mechanization needs of India's farmers requires close collaboration with state governments, along with skill development and financial support. Training programs for farmers, operators, and rural youth are essential to help them adopt and operate modern equipment confidently. Affordable credit and leasing options will further encourage adoption.

At CNH India, we are investing in research, local manufacturing, and advanced technologies, from smart tractors to precision tools. Our Technology Center of Excellence, called ITC (India Tech Center) in Gurugram develops embedded electronics, software, and analytics for both Indian and global markets. The center works on breakthrough technologies such as connectivity, robotics, AI, cloud solutions, and vehicle electronics.

We are also conducting pilots in partnership with state governments and industry stakeholders - from sugarcane harvesters that reduce labor dependency to balers that convert stubble into biomass, helping curb residue burning. Early results from high-tech combines show yield uplifts of 6–7%, while experiments with semi-autonomous tractors and drone applications signal the future of connected farming.

A New Green Revolution

With continued policy encouragement, industry collaboration, and farmer awareness, precision agriculture can redefine Indian farming, transforming it from a weather-dependent vocation into a knowledge-based, sustainable enterprise.

The revolution has already begun. Ensuring that every farmer, from smallholders to large producers gains access to precision technology will shape the next chapter of India's agricultural success story.

Reimagining CROP CARE

BIOLOGICALS, SOIL HEALTH, AND THE NEXT FRONTIER OF SCIENTIFIC AGRICULTURE

The crop care sector is undergoing a structural transition. For decades, it has been dominated by synthetic fertilizers and crop protection chemicals that delivered scale, predictability, and immediate results. However, the limitations of this model - declining soil health, rising input costs, resistance development, and residue-related trade barriers - are now impossible to ignore. The next phase of growth in agriculture will not come from "more chemistry," but from smarter biology.

As a scientist and R&D strategist working closely with farmers and industry, I see biologicals not as an alternative, but as a necessary evolution of crop care systems.

The Need for Biologicals: From Input Dependency to Biological Intelligence

India's soils are under stress. Years of chemical-intensive agriculture have led to reduced organic carbon, disrupted microbial diversity, and declining nutrient-use efficiency. The result is a paradox - farmers are applying more inputs but getting diminishing returns.

Biologicals - including biofertilizers, biopesticides, and bio stimulants, offer a fundamentally different approach. They do not merely supply nutrients or kill pests; they activate natural biological processes such as nutrient cycling, plant immunity, and rhizosphere interactions.

The need for biologicals arises from three converging realities:

- Soil degradation and productivity plateau
- Global demand for residue-free and export-quality produce

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Dr. Prafull Gadge is an agri-innovator, agri-infopreneur and CEO of Biome Technologies Pvt. Ltd. He leads innovations in soil microbiology, including the patented Soilometer for real-time soil microbial health analysis. His work focuses on sustainable agriculture, biological inputs, and empowering farmers through science-driven, profitable, and residue-free farming systems

- Climate variability requiring resilient crop systems

Biologicals, when used correctly, restore soil functionality, reduce chemical dependency, and improve long-term farm profitability. However, their success is deeply tied to one critical factor - soil health, particularly microbial health.

The crop care sector stands at a pivotal moment. Biologicals offer a pathway to restore soil health, enhance productivity, and align Indian agriculture with global sustainability standards. Their success depends on scientific integration, regulatory reform, and farmer-centric promotion

Growth Potential: A High-Value, Knowledge-Driven Market

The global biologicals market is expanding at double-digit growth rates, and India is emerging as a key player. Policy alignment with natural farming, organic missions, and sustainability goals is accelerating adoption. Corporate investments, startup innovation, and farmer awareness are all contributing to this growth.

Yet, unlike chemicals, biologicals are knowledge-sensitive inputs. Their performance depends on environmental conditions, application timing, compatibility, and most importantly, the existing microbial ecosystem of the soil.

This creates a new paradigm:

- The future of crop care will not be input-driven—it will be data-driven and biology-informed.
- Companies that integrate diagnostics, advisory, and biological inputs will define the next wave of agri-business leadership.

The Missing Link: Soil Microbial Health

Despite the growing interest in biologicals, one fundamental gap persists, we are promoting biology without measuring biology.

Conventional soil testing systems focus on chemical parameters like NPK and pH. While important, these do not capture the living component of soil, which governs nutrient transformation, disease suppression, and carbon sequestration.

Soil is not a medium—it is a living ecosystem.

Microorganisms drive:

- Nitrogen fixation and phosphorus solubilization
- Organic matter decomposition

- Production of plant growth-promoting substances
- Natural suppression of soil-borne pathogens

When microbial activity declines, even the best biological products struggle to perform. Conversely, in biologically active soils, small interventions can create significant impact.

This is why soil microbial health analysis must become central to crop care strategies. Real-time, field-level diagnostics can help farmers:

- Understand whether their soil is biologically active or dormant
- Select the right biological inputs
- Avoid unnecessary or ineffective applications
- Track improvements over time

Without this layer of intelligence, biological adoption risks becoming inconsistent and, at times, disappointing.

Licensing and Regulatory Limitations: A Structural Bottleneck

While the potential of biologicals is immense, the sector faces significant regulatory and licensing challenges.

Current frameworks are largely adapted from chemical paradigms, which do not fully align with the dynamic and living nature of biological products. Some key limitations include:

- Lengthy and complex registration processes that delay innovation
- Standardization challenges due to variability in microbial strains and formulations
- Inadequate quality control enforcement, leading to substandard products in the market
- Lack of differentiation between high-quality, research-backed products and generic offerings

These issues not only affect industry growth but also erode farmer trust.

There is a clear need for:

- Science-based, category-specific regulatory pathways
- Faster approval mechanisms for proven microbial technologies
- Stronger quality benchmarking and traceability systems
- Integration of field performance data into licensing decisions
- A robust regulatory ecosystem will be critical to unlock the true potential of biologicals.

Promotion Challenges: Beyond Marketing to Farmer Literacy

Another major limitation lies in how biologicals are promoted.

Unlike chemicals, biologicals cannot be sold purely through input marketing or dealer push. They require education, demonstration, and trust-building.

Unfortunately, the market is currently witnessing:

- Over-promising without scientific backing
- Generic recommendations without soil-specific insights
- Confusion among farmers due to multiple, overlapping product claims

This calls for a shift from "selling products" to building farmer capability.

Initiatives like agrochemical literacy and biological awareness programs are essential. Farmers must understand:

- When and where biologicals work best
- How to integrate them with existing practices
- The importance of soil health as a foundation
- Promotion must be rooted in science, transparency, and measurable outcomes.

The Way Forward: Integrating Diagnostics, Biology, and Advisory

The future of crop care lies in convergence.

To truly scale biologicals, we need to integrate:

Soil microbial diagnostics – to assess baseline health

Targeted biological inputs – based on soil and crop needs

Advisory systems – to guide application and monitor results

This integrated approach will transform biologicals from "optional inputs" to precision tools for sustainable agriculture.

In my experience, when farmers see measurable improvements - better root systems, reduced input costs, improved yield quality - they do not go back. The key is to make biology visible and understandable.

Pivotal Moment for Crop Care Sector

The crop care sector stands at a pivotal moment. Biologicals offer a pathway to restore soil health, enhance productivity, and align Indian agriculture with global sustainability standards. However, their success depends on scientific integration, regulatory reform, and farmer-centric promotion.

Most importantly, we must recognize a simple truth: Healthy soil biology is not just a component of agriculture - it is its foundation. If we can measure it, manage it, and mainstream it, biologicals will not just grow as a sector, they will redefine the future of farming.

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FROM FRAGMENTED FARMS TO STRUCTURED MARKETS

How SMART is Redefining Agribusiness in Maharashtra

Building competitive value chains, empowering farmer institutions, and unlocking market-led growth at scale

Agriculture in Maharashtra is at a decisive turning point. For decades, the state has stood as one of India's most diversified agricultural economies producing globally competitive commodities such as grapes, bananas, onions, and pulses. Yet, beneath this strength lies a persistent structural challenge: nearly 80 percent of its farmers are small and marginal, often navigating fragmented markets, volatile prices, and limited access to organized buyers.

Supported by the World Bank and implemented by the Government of Maharashtra, SMART represents more than an intervention it is a systemic shift. It repositions farmers as entrepreneurs integrated into competitive, demand-driven value chains, enabling them to move beyond subsistence toward structured agribusiness participation.

Palladium's Role: Driving Transformation and Measurable Impact

The journey began with intensive capacity-building interventions, equipping CBOs with the knowledge and skills required to function as business entities. Through 110 structured workshops, over 4,578 participants were trained in governance, enterprise management, and market readiness.

However, capacity alone was not enough. A key bottleneck was access to timely finance. Palladium addressed this by facilitating ☐63.31 crore in loan disbursements across 80 CBOs, enabling investments in infrastructure and modern machinery.

With strengthened financial and physical capacities, these institutions transitioned from primary production to secondary and tertiary value addition, enhancing both product quality and market competitiveness. This shift has already translated into measurable outcomes, with 444.22 MT of commodity trade facilitated. In parallel, over 500 CBOs supported in achieving legal compliance and more than 600 aligned with food safety and quality standards for accessing formal and high-value markets.

From Local Mandis to Global Markets

A powerful example of this transformation is the journey of the Ule Farmers Producer Company (FPC) in Solapur.

Established in 2017 with over 1,127 farmer-shareholders, the FPC initially supported grape growers facing high logistics costs and inadequate post-harvest infrastructure. In the absence of packhouses and cold storage, farmers were compelled to sell in distant markets, often at compromised prices.

The turning point came with targeted investments under SMART in packhouses, pre-cooling units, and cold storage facilities. With technical support from Palladium Consulting India Pvt. Ltd., the FPC strengthened its operational capabilities and aligned with export-grade standards.

This enabled the first full-scale export of 20 MT of bananas to Oman, marking a significant milestone for smallholder farmers entering international markets.

The impact has been substantial. Farmers have achieved nearly double the price realization compared to local markets, while gaining access to consistent demand.

"If farmers' incomes are to rise sustainably, the focus must shift from mere production to strengthening the entire value chain. Quality enhancement, processing, and direct market linkages are key to unlocking real growth in the rural economy. Initiatives like SMART are enabling farmers to transition from local markets to global opportunities." said, Shri. Praveen Pardeshi, Chief Economic Advisor to CMO and CEO, MITRA during "Cotton Quality and Value Chain Workshop" held at IIM Nagpur.

Empowering Women, Strengthening Communities

In the tribal belt of Ghoti in Nashik, women traditionally engaged in manual Hatsadi rice processing a physically demanding activity that provided only seasonal income. With limited infrastructure and no market access, their work remained restricted in both scale and impact.

Through SMART, this landscape has changed significantly. The women's cluster was supported with modern processing infrastructure and mechanized equipment, enabling the transition from manual labour to structured enterprise.

Alongside infrastructure, with continued technical and enterprise support from Palladium Consulting India Pvt. Ltd., targeted capacity-building interventions equipped women with the skills to manage production, improve efficiency, and operate as a collective business.

As a result, the enterprise now functions year-round, providing stable incomes and reducing dependency on seasonal labour. Mechanization has eased physical strain, while enterprise ownership has enhanced confidence and decision-making capacity.

Today, these women are not just workers they are enterprise managers and decision-makers, contributing to both economic and social transformation within their communities.

Strengthening Market Access Through Structured Platforms

A defining feature of the SMART Project is its emphasis on Buyer–Seller Meets (BSMs) designed to create direct, structured engagement between farmer institutions and organized buyers.

To date, 9 Buyer–Seller Meets have been successfully conducted, resulting in the signing of 250+ MoUs between CBOs and buyers. These engagements have enabled focused business discussions around quality, pricing, and supply commitments.

More importantly, they have established the foundation for consistent and long-term market linkages, enabling farmers to move from fragmented selling to predictable and organized market participation.

A Blueprint for the Future

By integrating institutional strengthening, infrastructure investment, financial access, and market linkage, it is enabling farmers to operate with greater confidence, clarity, and control over their economic outcomes.

As this model continues to scale, it offers a compelling blueprint for the future of Indian agriculture one where farming is no longer driven by uncertainty, but by structure, strategy, and sustained opportunity.

TRANSITION IN POULTRY STRESS MANAGEMENT

FROM TRADITIONAL REMEDIES TO CHROMIUM-BASED SOLUTIONS

Stress management in poultry has long relied on conventional practices, such as vitamin C supplementation, electrolyte supplementation, and environmental modifications, to address challenges like heat stress. While these methods have provided relief, the evolving realities of modern poultry farming, marked by complex stressors including disease pressure, oxidative damage, nutritional imbalances, and environmental fluctuations, demand a more comprehensive approach. A significant transition in this field is the adoption of chromium supplementation, either independently or in synergy with vitamin C, to address stress at its root cause.

The Impact of Heat Stress

Heat stress remains one of the most critical challenges in poultry production. Elevated temperatures trigger physiological changes such as:

- Reduced feed intake and growth rate
- Decline in eggshell quality and egg production
- Increased mortality
- Elevated blood corticosterone levels

These changes compromise immunity, impair glucose uptake due to insulin insensitivity, and accelerate muscle breakdown through gluconeogenesis. The result is a cascade of metabolic dysfunctions that traditional remedies alone cannot fully correct.

Why a modern approach is necessary for "root-cause" solutions?

Traditional strategies—electrolytes, vita-

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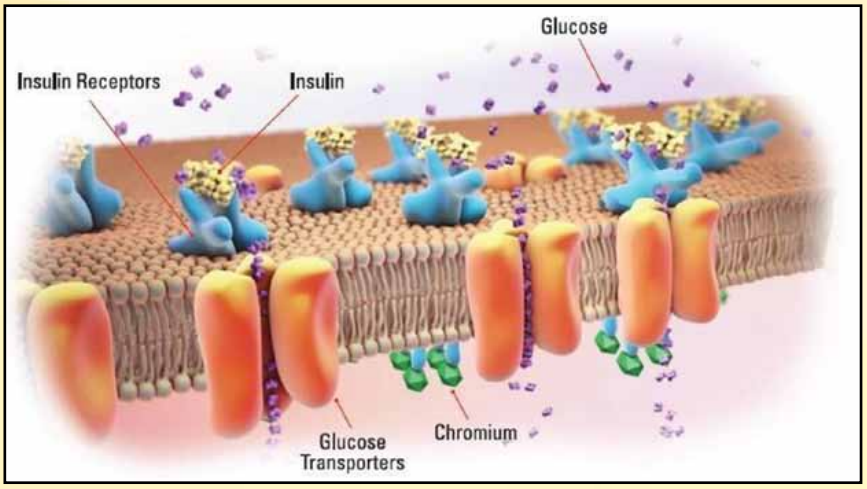
Fig 1. Role of Chromium in Enhancing Insulin Action and Glucose Uptake



min C, and ventilation—remain essential but insufficient. Today's poultry industry faces multifactorial stressors:

1. **Increased Metabolic Demands**: Modern broilers and layers have higher metabolic rates, leading to oxidative stress.
2. **Environmental Challenges**: Overcrowding, ammonia buildup, and fluctuating temperatures intensify stress.
3. **Disease Pressure**: Antibiotic resistance and emerging pathogens compromise immunity.
4. **Market Demands**: Producers must balance productivity with biosecurity, nutritional consistency, and raw material challenges.

These realities necessitate a shift from isolated solutions to integrated, root-cause interventions.

Chromium: The Cornerstone of Modern Stress Management

Chromium, a vital trace mineral, enhances insulin action and regulates glucose metabolism. Under stress, corticosterone levels rise, leading to hyperglycemia and inefficient glucose utilization. Chromium supplementation improves insulin sensitivity, stabilizes blood glucose, and reduces oxidative stress by boosting antioxidant enzyme activity. Figure 1 illustrates the role of chromium in enhancing insulin action and glucose uptake at the cellular level.

A significant transition in this field is the adoption of chromium supplementation, either independently or in synergy with vitamin C, to address stress at its root cause.

Key Research Highlights:

- Chromium is essential for carbohydrate, fat, and protein metabolism.
- As part of the Glucose Tolerance Factor, chromium potentiates insulin action.
- Organic chromium supplementation reduces heterophil-to-lymphocyte ratios, a stress marker, in heat-stressed chicks.
- Serum IgG levels improve with chromium supplementation, enhancing immunity.

Chromium Propionate: Addressing the Root Cause

Chromium propionate, a biologically active form of trivalent chromium, directly counters stress by:

- Reducing Corticosterone Levels
- Enhancing insulin action
- Accelerating glucose clearance
- Improving energy availability, feed intake, and immunity.

Field data shows up to **40% reduction in corticosterone (Fig. 3)** and **45% faster glucose clearance (Fig. 2)**, directly targeting the metabolic dysfunction behind summer stress.

Why Vitamin C Alone Falls Short?

Vitamin C neutralizes free radicals and supports adrenal function, but it cannot correct:

- Corticosterone surges
- Insulin dysfunction
- Impaired glucose uptake

Thus, despite higher inclusion rates, vitamin C alone cannot fully restore performance under heat stress.

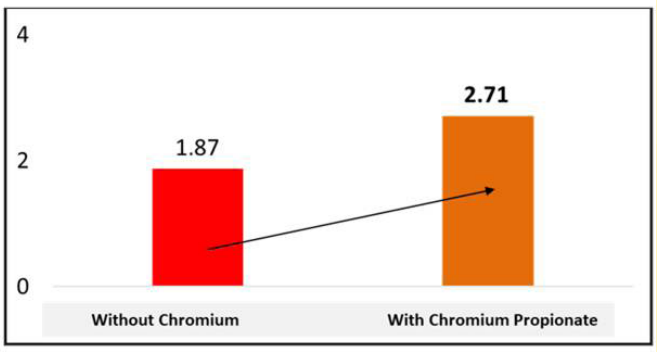


Fig 2. Blood Glucose Clearance (% per min.) (SPRE-23-20885)

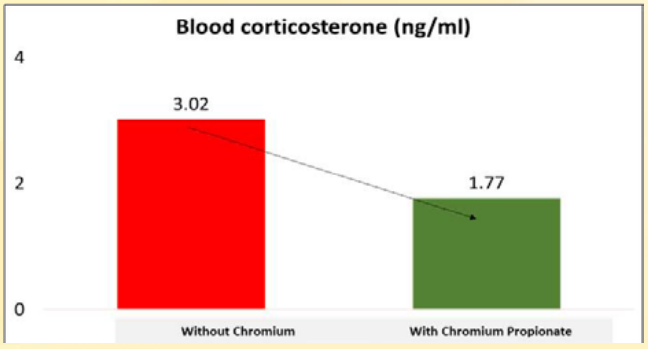


Fig 3. Blood corticosterone (ng/ml) (SPRE-22-2008)

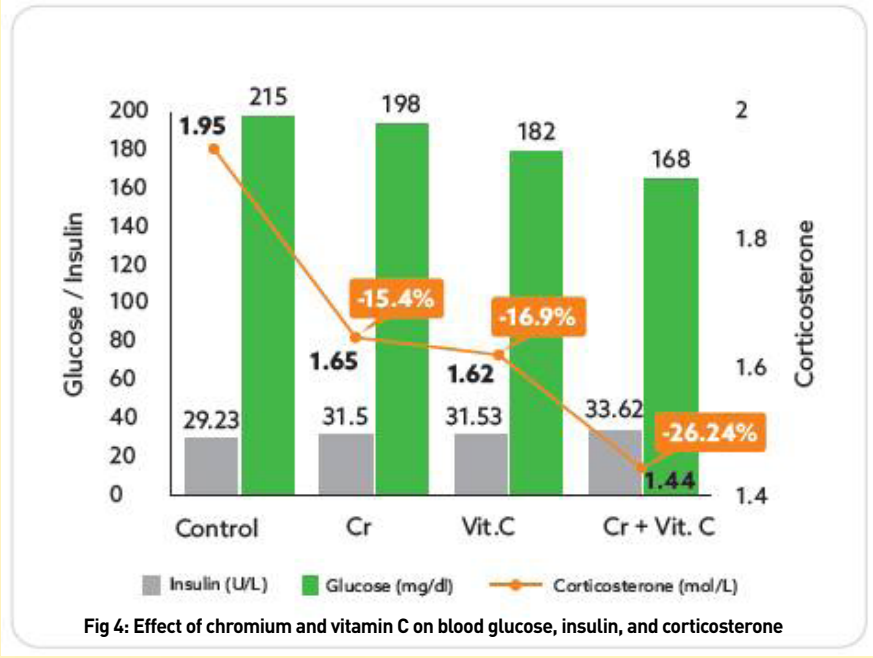


Fig 4: Effect of chromium and vitamin C on blood glucose, insulin, and corticosterone

How does the combination of Chromium + Vit C act synergistically?

Supplementation through feed with **Cr + Vit. C** demonstrates a positive metabolic shift in birds under stress conditions. The combination helps maintain stable insulin levels, supports improved glucose utilization (with a reduction in circulating glucose compared to the control), and significantly lowers corticosterone levels (around a 26% reduction vs. the control).

The role of Vitamin E in Poultry

Vitamin E plays a crucial role in summer management of poultry by acting as a powerful antioxidant that protects cells from heat-induced oxidative stress. Its supplementation supports immunity and helps maintain performance and egg production during high ambient temperatures.

Why Combine Chromium with Vitamin C and Vitamin E?

While chromium addresses metabolic stress and oxidative damage, vitamins C and E enhance the bird's ability to cope with environmental and thermal challenges. The combination provides a synergistic effect, offering comprehensive stress management by:

1. Reducing Corticosterone Levels
2. Improving Glucose Metabolism
3. Strengthening Immune Function
4. Enhancing Antioxidant Capacity
5. Supporting Thermotolerance
6. Promoting Muscle Integrity

A Modern Stress Management Approach

The poultry industry stands at a crossroads. Traditional stress management methods, while valuable, are no longer sufficient to meet modern challenges. Transitioning to chromium enriched with vitamins C and E represents this paradigm shift, improving endurance and immunity by addressing stress at its root cause. This marks the beginning of a new era in poultry stress management, where chromium emerges as a cornerstone of holistic farm practices.

It helps counter stress and elevate performance by:

1. Stress Mitigation
   - Controls corticosterone surges
   - Enhances insulin sensitivity
   - Regulates glucose metabolism
   - Strengthens cell membranes

Chromium propionate helps prevent corticosterone surges and improves glucose uptake by cells.

2. Immune strengthening
   - Neutralizes free radicals
   - Boosts antioxidant defense
   - Shields cell membranes from oxidative stress

   Vitamins C & E synergistically support antioxidant activity.

3. Performance Optimization
   - Enhances energy metabolism
   - Prevents muscle loss
   - Improves feed efficiency for growth and productivity

ONE ACRE, DOUBLE THE INCOME: A FARMER POISED FOR SUCCESS

"Drip irrigation and other modern practices completely transformed my farm. I earned more than twice this season compared to the previous year, my crops are healthier, and my land is now more fertile. I can confidently plan for the future." — Thirupathi Reddy, Gollapalli village, Telangana

Thirupathi Reddy, a young, progressive farmer from Gollapalli village in Chegunta block of Medak district, Telangana, owns 3.5 acres of agricultural land, where he cultivates paddy and seasonal vegetables. For years, he relied on traditional flood irrigation for vegetable cultivation, which posed several challenges. Cultivating water-sensitive and high value crops like chilli and ridge gourd became a risky proposition as they often suffered from water runoff, nutrient loss and soil erosion. Despite putting in great effort, irrigation was not uniform, resulting in inconsistent yields. Each season carried uncertainty not knowing whether the crops would survive, produce well, or generate enough income to support his family.

A turning point came through a community meeting on good agricultural practices held in his village under the Holistic Rural Development Project, supported by HDFC Bank's Parivartan initiative and implemented by S M Sehgal Foundation. The exposure significantly raised his awareness and encouraged him to adopt the recommended practices. Chosen for drip irrigation system demonstration, Thirupathi installed the system in one acre. In February 2025, he cultivated chilli on 0.5 acre and ridge gourd on 0.5 acre, using the new practices. While the drip system ensured even irrigation, minimized water wastage, and allowed easy fertigation, improved agricultural practices such as mulching and better seed varieties, nutrient and pest management, together with training and capacity building, laid a recipe for success.

Experiencing the efficiency of drip irrigation first hand, its ease of operation, ability to regulate water, and clear impact on crop health encouraged him to expand. In the next season, he confidently shifted to cultivating chilli across the entire 1 acre. In the first season, Thirupathi earned ☐1,38,840 from chilli and ridge gourd, with a chilli yield of 4.18 quintals in 0.5 acres. In the following season, he harvested 12.6 quintals from one acre, earning Rs 2,51,520 from chilli alone.

Today, Thirupathi uses drip and other practices across his 3.5-acre farm, with drip irrigation playing a critical role in improving water-use efficiency, productivity, and income stability. His success demonstrates that modern irrigation technologies, combined with appropriate training and agronomic practices, can significantly enhance returns.

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REBUILDING THE MIDDLE OF INDIA'S FOOD SYSTEM

Why Farmer Prosperity Depends On Smarter Supply Chains

For decades, conversations around agricultural reform in India have largely focused on two ends of the value chain: the farmer and the consumer. While these are undoubtedly critical stakeholders, one of the most persistent inefficiencies in the food system lies in the space between them - the complex web of aggregation, logistics, commerce, and information flows that determine how food moves.

At FarMart, this is the layer we have spent the last decade trying to understand and redesign.

India produces some of the world's most diverse and abundant agricultural output, yet farmers often remain disconnected from efficient markets. Fragmented commerce networks, delayed payments, information asymmetry, and logistical bottlenecks mean that value is frequently lost before produce even reaches buyers. These inefficiencies not only affect farmer incomes but also contribute to large-scale food loss and unnecessary environmental strain across the supply chain.

Our experience working across sourcing regions has reinforced a simple truth: improving farmer welfare requires more than interventions at the farm level. It requires strengthening the infrastructure that connects farms to markets. This belief has shaped how FarMart operates today.

Connecting Farmers, Processors, Food Businesses

Over time, we have built an AI-native platform that connects farmers, processors, and food businesses across geographies. Through this ecosystem, we worked with over 4.8 lakh farmers in 2025 across multiple agricultural foods. The goal is not merely to facilitate commerce, but to build systems that make agricultural commerce more predictable, transparent, and efficient for everyone involved.

Operating across 40+ agricultural products, our technology-led supply chain redesign avoided 23,567 tonnes of CO☐ emissions, prevented 18,305 metric tons of post-harvest food loss in 2025, enabled fresh water savings of 5.39 billion litres by improving movement efficiency and reducing embedded waste across agricultural sourcing, with over INR 23.4 billion aggregate payments earned by the farmers through FarMart during the year, strengthening income predictability and reducing reliance on fragmented mandi systems.

One of the most visible outcomes of this approach is improved market access for farmers and rural entrepreneurs. The detailed impact in 2025 is

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reflected in our Impact Report, but for now let's take the example of village-level entrepreneurs (VLEs), who play a crucial role in connecting local farmers to broader markets. Many of these entrepreneurs begin with strong relationships in their communities but struggle to scale their operations because of working capital constraints, price volatility, and delayed buyer payments. These barriers limit their ability to procure larger volumes, especially during peak harvest periods when farmers need reliable buyers the most.

Benefits Across The Ecosystem

By integrating these entrepreneurs into a more coordinated supply chain, we are seeing how technology can unlock new possibilities. With better price visibility, streamlined logistics, and faster payment cycles, many VLEs are able to expand their sourcing networks and work with significantly larger numbers of farmers. What begins as a small aggregation business often evolves into a stable rural enterprise that supports thousands of farmers in the surrounding region.

This kind of transformation illustrates an important principle: when supply chains become more efficient, the benefits ripple outward across the ecosystem.

The same efficiencies also play a role in addressing broader systemic challenges such as food loss and environmental sustainability. Much of the waste in agricultural supply chains does not occur at the farm itself but during handling, storage, or transport. When coordination between supply chain actors improves, the logistics are better planned, demand signals are clearer, and transactions are more transparent - these losses can be significantly reduced.

The deeper story is about the gradual redesign of systems that were never originally built for efficiency at scale. It is about improving how information flows between farmers and buyers, how payments move through the system, and how decisions are made across thousands of transactions every day.

FARMER PROSPERITY

Testament to FarMart's impact is Shri Yogesh Suresh Sawai, a Village-Level Entrepreneur (VLE) based in Aurangabad, Maharashtra. He began his agri output business in 2022, managing 10-12 vehicle loads monthly. Despite strong farmer relationships, growth was hampered by working capital shortages, delayed buyer payments, price uncertainties - limiting his ability to scale volumes, especially during peak harvest periods. After joining FarMart in 2023, and with better pricing and reduced pressure, he committed to larger volumes and streamlined logistics. As a result, his monthly vehicle movement rose from to 30+ with farmer reach expanded from 200 to over 2,000 enabled by reduced dependence on informal credit, improved planning. He shares, "As my business has grown through FarMart, I have been able to scale operations, work with many more farmers, and run my business with greater stability. This growth has also helped me provide better for my family and invest in my son's education, giving me the confidence to plan for the future."

Ensuring Consistent Operational Improvements

Agricultural supply chains are inherently complex, involving multiple stakeholders and layers of coordination. Building trust within such systems requires more than technology; it requires credible processes and clear accountability. For this reason, our approach increasingly focuses on embedding digital verification and data-driven decision-making into everyday operations.

From digital purchase order consent systems to AI-enabled monitoring of logistics and commerce flows, these tools help create a more reliable environment for both farmers and buyers. When partners know that transactions are transparent and traceable, the entire ecosystem becomes more resilient.

Of course, building better systems takes time. Food supply chains evolve slowly because they are shaped by decades of local practices, relationships, and economic realities. There are no quick fixes.

What we have learned, however, is that consistent operational improvements, even small ones, can compound over time. A more predictable payment cycle can encourage farmers to supply larger volumes. Better logistics planning can reduce spoilage. Improved market access can help rural entrepreneurs grow their businesses and extend opportunities to more farmers. When these improvements happen across hundreds of locations and thousands of transactions, the impact becomes meaningful.

The Role Of Technology

Technology will undoubtedly play a role in addressing these challenges, but it must be applied with a deep understanding of how agricultural systems function on the ground. Innovation in this space cannot be limited to advisory tools or isolated pilot projects; it must become part of the core infrastructure that enables commerce, logistics, and market access.

For FarMart, this is the journey we remain committed to - building supply chains that waste less, move faster, and create more value for the people who grow our food.

Farmer prosperity ultimately depends on the strength of the systems that support them. If we can redesign those systems with care, discipline, and transparency, the benefits will extend far beyond the farm, shaping a more resilient and sustainable food economy for the future.

The Road Ahead

Looking ahead, the challenge for India's agricultural sector will not only be increasing production but also building the infrastructure required to move food efficiently and responsibly across the system. Climate pressures, changing consumer expectations, and global supply chain shifts will make this task even more urgent.

WHAT COUNTS AS GREEN IN AGRICULTURE

REFRAMING CROP PROTECTION AS AN INVESTABLE ASSET CLASS

India's agriculture sector remains central to economic stability, livelihoods, and food security. The sector contributes nearly 18% to GDP and supports over 40% of the workforce, while sustaining steady growth of around 5% annually between FY2017 and FY2023, driving it into centre of India's climate transition, with significant capital interest. Global investors and development finance institutions are seeking credible and scalable green assets in emerging markets, and agriculture presents a significant opportunity. Financial flows to sustainable agriculture have remained high at over US $234 million annually in recent years, yet growth has been limited; a signal that capital is available but not reaching the right segments.

One of the most critical of those segments is crop protection. India is estimated to lose 15-25% of crop yields annually to pests and diseases, with losses expected to increase as climate change alters pest cycles and expands their geographic spread. Yet, crop protection remains largely absent from green finance frameworks, overshadowed by more easily classified priorities such as solar irrigation, micro-irrigation, and water-use efficiency, which dominate green bond allocations. The case for reframing crop protection as a climate-smart investment category is both straightforward and overdue. The fact that it has not happened yet reflects how green

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finance frameworks tend to be built (around what is easy to measure, classify and translate into financial language and metrics).

Why capital is not reaching crop protection

In practice, green agri-finance in India has concentrated around a narrow set of themes such as solar irrigation, micro-irrigation and water-use efficiency, whereas crop protection remains largely absent. A more complete approach to agricultural sustainability requires closer attention to crop protection, given that it directly influences yield stability, farm incomes, and the ability of farmers to manage climate-linked risks. As weather variability increases, pest outbreaks are becoming more frequent and less predictable, making crop protection a critical lever for adaptation as well as productivity.

The significance of the omission of crop protection extends beyond yield losses. Rising agrochemical use is contributing to soil degradation, resistance build-up, and growing regulatory scrutiny. These compounding pressures make the transition to climate-smart crop protection a financial imperative, where, without intervention, the credit quality of agri-lending portfolios is itself at risk.

Adoption of climate-smart crop protection remains constrained by a set of structural financing barriers. NBFCs continue to fund conventional solutions as they are standardised, widely understood, and embedded within existing value chains. In contrast, climate-smart alternatives often involve higher upfront costs, fragmented supply chains, and uncertain demand, making them harder to scale through traditional lending models.

A key barrier lies in classification ambiguity. Many climate-smart crop protection activities do not clearly align with existing ICMA and SEBI green bond frameworks, limiting the ability of lenders to categorise these exposures as green. This restricts their inclusion in GSS+ bond portfolios and reduces incentives for financial institutions to prioritise such lending. Moreover, this also creates a disincentivising structure where lending for activities that can be clearly labelled and counted towards green portfolios is favoured.

There is a clear opportunity to align financing structures with measurable sustainability outcomes

Investor perception further compounds the challenge. Crop protection is often associated with hazardous pesticide use, leading to caution among issuers when considering its inclusion in labelled instruments. Without clear differentiation between conventional and climate-smart practices, the entire category risks exclusion. Measurement is also a barrier as unlike sectors such as renewable energy, where outcomes are easily quantifiable, the benefits of improved crop protection such as reduced chemical intensity or enhanced soil health are more complex to standardise and verify.

These challenges result in a persistent financing gap in a segment that is central to climate adaptation in agriculture. Addressing this gap will require clearer definitions, improved measurement approaches, and a reframing of crop protection as a climate-smart investment category.

Building a Bankable Pipeline

A key priority is the development of a clear and unified taxonomy for sustainable agriculture, aligned with India's evolving climate finance taxonomy. Establishing standardised definitions for activities such as precision application, biopesticides, and integrated pest management can enable consistent classification, reduce ambiguity, and support the inclusion of crop protection within green and GSS+ frameworks. This effort would need to be anchored by public institutions such as the RBI and NABARD, with inputs from financial institutions and market participants, in order to unlock capital for under-financed segments like crop protection and enable better monitoring of financial flows and identification of priority interventions. Additionally, upcoming frameworks such as the National Adaptation Plan may also bring further clarity to the sector.

Strengthening asset performance is equally important for improving credit quality and investor confidence. Bundled models that combine financing with advisory services, pest monitoring, and input optimisation have a strong potential in India. For instance, DeHaat integrates credit with agronomic AI-driven advisory and input delivery, leading to higher yields and improved farmer repayment behaviour. It has expanded to serve 1.8 million farmers across 12 states, delivering over 7 million agricultural services. Such models demonstrate how better on-ground outcomes can translate into more robust lending portfolios.

There is also a clear opportunity to align financing structures with measurable sustainability outcomes. Linking lending terms to indicators such as reduced chemical intensity or adoption of integrated pest management practices can strengthen impact credibility. Globally, Olam International has implemented sustainability-linked financing tied to environmental performance metrics in agriculture, which has improved transparency and attracted green focused investors.

Unlocking the Next Layer Of Green Capital

The expansion of green agri-finance markets presents a clear opportunity. By directing proceeds into climate-smart crop protection, NBFCs can diversify their green portfolios while aligning with global standards. More importantly, this approach channels capital into a segment that directly addresses agricultural risk. As climate change intensifies pest pressures and increases yield volatility, the role of sustainable crop protection will become more central to resilience.

SAVE THE EARTH CONCLAVE 2026

BAMBOO AND 'WASTE-TO-WEALTH' ARE PILLARS OF INDIA'S SUSTAINABLE FUTURE

The second edition of the Save the Earth Conclave _ scaling climate & sustainability solutions _ was organized by Indian Chamber of Food and Agriculture (ICFA) at the Constitution Club of India to mark Earth Day on April 22. The event brought together policymakers, industry leaders, global institutions, and sustainability practitioners to accelerate India's transition toward a climate resilient and inclusive growth model.

Setting the context for the conclave, Dr. Tarun Shridhar (Rtd. IAS), Director General, Indian Chamber of Food and Agriculture (ICFA), emphasized that sustainability must move from intent to execution at scale. He highlighted the need for convergence between policy, science, industry, and farmers to create solutions that are both scalable and locally adaptable. Climate action today is not just an environmental priority, but a developmental and economic necessity. The real transformation will come from aligned, ground driven efforts that

Underscoring bamboo as a transformative opportunity, Union Cabinet Minister Shri Nitin Gadkari noted its potential to generate large scale employment, promote rural industrialization, and utilize degraded land productively

deliver measurable impact, Dr. Shridhar stated.

Shri Nitin Gadkari, Hon'ble Union Minister for Road Transport and Highways, laid out a bold vision linking sustainability with economic transformation by highlighting the Government's push toward ethanol and alternative fuels. He emphasized the need to convert "waste to wealth" and unlock new value chains that benefit both the environment and rural economy.

Underscoring bamboo as a transformative opportunity, Union Cabinet Minister Shri Nitin Gadkari noted its potential to generate large scale employment, promote rural industrialization, and utilize degraded land productively. He also spoke about India's emerging leadership in green fuels, including the potential of ethanol in sustainable aviation.

Bringing in the policy and behavioural dimension, Ad. Ashish Jaiswal, Hon'ble Minister of State for Finance, Planning, Agriculture and Rehabilitation, Government of Maharashtra, emphasized that sustainable development re-

quires not only institutional frameworks but also conscious individual action.

Focusing on grassroots innovation, Shri Pasha Patel, Chairman, Agriculture Price Commission, Government of Maharashtra, highlighted the role of bamboo and other sustainable resources in bridging ecology with farmer prosperity, while showcasing emerging models from the field.

Adding a global perspective, Mr. Takayuki Hagiwara, India Representative, Food and Agriculture Organization (FAO), stressed the importance of science led approaches and international collaboration in addressing climate and food system challenges.

Reinforcing the governance dimension, Ms. Padma Jaiswal, IAS, Secretary, Administrative Reforms, Government of NCT of Delhi, underlined the importance of institutional efficiency and policy implementation in translating sustainability commitments into outcomes, highlighting two key states Punjab and Haryana.

A key highlight of the inaugural session was the launch of the India Agriculture Sustainability Council (IASC), an institutional platform aimed at driving coordinated action, partnerships, and scalable solutions across agriculture and allied sectors

A key highlight of the inaugural session was the launch of the India Agriculture Sustainability Council (IASC), an institutional platform aimed at driving coordinated action, partnerships, and scalable solutions across agriculture and allied sectors.

The conclave included thematic sessions, expert deliberations, and stakeholder engagements focused on advancing scalable climate solutions and strengthening India's sustainability ecosystem.

HOW RURAL-AGRI ENTREPRENEURSHIP WILL BOOST IMPROVED RURAL LIVELIHOOD

India's rural economy is undergoing a significant transformation. According to the Economic Survey 2025–26, agriculture and allied sectors employ roughly 46% of India's workforce and contribute about 17–18% to GDP. This reflects both the sector's central role in livelihoods and the growing opportunity to enhance value creation within it. As India advances toward higher productivity and diversification, strengthening rural incomes will increasingly depend on moving from subsistence cultivation to enterprise-led growth. Rural-agri entrepreneurship presents a powerful pathway to unlock this potential. The question now is: how can this momentum be accelerated?

Shifting Agriculture from Subsistence to Enterprise

A new generation of rural producers is increasingly viewing agriculture as a business ecosystem rather than a livelihood fallback. By leveraging technology, improving supply chain efficiencies, and strengthening collective community institutions such as Farmer Producer Organisations (FPOs), agriculture is gradually transforming into an income-oriented enterprise.

Anchoring Enterprise in Community Institutions

Enterprise promotion works best when rooted in strong grassroots institutions. Partnerships with Self Help Groups (SHGs), Producer Groups (PGs), Cluster Level Federations (CLFs), and FPOs help identify credible entrepreneurs, build peer accountability, and ensure local ownership. Experience shows that when entrepreneurship is channelled through community platforms, risks are shared, participation deepens, and scale becomes more sustainable.

Strengthening Women's Economic Participation

Budget 2026's focus on initiatives such as SHE (Self-Help Entrepreneur) Marts, aligned with the Lakhpati Didi vision, signals a move from credit-linked participation toward enterprise ownership for women. However, credit alone is insufficient. Women often face barriers such as limited market exposure, fear of failure, and lack of collateral. SHGs and federations can address these through peer mentoring, collective marketing, and shared learning ecosystems, enabling more women to transition into confident entrepreneurs.

Bridging Information Gaps Through Digital Platforms

The proposed Bharat-VISTAAR (Virtually Integrated System to Access Agricultural Resources) multilingual AI platform represents a major opportunity. Small and medium landholders, particularly women farmers, often lack timely and contextual advisory support. By delivering region-specific insights on cropping decisions, input use, weather risks, market prices, and government schemes in local languages, digital platforms will support farmers to make enterprise-oriented rather than production-only decisions.

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Promoting Local Value Addition and Market Linkages

One of rural agriculture's enduring constraints has been limited local value addition. Smallholders frequently sell raw produce at low prices while value accrues elsewhere. Strengthening local processing, storage, branding, and market access supported by FPO-led value chains can ensure that a larger share of economic surplus remains within rural regions. Digital tools will further facilitate direct market connections and improved price realisation.

Expanding Access to Formal Credit

The RBI's proposal to double collateral-free MSME loans to ☐20 lakh from April 2026 addresses a longstanding constraint: availability of limited bankable collateral. In many rural areas, unclear land titles and limited asset ownership restrict access to formal finance. Expanded collateral-free lending has the potential to ease financing constraints, facilitating entrepreneurs to invest in machinery, adopt semi-automated processes, and upgrade branding and packaging. Access to formal credit strengthens both enterprise creation and expansion.

Building Skills Through Blended Capacity Ecosystems

Credit and technology must be reinforced by strong training systems. Blended capacity-building models, combining classroom inputs with field-level mentoring have proven more effective than standalone workshops. Training modules that integrate financial literacy, enterprise planning, quality standards, digital adoption, and market linkages equip farmers and rural youth to build viable businesses. Civil Society Organisations (CSOs) play a critical bridging role here, mobilising communities, strengthening institutions, and enabling convergence across government departments to unlock infrastructure and technical support.

Rural-agri entrepreneurship offers more than income diversification; it offers structural transformation. With coordinated action from communities, gram panchayats, state and central governments, financial institutions, and civil society, the rural economy can shift from dependency toward self-reliance. If implemented with institutional grounding, digital inclusion, gender sensitivity, and credit access, enterprise-led growth can significantly enhance rural incomes and contribute meaningfully to the vision of inclusive and resilient development under Viksit Bharat 2047.

Rural-agri entrepreneurship offers more than income diversification; it offers structural transformation. With coordinated action from communities, gram panchayats, state and central governments, financial institutions, and civil society, the rural economy can shift from dependency toward self-reliance

BEYOND MAPS

HOW GIS IS ENABLING SMARTER FARMING DECISIONS

The agriculture sector is one of the most important threads in the socio-economic fabric of the Indian economy. The sector's role extends beyond economic contributions, not only ensuring food security and stability for the nation but also posing as the primary source of livelihood for around 55% of India's population. This being acknowledged, it is only wise to strengthen this crucial pillar of support, and the answer lies in using technologies like Geographic Information Systems (GIS) to bring digital transformation in agriculture.

Esri's ArcGIS facilitates stakeholders to collect, maintain, analyze, and share agriculture data and make more informed decisions at all stages of the agricultural lifecycle. Indo ArcGIS allows the analysis of all field data in one centralized system. It enables integration of satellite imagery, field data, and real-time data streams to improve efficiency, profitability, and sustainability.

A Crop Management Solution developed using Esri's geospatial technology, implemented by the Haryana Space Applications Centre (HARSAC), is enabling the organization to effectively govern the full lifecycle of agricultural production in the State of Haryana. By removing demand-supply gaps and minimizing errors in yield estimations and procurement predictions, the Solution is fostering a culture of sustainable agriculture, along with bringing substantial savings to the State.

From soil and nutrient analysis to sustainable farming, GIS has a vital role to play in every facet of agriculture.

Agricultural Mapping

Accurate mapping of geographic and geologic features of farmlands enables scientists and farmers to create more effective and efficient farming techniques. Suitability analyses, facilitated by geospatial technology, help the farmers determine the optimal crops for each plot of land, based on its soil, climate, and social conditions, and conceptualize the best practices at all stages of the farming season. GIS offers vital insights related to crop health, soil conditions, and weather patterns in real-time. GIS allows the stake-

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holders to develop a holistic approach to precision farming. It helps in creating maps and dashboards that integrate important variables such as soils, irrigation, yield, production costs, profit, and compliance data.

Crop Yield Prediction

Accurate yield predictions are vital for food security and financial planning. Using GIS, predictive models can be developed to forecast crop yields based on historical data and current environmental conditions. Machine learning algorithms and statistical techniques are often applied to analyze spatial relationships and make accurate predictions.

Crop Health Monitoring

Instead of manual inspections, GIS enables remote monitoring of crop health using satellite imagery, providing insights about humidity, temperature, and overall growth. This helps identify areas needing attention. GIS allows farmers and agronomists to create detailed maps of fields, depicting variations in crop health indicators such as vegetation indices, chlorophyll content, and thermal imagery. These maps help visualize spatial patterns of crop health across large agricultural areas.

Insect and Pest Control

By monitoring changes in crop health indicators over time, GIS enables early detection of stress factors such as nutrient deficiencies, water scarcity, diseases, and pest outbreaks. Early identification allows farmers to take timely corrective actions, preventing potential yield losses and reducing the need for extensive interventions later in the season.

Irrigation Control

GIS facilitates the development of irrigation schedules tailored to specific field conditions and crop water needs. By analyzing spatial data on soil moisture, rainfall patterns, and evapotranspiration rates, GIS helps farmers and water managers optimize the timing, duration, and frequency of irrigation events to minimize water waste and maximize crop yields.

Using Geographic Information Systems (GIS), predictive models can be developed to forecast crop yields based on historical data and current environmental conditions

Water Quality Management

GIS assists in monitoring water quality parameters such as salinity levels and contamination risks. By analyzing spatial data on soil types, land use practices, and proximity to sources of pollutants, GIS helps in identifying areas vulnerable to water quality degradation and implementing measures to protect irrigation water sources. As much as 70% of good water is used in agriculture, and saving on this water use can help in addressing water stress. Wise usage of water can be made possible by adopting precision technology.

Crop Insurance and Loss Assessment

In periods of catastrophic events like floods, heavy rainfall, drought, etc., GIS can be used to determine exactly how much of a given crop has been damaged and the progress of the remaining crop on the farm. GIS can generate crop condition and distribution analytics, leading to faster loss adjustment and payout to the farmers. In the crop insurance business, high-resolution imagery plays a key role in speeding up the claim process. Using Indo ArcGIS and image processing software like ENVI, farmers and insurance providers can achieve the benefits of faster claim processes and payouts, visibility on in-season crop conditions at different time intervals fostering risk analysis and decision making, crop classification and crop risk analysis, acreage estimation of different crops, identification of inundation area and exposure monitoring, reduced operational and data processing cost, and more.

GIS is Transforming Modern Agriculture

GIS is transforming modern agriculture by enabling farmers to make smarter, data-driven decisions. The use of tools like ArcGIS helps stakeholders to optimize workflows, improve resource management, and enhance farm productivity and profitability. As global food demand rises, integrating GIS into agriculture is becoming essential. The GIS agriculture market is projected to reach about USD 2.61 billion by 2029. With advanced mapping, high-resolution imagery, and AI, GIS is reshaping farming practices. When combined with IoT sensors, drones, and historical data, it provides real-time insights that support better planning and more sustainable, efficient agricultural production.

HOW CLIMATE-RESILIENT FARMS AND PERMACULTURE ARE PAVING THE FUTURE OF COMMUNITY AGRICULTURE

Across India, farmers confront a reality where climate-induced volatility has become the norm. How long will the monsoon stay? When will a heatwave strike, or an unseasonal downpour wipe out a crop just before harvest? This growing unpredictability has seriously challenged conventional farming, raising the spectre of declining yields, rising costs, and increasing risk for small and marginal cultivators. As soil health deteriorates and water availability becomes uncertain, agriculture needs more than incremental change. It needs a transformation in how farmland is designed and managed anchored in ecological resilience rather than short-term output.

This is the promise of climate-resilient agriculture and permaculture-inspired design. Rather than merely reducing harm or cutting inputs, these approaches aim to regenerate land, restore ecological balance, and build systems that can endure disturbance. They make farms more dependable not just in a single good year, but across cycles of uncertainty.

Soil Health As The Foundation Of Resilience

Soil is a living ecosystem with natural structure, microbial life, and the ability to absorb, store, and release water and nutrients. Yet decades of chemical-intensive monoculture farming have stripped many Indian soils of organic carbon and resilience. The consequences are visible in poor yields, rising fertilizer dependence, and vulnerability to drought and erratic rainfall. Studies warn that rising temperatures and shifting monsoons are already undermining yield stability in staples such as wheat and rice.

Regenerative and conservation agriculture offer a pathway back. When soil is treated as a living system, practices such as minimal tillage, cover cropping, mulching, and organic amendments rebuild structure, increase organic matter, and restore microbial life. Over time, healthy soil behaves like a sponge, absorbing rainfall, retaining moisture during dry spells, buffering temperature

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swings, and supplying nutrients more steadily to crops.

Research supports this transition. Farms managed under permaculture principles have demonstrated higher soil carbon stocks, lower soil compaction, and increased earthworm populations and microbial activity - key indicators of restored soil life. On degraded land, rebuilding soil health can determine whether farming remains viable for the next generation.

Diversity And Land Design

Resilience in nature arises from diversity, and the same principle applies to farms. Reliance on monocultures makes agriculture especially vulnerable to climate extremes and pest outbreaks. A single unseasonal rain or heatwave can decimate an entire season's output.

Diversified systems combining perennials, annuals, trees, crops, livestock, and ground cover create layered resilience. Agroforestry, in particular, offers benefits beyond yield. Trees stabilise soil, reduce erosion, moderate microclimates, improve nutrient cycling, and support biodiversity. Evidence shows that agroforestry improves soil structure, increases water infiltration and retention, and mitigates the risks of both drought and heavy rainfall.

Long-term studies comparing diversified farms with monoculture systems show that while yields can remain stable, soil quality, biodiversity, carbon sequestration, and ecosystem services steadily improve over time. This is not a return to nostalgia or tradition alone, but a data-grounded recognition that ecological design helps farms absorb shocks and manage climatic variability.

Managed And Community Farmland As A Practical Model

In rural and peri-urban India, a notable shift is underway. Urban investors and non-farmers are increasingly viewing farmland not just as speculative property, but as a long-term asset and a way to reconnect with land. When managed with ecological intent, such land can support climate-resilient agriculture rather than fragmented real estate.

A Future Defined By Regeneration, Not Extraction

Climate-resilient farming and permaculture do not offer quick wins. They demand long-term commitment, observation, and collaboration. But when implemented with seriousness, they shift farming from extraction to regeneration, strengthening food security, livelihoods, and landscapes alike. In a warming and uncertain world, resilience may be agriculture's most valuable harvest.

Managed farmland models where ownership or leasing is paired with professional ecological management enable practices difficult for small, isolated farms to adopt. These include watershed-level planning, agroforestry corridors, soil and water conservation, composting systems, and long-term stewardship. Shared infrastructure like rainwater harvesting ponds, nurseries, and compost units improves both economic viability and ecological outcomes.

Crucially, these models generate local employment from land preparation and nursery work to harvesting and post-harvest processing while strengthening rural livelihoods and knowledge exchange between urban landholders and farming communities. Over time, such landscapes shift from passive investments to actively stewarded ecosystems.

Water Management, The First Line Of Defence

For much of India, climate stress manifests first through water either scarcity or sudden excess. Farms that endure climate shocks redesign how water moves through their landscapes. Instead of drilling deeper borewells, resilient systems slow, spread, and store rainwater through contour bunds, swales, check dams, recharge ponds, and terraces.

When combined with agroforestry and ground cover, soil and water conservation techniques reduce runoff, prevent erosion, improve moisture retention, and enhance carbon sequestration. These interventions buffer soil against intense rainfall, prevent waterlogging, and protect topsoil during extreme events. Because such measures require coordinated planning at scale, managed and community-based farmland models are particularly effective.

Knowledge Networks, Long-Term Vision And Policy Support

Ecological agriculture is as much a mindset as it is a practice. It recognises land as living infrastructure that requires patient care. In India, where holdings are fragmented and rainfall is unpredictable, this transition needs institutional support.

Agricultural extension systems must move beyond input-driven advice and provide guidance on soil health, landscape design, water management, and regenerative practices. Incentives should reward ecological outcomes such as soil carbon, water retention, tree cover, and biodiversity, not just seasonal yield. India's land restoration and climate commitments already acknowledge this direction through support for agroforestry, sustainable land use, and soil-water conservation.

BEYOND THE NAKED EYE

THE COMPLEX WORLD OF FORENSIC SOIL SCIENCE

Soil is primarily viewed through the lens of agriculture, as the medium that sustains crops and ensures global food security. However, soil holds a much deeper significance that go beyond the boundaries of the farm. In the realm of legal investigations, soil emerges as a "silent witness," a complex mixture of organic and inorganic components that can provide irrefutable evidence in criminal and environmental cases. Forensic soil science is a specialized discipline that applies the principles of morphology, mineralogy, chemistry and biology to answer legal questions. By analyzing the unique signatures within earth materials, forensic scientists can link suspects to crime scenes, identify the origin of unknown samples and even locate clandestine burials. This article explores the evolution, methodology and sophisticated technology that turn a handful of "dirt" into a powerful tool for justice.

Indian soil scientists working in forensics are bridging the gap between traditional pedology and legal application

The Philosophical Foundation: The Locard Exchange Principle

The entire framework of forensic soil science is built upon the Locard Exchange Principle, which states that "every contact leaves a trace". When a person enters a crime scene, there is a mutual transfer of material i.e. the individual takes something from the scene and leaves something behind. Soil is considered as ideal trace evidence because of its high transferability and persistence. Fine fractions, such as clay and silt, adhere readily to footwear, tire treads and clothing. Interestingly, these small amounts, i.e. often less than 50 micrometers in size nearly invisible to the untrained eye. This invisibility is a strategic advantage; suspects often fail to notice the soil trapped in their shoe treads and thus do not think of cleaning it, allowing investigators to recover pristine samples days or even weeks later.

The Inherent Complexity and Individuality of Soil

What makes soil so effective for forensic discrimination is its extreme heterogeneity. Soil is not a static substance; it is a dynamic system controlled by bedrock geology, climate, topography and land use. In the United States alone, there are over 50,000 recognized varieties of soil and their properties can change dramatically over distances of just a few meters. This individuality is further enhanced by "anthropogenic markers." They are man-made materials such as brick fragments, glass, paint or specialized fertilizers that reflect human activity. For instance, soil




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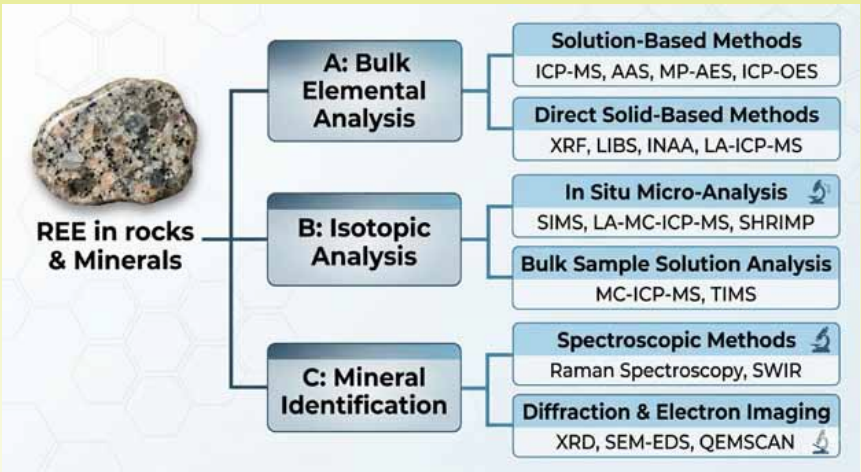
from an urban park will possess a vastly different chemical and physical profile than soil from an arable farming district, even if they share the same underlying parent material. This "geochemical signature" allows forensic experts to distinguish between samples with a high degree of statistical confidence.

A Systematic Four-Stage Analytical Approach

To ensure that soil evidence is admissible in court and scientifically robust, forensic soil scientists follow a rigorous, four-stage analytical protocol that moves from broad observations to microscopic precision.

- The first stage involves **Initial Screening**, which focuses on morphological characterization. Using tools like Munsell color charts and stereo microscopes, analysts compare the color, texture and structure of the questioned sample (from a suspect) against control samples (from a known location). While color is a primary indicator, it can be influenced by moisture and organic matter, requiring standardized drying and preparation.
- The second stage, **Semi-Detailed Characterization**, delves into the mineralogical and organic composition. Techniques such as X-ray Powder Diffraction (XRD) and infrared spectroscopy (specifically DRIFT) are employed to identify the specific minerals present in the soil. XRD is particularly significant as it allows for both qualitative and quantitative analysis of solid materials which helps to distinguish between soil types that might look identical to the naked eye.
- Stage three involves **Detailed Characterization**, utilizing high-resolution technology to analyze individual soil particles. Scanning Electron Microscopy (SEM) combined with Energy Dispersive X-ray Spectroscopy (EDS) allows for the examination of grain shape and elemental composition. Modern forensics has also integrated biological analysis, such as DNA profiling of microbial communities, to provide a "biological fingerprint" of the soil.
- The final stage is **Integration**, where the microscopic data is overlaid with landscape-scale models and digital maps. By combining laboratory results with databases like the Australian Soil Resource Information System (ASRIS), scientists can determine the most likely geographic origin of a sample.



Soil is a complex, data-rich medium that records human and environmental history

Predictive Geolocation: Solving the Unknown

While traditional forensic soil science often focuses on "comparative analysis" i.e. linking a suspect to a specific, known crime scene, which means that there is a growing field known as Predictive Geolocation. This is a "deductive" tool used when the crime scene location is entirely unknown. Instead of comparing two samples, scientists build an environmental profile of the evidentiary soil. This profile includes the mineralogy of the underlying bedrock, the types of vegetation (identified through pollen and spores) and even specific anthropogenic waste like industrial residues. By analyzing these attributes, investigators can narrow down a search area from a whole state or country to a manageable region, allowing police to prioritize their resources.

Predictive Soil Provenancing (PSP) and Digital Mapping

A major innovation in this field is Predictive Soil Provenancing (PSP), a quantitative method that utilizes Geographic Information Systems (GIS) and high-resolution digital soil grids. Unlike traditional methods that require a physical database of soil samples, PSP uses "soil attribute rasters" i.e. digital maps that model properties like pH, nitrogen levels and sand content across entire continents.

In a landmark demonstration in New South Wales, Australia, researchers used six soil attributes to narrow a search area. While searching for a matching pH level alone would have left 65% of the state to investigate, intersecting all six attributes (nitrogen, phosphorus, pH, sand, silt and clay) reduced the search area to just 8.4% of the original territory. This method is fully reproducible and objective, providing a powerful area-reduction tool for investigations.

Investigating Clandestine Burials and Environmental Crimes

Beyond homicide and theft, forensic geology plays a vital role in locating clandestine graves through the Geoforensic Search Strategy (GSS). Geologists analyze how the act of burial disturbs the soil profile and how the subsequent decomposition of organic matter creates "leachate plumes." They are chemical footprints that seep into the surrounding earth. By understanding these subsurface movements, experts can use geophysical tools like Ground Penetrating Radar (GPR) and electrical resistivity to detect anomalies beneath the surface.

This method is fully reproducible and objective, providing a powerful area-reduction tool for investigations.

The discipline is increasingly used to combat "substitution" crimes in the global mining industry. In these cases, valuable mineral concentrates are stolen during international transit and replaced with local sand or rock. Forensic mineralogy can identify the exact provenance of the substitute material, helping to trace where the theft occurred and who was responsible.

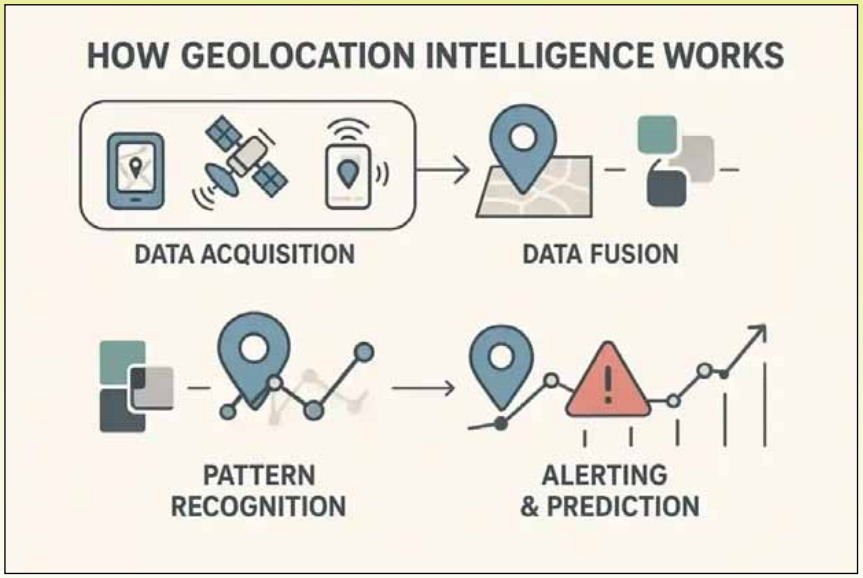
Opportunities for Soil Scientists in Forensic Science

The expansion of this field has opened numerous professional pathways for soil scientists, who possess the unique interdisciplinary skills required for such complex work.

- **Investigative Intelligence and Search Operations:** Soil scientists are increasingly recruited to assist in search operations for missing people or buried evidence. Their understanding of soil profile disturbance allows them to guide law enforcement in selecting the most effective geophysical tools, such as GPR.
- **Analytical Laboratory Specialists:** There is a high demand for soil scientists proficient in advanced analytical techniques like XRD, SEM-EDS, ICP-MS and Raman spectroscopy. These specialists bridge the gap between traditional soil science and criminalistics, translating complex geochemical data into actionable evidence.
- **Data Science and GIS Modeling:** The rise of Predictive Soil Provenancing (PSP) requires soil scientists who can manage large-scale digital soil databases and perform complex spatial analyses using GIS. This role involves creating rasters and predictive models that narrow search areas

across continents.

- **Environmental and Economic Forensics:** Opportunities exist in investigating environmental crimes, such as illegal waste dumping and economic crimes like global mineral theft. Soil scientists help maintain the integrity of supply chains by verifying the origin of earth materials.
- **Expert Witnessing and Legal Consultation:** Experienced soil scientists are needed to evaluate evidence and provide expert testimony in court. This requires not only scientific expertise but also the ability to communicate technical findings to legal professionals and juries using standard terminologies and comparability scales.
- **Academic Research and Method Development:** There is an ongoing need for researchers to develop new Standard Operating Procedures (SOPs), improve database resolution and explore emerging fields like soil microbial DNA barcoding.



Forensic Soil Science: The Indian Scenario

In the Indian context, forensic soil science has transitioned from a supplementary investigative tool to a specialized analytical discipline, integrated within the national forensic infrastructure. Forensic examinations are primarily conducted at the Central Forensic Science Laboratories (CFSLs) located in major cities such as Delhi, Hyderabad, Chandigarh and Kolkata, as well as at state-level Forensic Science Laboratories (FSLs). These institutions utilize a variety of physical and chemical methods, including grain size analysis and pH determination, to process soil as trace evidence. Furthermore, the establishment of the National Forensic Sciences University (NFSU) has provided a dedicated platform for advanced research and academic training, ensuring that Indian soil scientists are equipped with the technical expertise needed for modern criminalistics.

Indian soil scientists working in forensics are bridging the gap between traditional pedology and legal application. By applying the Locard Exchange Principle, they analyze soil adhering to footwear, tires and clothing to establish links between suspects and crime scenes. Notable research within the country has explored the use of Scanning Electron Microscopy (SEM-EDX) to compare soil texture and composition across geographically diverse regions like Kerala. This expertise is not limited to solving homicides but extends to environmental monitoring and detecting "substitution" crimes, where valuable minerals are replaced with local soil during transit. Through their work is in state and central laboratories, these scientists provide the expert opinions and substantiated reports necessary for the Indian judicial system.

Soil is Complex, Data-Rich Medium

Soil is far more than an agricultural commodity; it is a complex, data-rich medium that records human and environmental history. Forensic soil science has matured into a sophisticated discipline that combines ancient principles like the Locard Exchange Principle with cutting-edge digital mapping and molecular biology. For soil scientists, this field represents a profound opportunity to contribute to public safety and justice. By looking "beyond the naked eye," we can transform the very ground we walk on into a powerful tool for declaration, ensuring that even the most silent witnesses have their story heard in the courtroom.

WHY RURAL INDIA NEEDS INTEGRATION, NOT JUST INTERVENTION

India has not been short on rural development programmes. It has been short on rural development models. The distinction matters more than it might appear.

Programmes are time bound, budget bound, and often designed around a single variable, a crop, a subsidy, or a scheme. Models are systemic. They address the underlying architecture of rural livelihoods rather than patching individual symptoms. The reason farm distress persists in India, despite decades of policy attention, is largely because the interventions have been programmatic, while the problem has always been structural.

Project Chittoor is an attempt to build a model. Not a pilot in the conventional sense, one designed to prove a concept in isolation and then be quietly archived, but a working demonstration of what an integrated rural economy looks like when agriculture, energy, education, and tourism are designed to reinforce one another on the same piece of land.

The problem with Indian agriculture is not that it produces too little. It is that each acre is asked to do too little.

The ambition of Project Chittoor is to ensure that what is built here shapes the villages of the future, economically resilient, ecologically sound, and genuinely worth returning to

The Problem: A Single-Output Economy on Multi-Potential Land

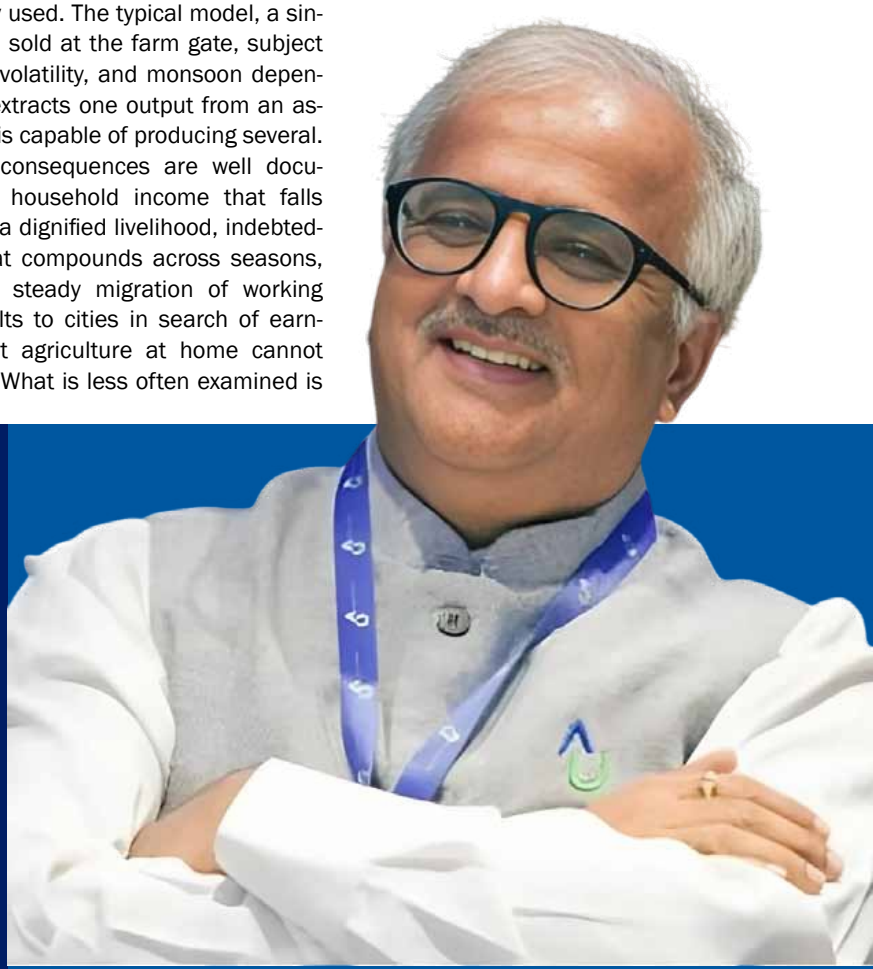
A farmer in Chittoor district today earns approximately Rs. 14,000 per acre per year. That figure reflects not the limits of the land, but the limits of how the land is currently used. The typical model, a single crop, sold at the farm gate, subject to price volatility, and monsoon dependence, extracts one output from an asset that is capable of producing several.

The consequences are well documented: household income that falls short of a dignified livelihood, indebtedness that compounds across seasons, and the steady migration of working age adults to cities in search of earnings that agriculture at home cannot provide. What is less often examined is the opportunity cost, the clean energy that could be generated on the same land, the tourism the same landscape could support, the processed foods that could move up the value chain rather than being sold raw, and the education infrastructure that could anchor the next generation without forcing them to leave.

Project Chittoor starts from the premise that the land is not the constraint. The model is.

The Solution: An Integrated Rural Economy Across 600 Acres

Backed by the Atria Group and spanning 600 acres in Chittoor district, Andhra Pradesh, Project Chittoor is designed to



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raise per acre annual farm income from Rs. 14,000 to over Rs. 1 lakh, a three to fourfold increase, by transforming each acre from a single crop unit into a diversified economic platform.

The model operates across five interconnected streams. Regenerative agriculture, through vertical food forests, integrated livestock systems, and agroforestry, produces multiple harvests across seasons while rebuilding soil health and groundwater recharge. Six megawatts of solar capacity installed across farm clusters allow farmers to generate and sell clean energy, reducing irrigation costs, while creating a second income stream from the same land. Value added food processing captures margin within the village rather than surrendering it to intermediaries. Agro wellness tourism, homestays, Ayurveda retreats, and farm to table experiences, creates non farm income without disrupting agricultural activity. And solar powered digital classrooms and STEM laboratories equip rural students with skills that make staying home a genuine option, not a compromise.

These are not independent initiatives running in parallel. They are deliberately integrated. The solar infrastructure that powers the farm also powers the school. The agroforestry that improves soil health also creates the landscape that attracts tourism. The food processing unit that adds value to the harvest also creates employment for family members who might otherwise migrate. Each element strengthens the others.

The goal is not to add income streams to a struggling farm. It is to redesign the farm as an integrated economy.

What This Solves For: Beyond Income

The income target, Rs. 1 lakh per acre per year across 250 plus rural families, is the headline metric. But Project Chittoor is solving several things simultaneously, and understanding the full scope matters for appreciating why the integrated model is necessary.

It is solving for ecological viability. Extractive farming practices have depleted groundwater, degraded soil, and reduced biodiversity across much of India's agricultural heartland. Project Chittoor's regenerative practices are not a premium add on, they are foundational to long term productivity. A farm that restores what it uses is a farm that remains viable across generations.

Rural India does not need more programmes. It needs more proof points, working models that can be studied, adapted, and scaled

It is solving for energy access and cost. The 6 MW solar capacity embedded across farm clusters reduces dependence on grid power for irrigation and cold storage, cutting input costs, and making operations more climate resilient. Farmers transition from energy consumers to energy producers, a shift that carries both economic and psychological significance.

It is a solution for youth retention. Rural migration is, at its core, an income and opportunity problem. When a village offers stable earnings, quality education, and meaningful livelihoods, the economic logic of migration weakens. Project Chittoor is designed to make reverse migration rational, not through sentiment, but through a genuine improvement in the material conditions of rural life.

And it is solving for replicability. The 600 acre initiative carries a documented roadmap to 6,000 acres, and then 60,000 acres, across multiple districts of Andhra Pradesh. The architecture is modular. What is validated in Chittoor is designed to be transferred.

Why This Model, Why Now

Several conditions make this moment particularly suited to integrated rural transformation of this kind. The cost of solar generation has fallen dramatically, making on farm clean energy economically viable at scale. Digital infrastructure, connectivity, remote education, and digital payments, has reached into districts that were previously isolated from the knowledge economy. Urban consumers have demonstrated sustained appetite for authentic rural experiences, traceable food, and wellness retreats, creating genuine demand for what agro tourism can supply.

At the same time, the consequences of not acting are becoming more visible. Climate volatility is making single crop dependence increasingly untenable. Groundwater tables in districts like Chittoor have fallen to levels that threaten long term agricultural viability. And the social cost of continued rural to urban migration, overcrowded cities, depleted villages, and severed intergenerational

ties, is a burden that neither the migrant nor the city absorbs gracefully.

The window for establishing a replicable rural model, one that works with current technology, current market demand, and current policy frameworks, is open. Project Chittoor is built to operate within it.

The Role of the Atria Group

The integrated nature of Project Chittoor is not incidental. It reflects the deliberate application of the Atria Group's cross sector capabilities, Atria Renewable in clean energy deployment, Atria Education in learning infrastructure, and operations across hospitality and connectivity, to a single, coherent rural transformation initiative.

This matters because integration at the field level requires integration at the institutional level. A rural transformation model that depends on coordinating five or six independent agencies carries enormous execution risk. When those capabilities sit within a single group with shared accountability, the coordination problem is substantially reduced, and the pace of implementation increases.

The Atria Group's involvement also signals something important for the broader conversation about private sector participation in rural development: this is not philanthropy structured to look like a project. It is a demonstration that a business model exists for rural transformation, one where patient capital, deployed with a systems perspective, generates returns that are financial, social, and ecological simultaneously.

Rural India does not need more programmes. It needs more proof points, working models that can be studied, adapted, and scaled.

A Blueprint for Andhra Pradesh and Beyond

Andhra Pradesh has the agricultural land, the solar irradiance, the cultural heritage, and the human capital to become a national model for next generation rural transformation. What has been missing is a working demonstration that the integrated approach is feasible at scale.

Project Chittoor is that demonstration. The 600-acre foundation is the first chapter of a roadmap that extends to 60,000 acres across multiple districts. Each phase of expansion refines the model, validates the economics, and builds the operational infrastructure for the next. The goal is not to create an exceptional case study in one district, but to establish a transferable blueprint that other districts, and eventually other states, can adapt.

The villages of Chittoor district shaped this initiative. The ambition of Project Chittoor is to ensure that what is built here shapes the villages of the future, economically resilient, ecologically sound, and genuinely worth returning to.

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