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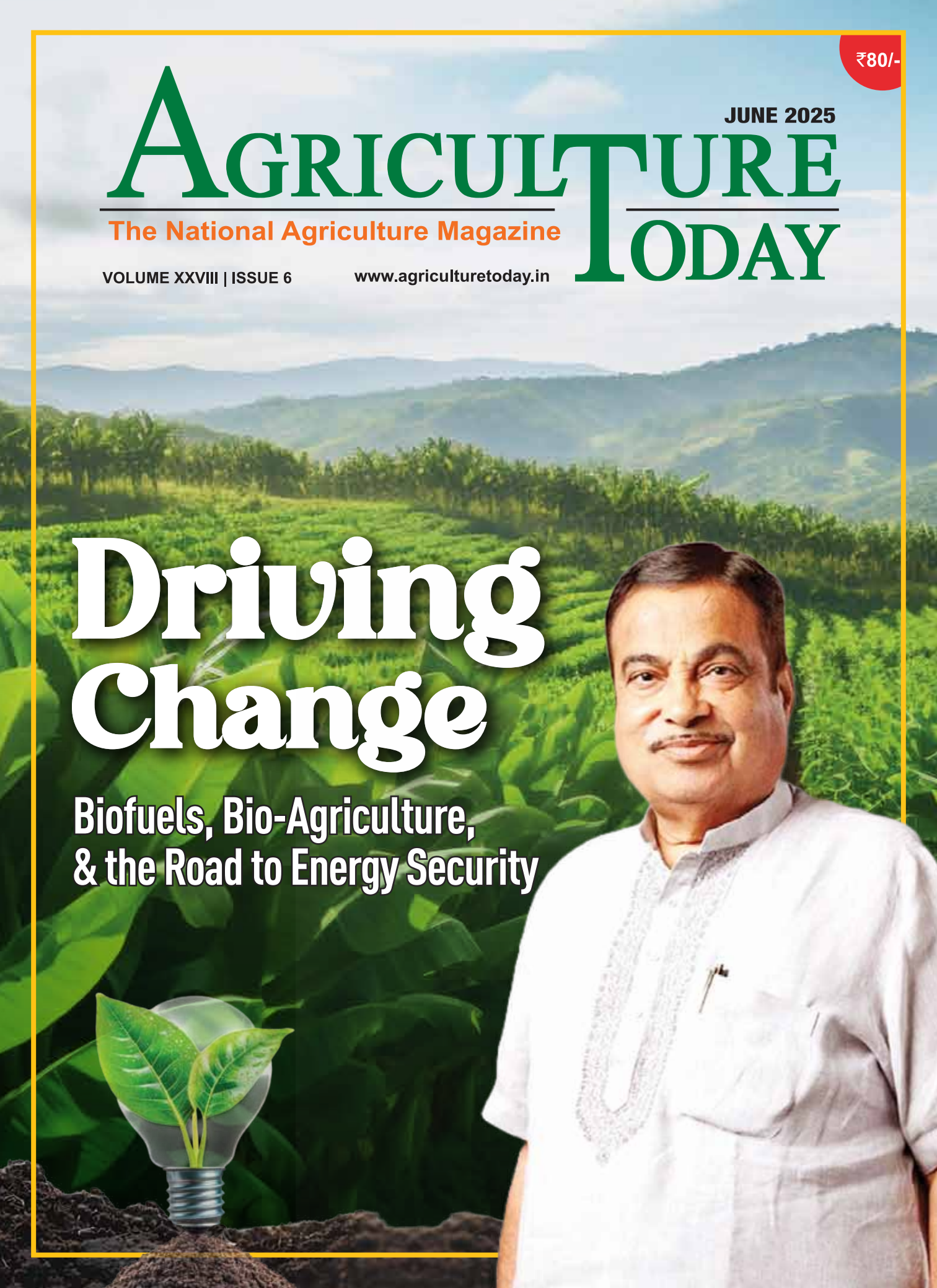
Driving Change

Biofuels, Bio-Agriculture, & the Road to Energy Security



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PREPARING FOR THE 16TH AGRICULTURE LEADERSHIP CONCLAVE WITH ENTHUSIASM AND PRIDE

As we bring you this June edition of Agriculture Today, the entire team at the Agriculture Today Group is buzzing with excitement and anticipation. Just a few weeks away, on 9th and 10th July 2025, we will host the much-awaited 16th Agriculture Leadership Conclave in New Delhi—a landmark event that has become a beacon of inspiration and progress in Indian agriculture.

Reflecting on this incredible journey fills us with immense pride. Sixteen years ago, we pioneered the concept of recognising leadership in agriculture through the Agriculture Leadership Awards, a first-of-its-kind initiative in the sector. Since then, the awards and conclave have grown into a prestigious platform that honours the titans and trailblazers of Indian agriculture—those whose vision, innovation, and dedication have shaped the future of farming, agribusiness, research, and policy.

Each year, a distinguished jury meticulously selects the most deserving individuals and institutions, ensuring that the awards remain a true symbol of excellence and impact. Over the years, the presence of top policymakers and industry leaders at our award functions has further elevated the stature of this event, underscoring the critical role of leadership in driving agricultural transformation.

As we prepare to welcome the brightest minds and most passionate stakeholders to this year's conclave, our excitement is palpable. The event promises to be a vibrant forum for dialogue, collaboration, and celebration—a unique opportunity to connect with those who are shaping the future of Indian agriculture.

We invite all our readers and stakeholders to join us in this journey of inspiration and innovation. Together, let us celebrate the achievements of our agriculture leaders and work towards a sustainable, prosperous future for Indian agriculture.

Stay tuned for more updates as we count down to the 16th Agriculture Leadership Conclave!

Rajni Shaleen Chopra

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FROM THE CEO'S DESK

Ushering in the Next Green Revolution with Bio-Control and Bio-Stimulants

As the world stands at the crossroads of food security and environmental stewardship, the agricultural landscape is undergoing a quiet but profound transformation. The last few years have witnessed remarkable technological advances in the bio-control and bio-stimulants sector, offering a beacon of hope for sustainable farming and the promise of a new green revolution.

Bio-control agents and bio-stimulants, once considered niche alternatives, are now at the forefront of mainstream agricultural innovation. Powered by breakthroughs in biotechnology, microbiology, and digital agriculture, these solutions are redefining how we nurture crops and protect them from pests and diseases. Modern bio-control products, developed through advanced microbial selection and fermentation techniques, are not only more effective but also tailored to specific crops and local agro-climatic conditions. Meanwhile, bio-stimulants derived from seaweed, beneficial microbes, and plant extracts are enhancing plant resilience, improving nutrient uptake, and restoring soil vitality—often outperforming their chemical counterparts in both efficacy and sustainability.

The integration of digital tools has further accelerated this evolution. Precision agriculture platforms, IoT-enabled sensors, and AI-driven diagnostics now empower farmers to monitor soil health, pest populations, and crop nutrition in real time. This data-driven approach ensures that bio-inputs are applied judiciously, maximizing benefits while minimizing waste and environmental impact. Such synergy between biology and technology is not just a scientific triumph but a practical pathway to reducing our reliance on synthetic agrochemicals, cutting input costs, and safeguarding ecosystem health.

The journey towards a truly sustainable bio-agri model extends beyond technology alone. It demands a holistic vision—one that embraces farmer education, robust regulatory support, and equitable market access. Public-private partnerships and farmer-led innovation networks are essential to bridge knowledge gaps and ensure that smallholders, who form the backbone of our food systems, are not left behind. At the policy level, streamlined regulatory frameworks and incentives for sustainable practices can accelerate the adoption of bio-based solutions while maintaining food safety and quality.

The roadmap for the next green revolution is thus clear: it is built on the pillars of scientific innovation, digital empowerment, and inclusive growth. By nurturing this ecosystem, we can transform agriculture into a force for regeneration—restoring soils, revitalizing rural economies, and feeding a growing population without compromising the planet's health. The future of farming is not just about higher yields, but about cultivating harmony between people, technology, and nature. Let us seize this moment to lead the way.

Haris Khan

AATMNIRBHAR BHARAT

Biofuels and Bio-Agriculture

Pioneering India's Green Energy and Farming Future

As Union Minister for Road Transport and Highways, my journey in public service has always been guided by a vision to transform India into a self-reliant, sustainable, and prosperous nation. Over the years, I have dedicated myself to harnessing the immense potential of biofuels and bio-agriculture, not only to address our energy and environmental challenges but also to empower our farmers and rural communities. In this article, I will share my perspective and the work I have undertaken in these vital fields.

> "Together, we can make India a global leader in biofuels and sustainable agriculture, ensuring prosperity for generations to come"

Shri Nitin Gadkari is Minister of Road Transport & Highways, Government of India

Championing Biofuels: A Pathway to Energy Security and Rural Prosperity

India's dependence on fossil fuels has long been a matter of concern. Every year, we import nearly 85% of our fuel requirements, amounting to an expenditure of around Rs 22 lakh crore. This not only strains our economy but also exposes us to global uncertainties. I have always believed that the answer lies in leveraging our agricultural abundance to produce clean, indigenous fuels-biofuels that can power our growth while uplifting our rural heartland.

Ethanol: From Surplus Crops to Green Energy

One of my key initiatives has been to promote the use of surplus agricultural products-such as broken rice and sugarcane-for ethanol production. By diverting excess
produce into ethanol, we reduce the government's burden of procuring these crops at minimum support prices, while simultaneously creating a new revenue stream for our farmers. This approach also addresses the pressing issue of agricultural surplus, particularly in sugar, wheat, and rice.

I have advocated for the expansion of ethanol blending in petrol, a policy that has already begun to bear fruit. Ethanol blending not only cuts down on our crude oil imports but also lowers vehicular emissions, contributing to cleaner air in our cities and towns. I am particularly optimistic about the potential of bamboo from the Northeastern states as a feedstock for ethanol, which can open up new economic opportunities in these regions.

Tackling Stubble Burning: From Pollution to Bio-CNG

Every winter, North India grapples with severe air pollution caused by the burning of crop residues, especially rice straw (parali) in Haryana and Punjab. Instead of viewing this as a problem, I have seen it as an opportunity. We are actively encouraging farmers to sell their crop residues for biofuel production, turning waste into wealth.

> "By empowering our farmers, promoting sustainable practices, and embracing innovation, we are laying the foundation for a greener, cleaner, and more prosperous future"

Today, over 400 projects are underway in Haryana, Punjab, and Maharashtra to convert rice straw into biofuel, particularly bio-CNG. These efforts not only mitigate the environmental damage caused by stubble burning but also provide farmers with an additional source of income. The conversion of rice straw to CNG has proven viable, with a ratio of approximately 5:1 in tonnes, and over 40 plants are already operational in states like Punjab, Haryana, Western Uttar Pradesh, and Karnataka. Our goal is to process all available agricultural waste and significantly reduce seasonal air pollution.

Bio-Aviation Fuel and Green Hydrogen: Fuels of the Future

I have consistently emphasized the need for policy diversification in the biofuel sector. Sustainable Aviation Fuel (SAF) represents a promising frontier, with the potential to build a ☐2 lakh crore economy in India. By investing in bio-aviation fuel, we can reduce our carbon footprint in the aviation sector and position India as a leader in green aviation technology.

Similarly, green hydrogen is another area I am passionate about. Hydrogen, produced from renewable sources, is the fuel of the future. By promoting research and investment in hydrogen technologies, we can further reduce our dependence on imported fossil fuels and create new industries and jobs for our youth.

Waste-to-Energy: Circular Economy in Action

Our commitment to sustainability extends to the conversion of various types of waste-agricultural residues, restaurant waste, and more-into valuable

biofuels. By developing CNG and ethanol production from farm and biomass waste, we are not only addressing environmental concerns but also promoting a circular economy. These initiatives are particularly crucial for rural, tribal, and forest areas, where they provide new income sources and enhance economic stability.

I firmly believe that by converting waste into resources such as bio-aviation fuel, we are adding value to agricultural activities and promoting sustainability at every level.

Empowering Farmers: From Annadata to Urjadata

My vision is to transform the role of our farmers from mere food-givers (Annadata) to energy-givers (Urjadata), fuel-givers (Indhandata), and ultimately, hydrogen-givers (Hydrogen-Data). By integrating them into the biofuel value chain, we are ensuring that the benefits of India's green energy transition reach the grassroots. This transformation is not just about technology-it is about economic empowerment and social upliftment.

Bio Agriculture: Sustainable Farming for a Greener Tomorrow

While biofuels address our energy needs, bio-agriculture is central to ensuring food security, soil health, and environmental sustainability. My work in this area has focused on promoting organic farming, water conservation, and innovative practices that enhance productivity without harming the environment.

Biochar: A Revolution in Soil Health and Rural Entrepreneurship

One of the most exciting developments in recent years has been the promotion of biochar-a carbon-rich product obtained from the pyrolysis of organic matter. Biochar has the potential to rejuvenate degraded soils, improve water retention, and boost crop yields. Recognizing its transformative potential, I recently inaugurated the Biochar Centre of Excellence at Kanha Shanti Vanam near Hyderabad.

This initiative aims to train rural entrepreneurs, especially women and youth, in the production and application of biochar. By setting up biochar units and distributing the product to farmers, we are creating a sustainable rural business model. The centre offers hands-on training, allowing participants to witness the impact of biochar on soil quality, crop yield, and water usage in real conditions.

Early trials have been promising. Farmers from Madhya Pradesh and Gujarat reported a 27% increase in yield and reduced water usage after applying biochar. The process has also helped reclaim previously uncultivable land, turning it into productive farms and medicinal gardens. Our goal is to replicate this model across other states, integrating biochar modules into rural skilling programs and promoting agroforestry.

Organic Farming and Water Conservation

My commitment to sustainable agriculture began during my tenure in Maharashtra, where I introduced agrarian reforms focused on water conservation and organic farming. By encouraging farmers to adopt organic practices, we are reducing the reliance on chemical fertilizers and pesticides, improving soil fertility, and ensuring long-term food security. Water conservation remains a top priority. Through watershed management, rainwater harvesting, and micro-irrigation, we are helping farmers make the most of every drop. These measures not only increase resilience to droughts but also reduce input costs and enhance farm incomes.

Agroforestry and Reforestation

The integration of agroforestry-growing trees alongside crops-has been another area of focus. Trees provide shade, improve soil structure, and increase biodiversity. Through partnerships with organizations like Heartfulness, we are working towards planting 30 million native trees by 2030, restoring degraded landscapes and supporting livelihoods.

The Road Ahead: Vision for a Sustainable and Prosperous India

Our journey towards energy self-reliance and sustainable agriculture is far from over. There is immense scope for expanding the biofuel economy, which currently stands at Rs2 lakh crore, compared to the Rs22 lakh crore fossil fuel economy. By investing in large-scale production of green fuels from biomass, we can create a win-win situation for all stakeholders-farmers, entrepreneurs, industry, and the environment.

I urge industry leaders to step forward and invest in the biofuel sector. Together, we can build a robust ecosystem that supports research, innovation, and large-scale deployment of bioenergy technologies. The government is committed to providing the necessary policy support and incentives to make this vision a reality.

Self-Reliant, Resilient, And Inclusive India

As I reflect on the work done in the fields of biofuel and bio-agriculture, I am filled with optimism. The initiatives we have launched are not just about reducing our carbon footprint or cutting down imports-they are about building a self-reliant, resilient, and inclusive India. By empowering our farmers, promoting sustainable practices, and embracing innovation, we are laying the foundation for a greener, cleaner, and more prosperous future.

I remain steadfast in my commitment to these causes and invite all stakeholders-farmers, entrepreneurs, researchers, and citizens-to join us on this transformative journey. Together, we can make India a global leader in biofuels and sustainable agriculture, ensuring prosperity for generations to come.

SHRI NITIN GADKARI INAUGURATES INDIA'S FIRST BIOCHAR CENTRE OF EXCELLENCE

Shri Nitin Gadkari, Union Minister of Road Transport and Highways, inaugurated on May 5 a Biochar Centre of Excellence promoting rural entrepreneurship at Kanha Shanti Vanam – the headquarters of Heartfulness Institute, which houses the largest meditation centre in the world, in the outskirts of Hyderabad.

Shri Kamesh Patel (Daaji), President Founder & Guide of Heartfulness Institute and Shri Nath Parameshwaran, Senior Director at PayPal also graced the occasion.

The Centre has been established to provide skill development, and capacity building for rural entrepreneurs in villages for biochar. The initiative aims to encourage women and youth entrepreneurs to set up biochar units, produce biochar, and distribute it to farmers as part of a rural business model.

The Centre of Excellence will also offer an end-to-end experience of how biochar is produced, processed, and applied to the soil, enabling participants to visually study and understand its impact on crops, soil, and forests.

Making India More Self-Reliant In Agriculture

Speaking on the occasion, Shri Nitin Gadkari said, "Small businesses, rural entrepreneurs and farmers form the backbone of India's economy. This unique initiative brings entrepreneurs and farmers together to equip them with modern agricultural technologies and know-how on farming. We want our farmer community to have superior yield, better income, make agriculture dependable and provide economic opportunities for small rural entrepreneurs in the villages.

With the Biochar Centre of Excellence and promoting Rural Entrepreneurship at Heartfulness, we are sure to make India more self-reliant in agriculture. This is a wonderful initiative, and we hope that rural entrepreneurs and farmers will benefit from this initiative."

"We must be wise in how we produce crops - not only by adopting modern techniques but also by being sensitive to soil health and nutrition. A Centre of Excellence like this will train rural entrepreneurs, farmers, and agriculturists in sustainable farming, helping them adopt biochar as an effective carbon-sequestering agent for better plant survival rates and afforestation. Our vision is to establish a biochar unit in every village in the country for the benefit of all," added Shri Kamlesh Patel (Daaji), Founder & Global Guide of Heartfulness Institute.

Shri Nath Parameshwaran expressed happiness that the initiative aligns with the Skill India vision of Prime Minister Shri Narendra Modi.

TRANSITIONING TO HIGH YIELD PROFITABLE CROPPING

RELOOKING AT THE FARMER'S TOOLBOX

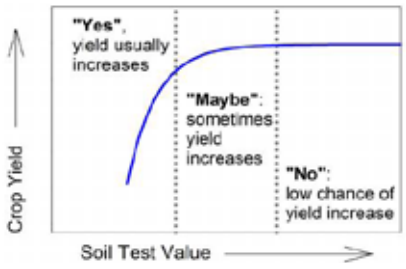
Rational Regenerative farming is becoming a necessity to counter the challenges of low productivity and profits of farmers. If the farm profits are not increased in the short term there is a fear of growing unrest in our food production systems. The problem is not of absence of technology but the delay in reaching them on priority basis to the farms. Farming is a patient activity and experimentation is costly though necessary. With the retail input channel being flooded with multiple products farmers still are not able to increase their per acre/hectare yield substantially. The main reason is irrational use of inputs which cost the farmer dearly. Frantic use of inputs also impacts consumers with respect to the food quality due to pesticide residues in food compromising demand in export and high value market. In absence of a dependable universal advisory system farmer slides further down the productivity treadmill taking all the blame for it.

The gaps in the system can only be filled by proper advocacy by expert recommendation agencies/experts as per need of the farm and targeted production. We have seen that when right technology reaches the farm gate farming turns profitable! In the age of AI this may not be difficult or costly -– the only question is when?

Farmers toolbox

Farmers toolbox is a set of inputs used by him to grow his crops. Right from seeds, fertilizers, pesticides etc to the services he avails to use these inputs on his field. More is not necessarily better. Productivity is a ratio of maximizing yields at minimum costs. Apart from the market rates, which are beyond the control of the farmer, low productivity is a wasteful exercise which he cannot prevent as it is his only profession and means of survival.

Yields are often decided by the status of the soil, the nutrient and allied fertility parameters. It is imperative for the farmer to test his soil for all parameters which can unfold what needs to be done to achieve target yields. It also makes him aware of the deficiencies and reasons for low productivity very clearly. Soil diversity is an important feature which has its base as organic carbon. Soil respiration often gives an idea of the presence of toxic contaminants which may affect microbial diversity even in the presence of sufficient carbon. The impact of soil testing can go up to almost 2x to 3x as compared to imbalanced/blanket use of fertilizers. Blanket use of input often leads to compromised yields and profits of the farmer.



Soil test value vs. probability of crop yield response to nutrient addition. Crop yield increase due to nutrient addition is likely at low soil test values and unlikely at high soil test values. (Chart © Oregon State University. Prepared by Dan M. Sullivan. Horneck, D & Sullivan, Dan & Owen Jr, James & Hart, J. (2011). Soil Test Interpretation Guide. Oregon State University Extension.

More Crops Per Rupee Spent

Every rupee used by the farmer should give him a benefit not only for increasing yields but also have the lowest impact on soil fertility. Whatever is taken from the soil as yield must be returned back as carbon which feeds the microbes in the soil to be keep it super productive. Soils with 1 % soil organic matter (SOM) can retain 10,000–11,000 litres of plant-available water per hectare to a depth of 30 cm. Microbes keep this giant food web in soil running which channelizes different nutrients. It is just like a giant honeycomb which has spaces for equal distribution of food, air, water keeping soil healthy, porous and productive. This structure can improve the efficiency of fertilizers by retaining them in the soil and preventing leaching. Biofertilizers also work efficiently. Thus, a healthy mix of organic fertilizers, biofertilizers and last use of chemical fertilizers as per soil

About the **AUTHOR**

Dr Sandeepa Kanitkar is the founder chairperson and Managing Director of Kan Biosys. She is an industrial microbiologist who has spent 35 years unleashing the power of microbes for agriculture. Starting from the first patent for producing liquid biofertilizers which won the United Nations WIPO Gold Medal, she is involved in improving the efficiency of fertilizers and pesticides using microbes

test helps to target yields. Each rupee thus spend can give More Crop per drop of irrigation/ rainwater and per rupee spent on inputs for fertilizing soil. Due to the nourished biodiversity biopesticides work better if used with package of practices. Last but not the least chemicals pesticides can be used in moderation in case of need as per ETL levels/weather factors [humidity] keeping the PHI – preharvest interval in mind. Microbes provide buffers against climate shocks. Bio stimulants can be used in moderation as per need during crop period. Thus, a healthy balance of inputs helps keep the cost in check.

Cheap Is In Fact Costlier

It is seen that the market has all types of inputs promising the world. The prices also vary greatly. Many a times farmers are confused and opt for the cheapest one as it is affordable. Quality is many a times ignored. Such inputs just increase the cost of cultivation without imparting any great benefits. Thus, they are costlier and the search for the best input is delayed to next year. This kind of experimentation is costly and time consuming and often deceptive.

Budgeting is often a good exercise for the farmer and new inputs, or innovation should be tried based on answering certain questions as follows –

1. What is my pain point?
2. What is the pain point costing me?
3. What is the contribution of the cost with respect to the benefit I am getting of existing inputs?
4. Can I get my existing POP validated by an expert with respect to soil testing?
5. What is the budget I can allocate to each input?
6. How much space in my field I have for checking any new input to be added to my POP next year? What are the results of my Vision plot?
7. Am I able to improve my yield and profits year after year based on improving my POP?

Rational Use Starts With The Principle Of Elimination Of Inputs With Low Cost To Benefit Ratio

Rational use of inputs is allocating them properly in budget and working on issues

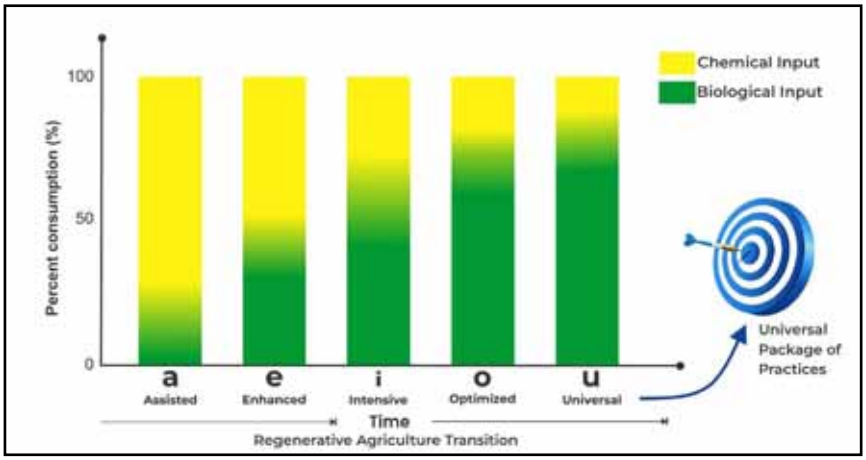
Only aggregation models based on collective farming by FPO's can achieve economic of scale for field and food crops

which impact yield. Often, we see that frantic use of inputs, especially pesticides, costs the farmer heavily. It is more of saving the crop rather than increasing the yields. Biopesticides can solve this issue for the farmer to a great extent. Starting from simple inputs based on CIB registered *Trichoderma viride* [Tricho-shield Combat] for soil drenching along with Mycorrhiza [Mycozoots] can help ward of fungal infections from the start. Using CIB registered *Trichoderma harzianum* [Nemastin] every new moon day [just for building POP easily] helps to keep plant parasitic nematodes in check. Using formulations of Bacillus subtilis [Milastin-K] and *Pseudomonas flourescens* [Sudo] every month as foliar sprays help control many foliar fungal diseases. Using *Beauverria bassiana* [Brig Boss] every new moon day [for timing POP easily] helps to build inoculum in soil and foliage for causing epizootics and keeping crop eating insects in check. Pheromones for mating disruption can be used to keep the insect populations in check avoiding frantic use of insecticides. Building soil biology for biocontrol is not expensive and allocating 10% to 20% of the cost of cultivation can yield consistent results. Using chemical pesticides can thus be done on need based basis which can keep pesticide residues at bay!

Food toxicity cannot be ignored

Food toxicity is becoming increasingly important. The heavy metal contamination and nitrates in our food is leading to great physiological stresses not only in human but entire food chain. The analysis of grain nutrient content reveals a significant reduction in essential [P, Ca, Zn, Fe and Cu] and beneficial [Ni and Si] elements but increase in toxic ones [As, Cr, Ba, Sr and Al] in rice cultivators. Likewise in wheat most elements [except Ba and Sr] have decreased. This shows declining mineral diet quality affecting human and animal health. Between 160 to 2010 the mineral-diet quality index in rice and wheat has dropped by about 57% and 36% respectively. In the coming years, this decline could increase noncommunicable diseases like iron-deficient anemia, respiratory, cardiovascular and musculoskeletal disorders in India highlighting the importance of nutrient profiling of our food cultivated using sustainable practices.

Similarly, we have every reason to worry about the impact of pesticides on bees as our survival depends on food pollination. Pesticides affecting non-target beneficial insects or animals also harm us indirectly as they enter the food chain to cause multiple side effects. Integrated pest management becomes important where in microbial biopesticides are used to increase their inoculum in field as a part of POP as first line of defense.



Tabe 2: A<E<I<O<U – step wise transition to regenerative practices using biologicals.

Sustainable Models for Eco-Agri Revolution

After the Green Revolution, it is now time for an Ever-Green Revolution based on Eco Agriculture or Agroecology. In 2018, the FAO described Agroecology/Eco Agriculture as a means to transform food and agriculture systems by addressing root causes and emphasizing the improvement of efficiency in resource use, conserving, protecting, and enhancing natural ecosystems, protecting and improving livelihoods, promoting equality and well-being, and enhancing the resilience of people, communities, and ecosystems.

A timely transition to a sustainable eco-agriculture approach is essential to protect food security, the well-being of people, and farmers' prosperity. Eco Agriculture is a broad term that can inclusively refer to agroecology, regenerative, organic, natural, jaivik, etc., and is increasingly being recognized as the way to help save the planet.

While discussing this with Prof. Swaminathan and the ICFA team, the idea of a Working Group emerged. When I was requested to form the Eco Agri Working Group through ICFA, I consulted with different sectors and tried to determine the "why" and "how" of the impending Eco Agri Revolution.

THE WORKING GROUP – ROAD MAP

While discussing with everyone, it was decided to take up the preparation of a Road Map and Action Plan. It was soon realized that, although policy matters and incentives from the Central and State Governments are important, participation and action at all levels- as everybody's mission-are the real need.

Subsequently, several round tables and national and international meetings have been organized through the Working Group (ICFA). Agriculture Today became very successful, with enthusiastic contributions from all sectors.

The 20:20 model represents an evolutionary and appropriate path for transformation

As the next logical step, three expert groups have been formed to help prepare the Road Map and Action Plan:

1. Policy Matters
2. Agri Bio Inputs
3. Technology Transfer and Extension to Grassroots Levels

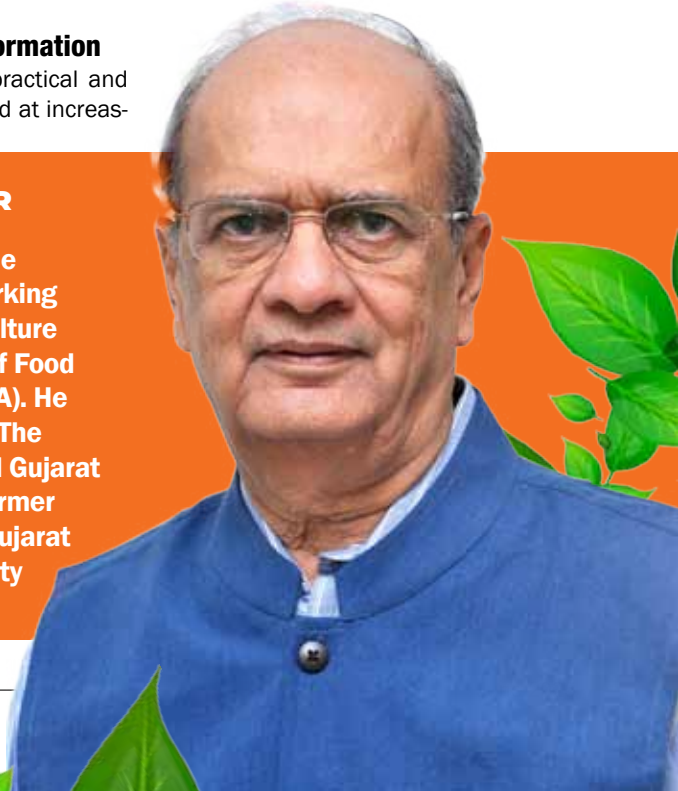
20:20 Model for Transformation

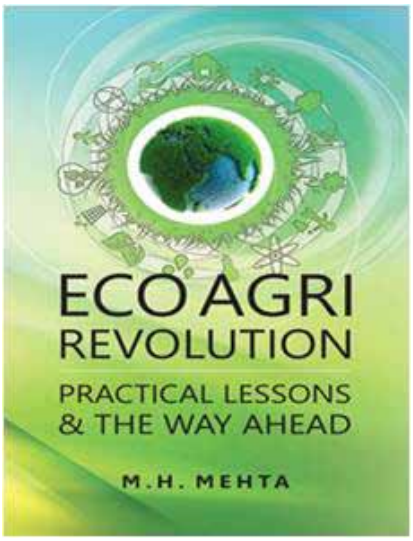
The "20–20 Model" is a practical and sustainable approach aimed at increasing farm production by 20% while reducing input costs by 20%. This model relies on the use of new-generation, eco-friendly bio-inputs such as bio-fertilizers and bio-pesticides (both microbial and botanical), as well as products derived from farm agro-wastes. It represents a "middle path" between conventional chemical-based agriculture and fully eco-friendly farming, recognizing that an immediate switch away from chemicals is neither feasible nor effective, as evidenced by numerous failed attempts at abrupt transitions.

Instead, the 20–20 Model advocates for a stepwise transition by integrating eco-friendly products alongside conventional inputs. This approach helps lower input costs and enhances farm productivity in a sustainable manner. The model is evolutionary, allowing for gradual adoption of biologicals and bio-inputs, which are gaining popularity due to environ-

About the **AUTHOR**

Dr. M. H. Mehta is the Chairman of the Working Group on Eco Agriculture of Indian Chamber of Food and Agriculture (ICFA). He is Hon. Chairman of The Science Ashram and Gujarat Life Sciences and former Vice Chancellor of Gujarat Agricultural University





Typical Bio input Packages-cotton/Soybean/Rice/Vegetables

Typical Productivity Enhancement Data: Multi Microbial Products, Bio-Fertilizers, Bio-Composts, and Biocontrol
(Application of Bio Products – Superlife, Wonderlife, Bio Compost)

Crop	Location	Result
Banana	Agricultural University-Navsari, Trichy-Tamil Nadu, Mauritius	Above 25% more production with above 20% reduction in urea dose.
Rice	Bangkok – Thailand, Vapi-Gujarat	Increase in production from 14 to 19%.
Maize	Gauteng – South Africa	25% more production, 25% less Urea.
Soybean	M.P., U.P. (Solidaridad, International)	Increase in yield by 17-22%. Lowering input cost by 20%
Papaya	North Gujarat	Up to 21% increase in yield achieved.

mental concerns, consumer awareness, and the need for cost-effective solutions for farmers.

Hybrid, low-input strategies like the 20–20 Model have been shown to deliver environmental benefits, such as reduced chemical use, improved soil health, and greater resilience, while maintaining or even increasing profitability3. This balanced approach is increasingly recognized as a viable and scalable solution for sustainable agriculture.

This shortlist is only indicative, and many examples of successes by farmers' groups, companies, and NGOs are increasingly available, highlighting the emergence of new-generation eco-friendly farming. Furthermore, these examples can be doubled or tripled year by year.

20:20 Model
- Reduce agri-input costs > 20%
- Improve farm production > 20%
- New generation agri bio inputs

Similar increasing trends are being observed under various terms such as Organic, Regenerative, Natural, Jaivik, etc., often in various combinations. However, under the common name of Eco-agriculture, all these approaches represent the middle path of gradual transformation, which is the way forward.

Time Now for Evergreen Revolution – Prof. M.S. Swaminathan

Future of Eco Agriculture

Although the growth rate of biological inputs will be high, chemicals cannot be eliminated overnight. In conventional practices, there is already a trend of both being used together, with biologicals growing at a much faster rate. Against this background, the 20:20 model represents an evolutionary and appropriate path for transformation. Additionally, the organic sector will require exclusive biological input packages. Apart from India, neighbouring countries and African nations are also exhibiting similar trends.

The main driving forces behind the demand for biological and eco-friendly inputs include environmental concerns, increased consumer awareness, farmers' urgent need for low-cost inputs, and the rapid development of newer and more effective bio-products.

It has been observed that even small, illiterate farmers adopt new and better products more quickly than expected. The Working Group (Eco Agriculture) is developing a roadmap and action plan with these factors in mind. We all need to unite for a common mission to support agriculture, protect the environment, and ensure a sustainable future.

SHIFT TO BIOLOGICALS

A NECESSITY, NOT JUST A TREND

The global agri-food system is at a crossroads. While we've made immense strides in boosting food production over the past century, this progress has come at a high environmental cost. Overusing synthetic pesticides and chemical fertilisers has degraded soils, reduced biodiversity, and accelerated greenhouse gas emissions. As climate change intensifies and the global population nears 10 billion, we must transition to a new model of agriculture—one that is productive yet sustainable. This is the promise of the Evergreen Revolution, a concept that advances productivity without compromising the environment.

Biological technologies—specifically biocontrol agents and bio stimulants — are at the heart of this transformation. As someone who has dedicated more than two decades to developing and commercialising microbial solutions at Bionema Group, I've witnessed firsthand how these innovations can fundamentally reshape agriculture.

Redefining Pest Control: Technological Progress in Biocontrol

The biocontrol industry has evolved rapidly from niche to necessity. Traditionally dominated by well-known species like *Bacillus thuringiensis* and *Beauveria bassiana*, the field has expanded significantly with genomic tools and fermentation technologies.

Genomics-driven discovery enables us to identify novel microbial strains with enhanced virulence, environmental stability, and host specificity. We no longer rely solely on classical screening—we can pinpoint genes involved in metabolite biosynthesis or insecticidal activity using bioinformatics and genome editing tools.

In parallel, **synthetic biology** allows researchers to engineer microbial agents to express specific secondary metabolites, such as lipopeptides and volatile organic compounds (VOCs), which can deter pests or prime plant immunity. These next-generation microbes are more consistent in field performance and can also be tailored for specific pests or geographies.

Another frontier is **innovative delivery systems**. At Bionema, we've developed microencapsulation technologies that shield spores and nematodes from UV and desiccation. These systems enable the slow, targeted release of biocontrol agents in response to root exudates or moisture changes, greatly improving field efficacy.

RNA interference (RNAi) and microbial carriers hold future potential for precision pest management. Integrating

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RNAi with microbial consortia could deliver gene-silencing effects against particular targets, further reducing non-target risks.

Unlocking Plant Potential: Innovation in Bio Stimulants

Bio stimulants—particularly those based on microbial consortia such as PGPR (plant growth-promoting rhizobacteria) and mycorrhizal fungi—are gaining momentum because they can boost nutrient use efficiency, enhance stress tolerance, and improve yield quality.

Recent advances in **multi-omics approaches** (transcriptomics, metabolomics, proteomics) have deepened our understanding of the complex interplay between microbial inoculants and plant physiology. These insights allow us to refine formulations based on the plant's metabolic state or environmental conditions.

A notable innovation is the rise of **biofilm-based inoculants**. Instead of applying single strains, we are developing microbial consortia embedded within structured biofilms. These formulations offer improved colonisation and long-term resilience in the rhizosphere, mimicking natural soil microbiomes.

Digital agriculture is another enabler. **AI-powered tools and remote sensing** can now precisely guide the application timing and dosage of biostimulants. This integration of biologicals with digital platforms—what I often refer to as "intelligence-driven farming"—is a game changer for large-scale adoption.

Lastly, **engineered co-formulations** that combine microbial biostimulants with natural extracts (such as seaweed or humic substances) are emerging. These synergistic products activate multiple plant growth and defence pathways, offering farmers enhanced returns on investment.

From Lab to Field: Commercialisation and Barriers

Despite robust innovation, the widespread adoption of biocontrol and bio stimulants still faces systemic hurdles. Regulatory fragmentation remains a significant barrier. For instance, Europe's bio stimulant regulations under the new Fertilising Products Regulation (EU 2019/1009) have provided clarity, but many global markets still lack harmonised frameworks.

We are at the tipping point of a new agricultural era. But innovation alone is not enough. We need a concerted, coordinated effort that combines science, policy, and practice

Better product validation is also needed. Biologicals, by nature, interact with variable soil microbiomes and climates. That means performance may differ by region, necessitating localised field trials, farmer feedback loops, and technical support to ensure consistent results.

Education is another gap. Many growers are unaware of how and when to use biologicals effectively. To bridge the knowledge divide, training, demonstration plots, and digital extension services must be renewed.

A Roadmap for The Evergreen Revolution

So, how do we build a scalable, bio-based, and science-driven agricultural model?

1. Technology Hubs and Innovation Incubators

Governments and industry must invest in regional biocontrol centres to support R&D, formulation optimisation, and on-farm validation.

2. Precision Delivery Platforms

Biologicals should be integrated with irrigation systems, drone sprayers, and seed treatments to ensure cost-effective, targeted applications.

3. Regulatory Streamlining

Global alignment on microbial safety evaluation and fast-track registration pathways can help biologicals compete with synthetic inputs on a level playing field.

4. Farmer Training Networks

We must empower local advisors and cooperatives to champion biologicals as core tools in sustainable farming.

Closing Thoughts

The shift to biologicals is not just a trend but a necessity. As someone who has worked with farmers, researchers, and regulators across continents, I can confidently say we are at the tipping point of a new agricultural era. But innovation alone is not enough. We need a concerted, coordinated effort that combines science, policy, and practice.

With sustained investment, bold leadership, and a shared vision, we can build a food system that nourishes both people and planet.

Towards an EVERGREEN REVOLUTION

Technological Advances and the Roadmap for a Sustainable Bio-Agriculture Model

As the world grapples with climate change, soil degradation, and the ecological costs of chemical-intensive farming, the agricultural sector is experiencing a paradigm shift. This shift aims to achieve productivity without compromising environmental sustainability—an objective captured by the concept of the "Evergreen Revolution." Unlike the Green Revolution, which focused largely on maximizing yields through chemical inputs, the Evergreen Revolution calls for long-term sustainability rooted in biological solutions. Central to this vision are advancements in biostimulants and bio-control —technologies that are rapidly reshaping the landscape of modern agriculture.

About the **AUTHOR**

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Technological Advances in Bio-Stimulants and Bio-Control

1. Seaweed & Amino based Formulations

Seaweed and amino acid-based biostimulants are emerging as vital tools in promoting sustainable agriculture. Derived from natural sources, these biostimulants enhance plant growth, resilience, and nutrient efficiency without the environmental drawbacks associated with conventional agrochemicals. Their natural, eco-friendly composition supports sustainable agriculture by enhancing plant growth, improving stress tolerance, boosting nutrient efficiency, and balance the reliance on chemical inputs.

2. Precision Microbial Technologies

The discovery and engineering of beneficial microbes have taken a leap forward thanks to innovations in genomics, metagenomics, and CRISPR-based editing. Researchers can now isolate strains of bacteria and fungi with high bio-efficacy, tailoring them to target specific pests or promote nutrient uptake in particular crops. Microbial consortia—combinations of compatible microorganisms—are increasingly used to provide multiple benefits, from pest resistance to improved soil health.

3. Nano-Biotechnology in Formulations

One of the key challenges in bio-inputs has been shelf life and efficacy under field conditions. Nanotechnology is ad-

dressing this by enabling encapsulation of active ingredients in nano-carriers. These nano-formulations improve the stability of bio-control agents, allow for controlled release, and enhance absorption in plants. This results in reduced application rates and better field performance.

3. Integration of Artificial Intelligence and Remote Sensing
AI and big data analytics are transforming how bio-inputs are applied in the field. Machine learning models analyze data from drones, satellites, and on-ground sensors to predict pest outbreaks and recommend precise interventions. This enables timely application of bio-control agents, reducing crop loss and input wastage. AI also plays a key role in customizing biostimulant regimens based on crop phenology and local soil conditions.

4. RNAi-Based Bio-Control
RNA interference (RNAi) is emerging as a highly targeted approach to pest control. Unlike broad-spectrum chemical pesticides, RNAi-based solutions silence specific genes in pests without affecting non-target organisms. This next-generation technology holds promise for managing resistant pests and reducing chemical residues in food.

5. Smart Delivery Mechanisms
Innovations in formulation science are leading to smart delivery systems such as alginate beads, microcapsules, and biodegradable polymers that protect bio-inputs from harsh environmental conditions and release them in response to specific triggers such as moisture, temperature, or root exudates. These mechanisms optimize effectiveness while minimizing ecological impact.

6. Bioinformatics and Metabolomics
Advances in bioinformatics allow researchers to decode complex plant-microbe interactions. Metabolomic profiling identifies bioactive compounds that stimulate plant growth or defense responses, helping design more effective biostimulant formulations. Such insights are essential in developing crop-specific or stress-specific solutions.

Creating a national "Bio Input Index" or certification system can help ensure product quality and build market confidence

A Roadmap for a Sustainable Bio-Agriculture Model

Realizing the full potential of bio-control and bio-stimulants requires a structured roadmap that brings together technology, policy, and farmer engagement.

1. Strengthening the Research-Industry Ecosystem
Public-private partnerships must be fostered to accelerate innovation. Agricultural universities, research labs, and industry players should collaborate to scale lab-to-land transfer of microbial and natural product technologies. Establishing bio-agriculture incubators can nurture start-ups that bring disruptive solutions to market.

2. Enabling Farmer-Centric Deployment
For any technology to make an impact, it must reach the end user effectively. Localized demonstrations, community-led field trials, and digital advisories in regional languages can enhance trust and adoption. Integration of bio-inputs into existing farming systems through training on Integrated Pest and Nutrient Management (IPNM) is crucial.

3. Regulatory Reforms for Bio-Inputs
The current regulatory landscape for bio-inputs is often slow and fragmented. There is an urgent need for a streamlined, science-based registration framework for bio-control agents and biostimulants. Creating a national "Bio Input Index" or certification system can help ensure product quality and build market confidence.

4. Building an Efficient Supply Chain
Many bio-inputs require cold chain logistics and careful handling. Investment in decentralized production units managed by farmer producer organizations (FPOs) can enhance accessibility. Tech-driven platforms can match supply and demand, especially in remote or underserved regions.

5. Incentivizing Sustainable Practices
Governments can promote adoption through incentives such as carbon credit mechanisms for using bio-inputs, insurance benefits for sustainable practices, and subsidies on validated bio-products. This will encourage the transition from synthetic inputs to regenerative practices.

6. Climate-Smart and Soil-Positive Farming
Biostimulants play a significant role in improving soil organic carbon, water-use efficiency, and crop resilience to climate stress. These traits are fundamental to building a climate-smart agricultural system. Additionally, bio-inputs reduce greenhouse gas emissions by minimizing the need for synthetic fertilizers and pesticides.

7. Monitoring and Evaluation through Digital Tools
The impact of bio-agri practices can be tracked using blockchain, IoT, and satellite imaging. Real-time data can help stakeholders evaluate ROI, environmental benefits, and crop performance, thereby guiding future strategies.

New Era in Agriculture

The fusion of biological science with digital innovation is driving a new era in agriculture—one where sustainability and productivity go hand in hand. Technological advances in bio-control and biostimulants are not just eco-friendly alternatives; they are key enablers of the Evergreen Revolution. With the right roadmap involving research, policy, infrastructure, and farmer support, India and the world can build a resilient and regenerative agricultural system that ensures food security while nurturing the planet.

BIOLOGICALS CATALYZING AN EVERGREEN REVOLUTION

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The launch of India's Green Revolution in the 1960s was important for the country's quest towards achieving self-sufficiency in food production. Consequently, agricultural practices, such as the application of high-yielding crop varieties, synthetic fertilizers, and chemical pesticides especially in Punjab and Haryana, boosted agricultural productivity. However, the ecological consequences were dire. Intensive farming practices severely degrade soils by depleting essential Micro & Macro nutrients, microbial diversity and organic matter.

Furthermore, chemically loaded water reached & polluted Ground Water runoff eroded rivers and lakes. Excessive extraction of water for irrigation resulted in depleting the groundwater table level. Moreover, the widespread reliance upon pesticides led to resistant pest populations, secondary pest outbreaks vanishing beneficial species such as pollinators and soil microbes. The over application of nitrogen fertilisers further exacerbated the emission of greenhouse gases. Therefore, these factors, worsened by climate change, necessitated the need for adaptation to more eco-friendly agricultural practices.

New Agricultural Paradigm

Responding to these challenges, the concept of an *Evergreen Revolution*, proposed by Dr. M.S. Swaminathan, aims to usher in a new era of agriculture—one that enhances productivity without compromising ecological integrity. This model calls for an agricultural paradigm that regenerates soil, conserves water, and promotes energy-efficient practices, while preserving biodiversity and long-term ecosystem health. Role of Biologicals is going to be most critical in realizing the vision of Ever Green Revolution.

Primary constituents of such a vision are biological control agents and biostimulants, which represent nature-based technologies for phytoprotection and plant growth promotion. To elaborate, biological control encompasses the management of phytopathogens and insect pests using beneficial microorganisms, entomophagous insects, and naturally derived biochemicals, as well as secondary metabolites from living organisms. Similarly, biostimulants are substances that enhance plant physiological processes, such as extracts of seaweeds, amino acids, and humic acid, thereby improving nutrient uptake, stress tolerance, and overall plant vigour. Ultimately, the strategic integration of these biologicals offers significant opportunities to meaningfully sustain Indian agriculture by fostering agroecosystem resilience and reducing reliance on synthetic inputs.

Recent Developments in Biocontrol and Biostimulant Technology

Presently, the implementation and development of biocontrol agents and biostimulants in India are gradually increasing with the support of private industry and research institutions like the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities. Significantly, researchers are characterizing locally adaptive strains of beneficial microbes like Trichoderma, Pseudomonas, and nitrogen-fixing bacteria, which are more suited to local conditions. To further advance this, India needs innovations in formulation technologies like encapsulation and nano-formulations for better product shelf-life and effectiveness in varying storage and field conditions. Despite encouraging government policies, bio-inputs still comprise only about 9% of pesticide use in India. Therefore, improving formulation stability and efficacy are essential for garnering support from farmers.

A bio-economy strategy would facilitate upgrades in policy and regulation. Bio-Pesticides should be registered under CIBRC for commercialization. This is improving the passage of biosafety regulations without trimming on quality and safety

Furthermore, genomics, proteomics, and metabolomics are enabling the understanding of plant interaction with beneficial microbes in Indian agro-climatic contexts. Consequently, this provides ground for developing more sophisticated bio-agents. Moreover, precision agriculture, such as drone and soil sensor spraying and real-time nutrient monitoring and digital initiatives like e-Kranti enhance bio-input optimisation. Importantly, these technologies are critical in addressing the demands of fragmented and small landholdings typical of India.

Additionally, the scientific investigation of natural extracts like neem and seaweed is turning India's rich traditional knowledge and biodiversity into invaluable resources. Correspondingly, emphasis is placed on sustainable methods of harvesting and efficient extraction so that bio-pesticides and biostimulants can be derived from secondary metabolites without compromising availability.

India's Sustainable Bio-Agricultural Model

Considering the above, the Indian-specific version of the Sustainable Bio-Agricultural Model focuses on biostimulant and biocontrol advancements in agriculture. This model simultaneously addresses the critical need for ecological restoration and agricultural production. Firstly, a construction of soil health and remediation is of paramount importance because about 30 percent **(Outlook Business)** of India's agricultural land is under soil degradation. Secondly, there is also the promotion of biodiversity and conservation of water, alongside reduced use of synthetic chemicals. Thirdly, it also includes Integrated Pest Management (IPM) with biological

control as a primary strategy, as well as increased utilization of bio-stimulants for Nutrient Use Efficiency (NUE).

Biocontrol Boosts Crop Protection Naturally

For instance, pest control using biocontrol agents has also proven to be useful in primary crops like rice, cotton, vegetables and pulses within the confines of not harming other species or the environment. In addition, biostimulants are able to assist crops in enduring common stresses such as water scarcity or salinity, which are often worsened by climate change. Evidently, there is a noticeable shift towards organic farming in India, endorsed by various government schemes like the Paramparagat Krishi Vikas Yojana (PKVY). India also had 2.78 (Down To Earth) million hectares of land under certified organic farming in 2020, indicating the bio-agri model's potential.

Bio-Inputs Reduce Climate Impact

Beyond productivity, bio-inputs also help combat climate change. Bio Solutions tend to reduce greenhouse gas emissions by reducing the use of fertilisers and pesticides derived from fossil fuels. Regenerative agriculture Practices which focus on soil, biodiversity, and ecosystem restoration, are actively being adopted by many forward-thinking farmers in India, thus making bio-inputs a crucial part of this consented movement.

Strategy Required For Evergreen Revolution

To effectively implement the adoption of bio-inputs and achieve the goals set out in the Evergreen Revolution, a precise roadmap is needed for India. First, there should be increased funding for research and development focused on finding new local microbial strains, innovative products, and cost-effective production methods for Indian farming. Stronger collaboration between ICAR, agricultural universities, KVKs, and private companies is also needed to ensure scientific advancements can be applied in the fields.

Secondly, more efforts are required to educate farmers. Alarmingly, Indian farmers are still not aware of bio-inputs, despite the growing number of registered products. Therefore, training sessions, field visits, outreach through mobile apps and government channels, and verifying claims are essential for building trust. Farmer Producer Organisations (FPOs) that were launched on 29 February 2020 can effectively gather demand, help small farmers access quality bio-inputs, and encourage adoption.

Policies should provide appreciation in the form of rewards to farmers who adapt to eco-friendly approaches; these incentives should align with the international objectives on climate, food, and soil health

Government Initiatives

Next, a bio-economy strategy would facilitate upgrades in policy and regulation. Bio-Pesticides should be registered under CIBRC for commercialization. This is improving the passage of biosafety regulations without trimming on quality and safety. Furthermore, support from government schemes such as the National Mission for Sustainable Agriculture (NMSA), Rashtriya Krishi Vikas Yojana (RKVY), Mission Organic Value Chain Development for North-Eastern Region (MOVCDNER), etc., will continue to be important. Crucially, policies should provide appreciation in the form of rewards to farmers who adapt to eco-friendly approaches; these incentives should align with the international objectives on climate, food, and soil health.

Infrastructure and Quality Standards Needed

Strict control of the infrastructure and quality control around the market for bio-inputs is crucial. While the Indian biopesticide industry is certainly a tiny fraction compared to chemical pesticides, it is growing, expecting to reach 130.4 million U.S. dollars in 2029. Consequently, creating and maintaining effective supply chains and tackling the issue of counterfeit products, alongside creating storage and distribution infrastructure, will be necessary to enable expansion.

Bio-Solutions Drive Sustainable Agriculture Forward

The Evergreen Revolution is more than an agricultural transformation—it is a national mission integrating food security, climate action, and ecological restoration. Bio-inputs offer a holistic, science-backed pathway to safer food, lower emissions, and resilient farming communities. Transitioning to residue-free farming through biological interventions will not only meet the growing demand for safe food at home but will also boost exports and consumer safety. India's continuous advancements in biocontrol and biostimulant technologies provides an opportunity to build a brighter Future through adopting Evergreen Revolution.

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NEW AGE BIOLOGICALS WILL HELP GROW MORE FOOD FOR ALL SUSTAINABLY

Biologicals boost sustainability in farming by supporting regenerative agriculture, leading to more productive and profitable farms

Events unfolding across the agriculture landscape worldwide confirm that there is no single silver bullet that can tackle the multifarious biotic, abiotic and climate change challenges that the crops are facing. At the same time, we are also witnessing food consumption as well as the demand for more diverse and complex diets steadily rising. It is well recognized that to meet global needs, food production must increase by 70 per cent by 2050.

The Green Revolution in India was indeed a landmark achievement, but it also gave rise to a range of second-generation challenges. Combined with a growing population and increasing per capita income, these challenges have placed immense pressure on the agricultural sector.

Estimates suggest that India's population will exceed 1.6 billion before stabilizing around 2030. Consequently, food demand is projected to reach 400 million tonnes (MT) by 2050. To meet this growing need for food, feed, and fodder, while also maintaining a GDP growth rate of 8–9 per cent to reduce poverty and drive economic progress, India's agricultural sector requires to more than ever demonstrate and maintain resilience.

Extreme weather, scarce water sources, pest resistance and newer diseases threaten crop losses and clearly require a multipronged strategy to make sure that crops are cultivated in a viable and sustainable way.

Our growers are fast adopting regenerative agriculture practices and leveraging digital apps as well as precision agriculture tools to nurture and restore soil health, tackle climate uncertainties, conserve water resources and protect biodiversity while increasing productivity. Biologicals will offer farmers one more tool in their arsenal which will enhance productivity and profitability in a sustainable manner.

Core Of Our Best Practices

Biologicals play a significant part, supporting farmers to use natural resources, like water, and farm resources, like inputs, more efficiently. As they increase yields, biologicals prevent the

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expansion of farmland. Biologicals are applied precisely, and have a low impact on the surrounding environment, protecting biodiversity. They contribute to healthier soils, improving soil's ability to retain scarce water and to capture and store more carbon, reducing the greenhouse gas emissions from agriculture.

Biologicals is at the core of our best practices aimed at enhancing soil health, boosting crop resilience, and supporting chemical inputs. Food chain and public pressure towards low or no residues in food needs more farming options. Reduced solution efficacy due to resistance and pest shifts demands new modes of action. Biologicals and seed treatment are at the forefront of this shift. By innovating boldly, we can transform the future of food security for all.

Why are biologicals important for sustainable farming? Natural organisms like bacteria, fungi, and plant extracts help in nutrient cycling, pest and disease management, and improving plant growth. Three key constituents of biologicals - biocontrols, biostimulants and nutrient use efficiency – provide farmers with more choices to manage resistance, improve soil health, reduce residue in foods, and address climate change impacts.

Innovative And Effective Biological Portfolio

Backed by best-in-class internal R&D and strengthened by external partnerships and the acquisition of market-leading biostimulants company Valagro, Syngenta Biologicals offer growers an innovative and effective biological portfolio focused on their needs such as how to manage pests and diseases, address abiotic stresses and enhance soil health and nutrient use efficiency.

It is worth mentioning here that the soil health solutions enable growers to harvest good quality produce even in low fertile soil and saline condition. Syngenta Biologicals has world class biological solutions for stress management that helps to get superior quality produce under stressful environmental conditions. Our distinctive R&D approach has enabled us to establish an industry-leading biological pipeline including breakthrough solutions across key product categories.

Moreover, the use of biologicals, whose market size is poised to grow to $ 20 billion by 2030, has minimal environmental footprint, promotes biodiversity, and supports long-term soil fertility, making farming systems more resilient to climate change. By integrating biologicals into agricultural practices, farmers can achieve higher productivity while preserving the ecological balance, ensuring food security for future generations.

At the same time, biologicals complement and enhance conventional crop protection solutions, providing growers with more flexibility. This allows them to better address consumer, societal and regulatory demands for more sustainable farming methods. As an important element in ICM or Integrated Crop Management, biologicals help growers manage plant health and pest problems effectively and safely.

Promising Advancements

The advancements in biologicals are promising. Biological Pest Control methods like pheromones, beneficial insects, and microbiome-based solutions are optimizing chemical use. Biodegradable Polymer Coatings for slow-release fertilizers will reduce environmental impact. Bio-Enriched Soil Technologies (BEST) enriches soil with cactus mucilage, allowing soil systems to hold water and increasing bioavailability of crops. There are also advancements in Synthetic Biology which incorporate engineering with research, resulting in components like enzymes, genetic circuits, and cells that support sustainable farming and global food security.

We need to recognize that biologicals are innovative agricultural technologies that harness the power of nature to protect and improve crops. Biologicals boost sustainability in farming by supporting regenerative agriculture, leading to more productive and profitable farms. They are complementary to traditional inputs. These products may include organisms, natural molecules, plant extracts, and other bio-based materials. With a journey that spans more than a century, Syngenta is in the forefront of serving the farmers world-wide, with its basket of innovative products in not only crop protection domain but also in seeds, vegetables and broad-acre crops, seed care and now biologicals.

(Views expressed are personal)

BIO-CONTROL AND BIO-STIMULANTS
THE FUTURE OF SUSTAINABLE FARMING

The agricultural sector is witnessing a transformative shift driven by the urgency to enhance productivity sustainably while minimizing environmental impacts. Central to this transformation are bio-control agents and bio-stimulants, which promise eco-friendly alternatives to conventional chemical fertilizers and pesticides. Recent technological advances in these sectors are catalysing a paradigm shift towards a sustainable bio-agriculture model, integral to the envisioned "Evergreen Revolution" — a sustainable, resilient, and productive agricultural future.

The Evolution of Bio-Control and Bio-Stimulants

Bio-control involves the use of natural predators, pathogens, or competitors to manage pest populations, reducing reliance on chemical pesticides. Bio-stimulants, on the other hand, are substances or microorganisms that enhance plant growth, nutrient uptake, and stress tolerance without direct nutritional input. Both sectors are crucial for sustainable agriculture, promoting soil health, biodiversity, and environmental safety.

Technological Advances in Bio-Control

Genomic and Molecular Techniques: Advances in genomics have vastly improved our understanding of pest and pathogen biology. Genome sequencing of biocontrol agents like Bacillus thuringiensis, Trichoderma, and Pseudomonas spp. has enabled the development of more targeted and efficient strains. Molecular tools like CRISPR-Cas9 facilitate the engineering of biocontrol microbes with enhanced efficacy, stability, and host specificity, reducing non-target effects.

Bioprocessing and Fermentation Technologies: Innovations in fermentation technology have optimized the mass production of biocontrol agents, making them more cost-effective and scalable. Continuous fermentation, bioreactor design improvements, and formulation technologies enhance the shelf life and field stability of microbial biocontrol products.

Nanotechnology: Nanotechnology is emerging as a game-changer, enabling

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the delivery of biocontrol agents with enhanced penetration, targeted action, and controlled release. Nanoparticles can improve the stability and bioavailability of microbial agents, making biocontrol strategies more effective and durable.

Precision Agriculture: Integration of biocontrol agents with precision agriculture tools—drones, remote sensing, GIS mapping—allows targeted application, reducing wastage and environmental impact. These technological integrations optimize timing, dosage, and placement, increasing efficacy.

Technological Advances in Bio-Stimulants

Microbial Consortia and Synthetic Biology: Development of microbial consortia—combining multiple beneficial microorganisms—has improved plant growth promotion and stress resilience. Synthetic biology techniques enable the design of customized microbial strains with enhanced functionalities such as nutrient solubilization, hormone production, and pathogen suppression.

Omics Technologies: Metabolomics, proteomics, and transcriptomics provide insights into plant-microbe interactions and mechanisms of action of bio-stimulants. This knowledge facilitates the formulation of tailored bio-stimulant products for specific crops and environmental conditions.

Formulation Innovations: Advanced formulations—such as encapsulation, biocomposites, and bio-coatings—improve the stability, shelf life, and delivery efficiency of bio-stimulants. Nano-formulations further enhance penetration and sustained release, ensuring prolonged plant benefits.

Data-Driven Design: Big data analytics and machine learning models analyze vast datasets on crop responses, environmental factors, and microbial interactions to predict optimal bio-stimulant formulations and application regimes, boosting efficiency and adoption.

Integrating Technologies for a Sustainable Bio-Agri Model

The convergence of these technological advances fosters a holistic, sustainable bio-agriculture framework — the backbone of the Evergreen Revolution. This model emphasizes several key pillars:

Enhanced Productivity: By leveraging bio-stimulants to improve nutrient use efficiency and stress resilience, farmers can achieve higher yields with reduced chemical inputs.

Environmental Sustainability: Bio-control and bio-stimulants reduce chemical runoff, soil degradation, and biodiversity loss, contributing to healthier ecosystems.

Farmer-Centric Approaches: Precision application and data-driven recommendations empower farmers to adopt sustainable practices efficiently.

Climate Resilience: Microbial solutions bolster plant resilience against pests, diseases, drought, and salinity, vital under changing climate scenarios.

The roadmap for a sustainable bio-agri future hinges on robust R&D, supportive policies, farmer engagement, and integrated technology adoption

Roadmap for a Sustainable Bio-Agri Model

To realize the full potential of bio-control and bio-stimulants, a strategic roadmap is essential:

Research & Development: Invest in cutting-edge research utilizing genomics, synthetic biology, and omics technologies to develop highly targeted, efficient, and environmentally safe biocontrol and bio-stimulant products.

Regulatory Framework & Standards: Establish clear, science-based regulatory pathways that facilitate innovation while ensuring safety and efficacy. Standardization of product quality and efficacy testing is vital for farmer confidence.

Capacity Building & Awareness: Educate farmers, extension workers, and industry stakeholders on the benefits and usage of bio-based inputs through training programs, demonstration plots, and digital platforms.

Public-Private Partnerships: Foster collaborations among government bodies, research institutions, startups, and agribusiness companies to accelerate innovation, scale-up, and distribution.

Technology Adoption & Digital Platforms: Develop user-friendly digital tools—mobile apps, decision support systems—that leverage AI and big data to guide farmers in optimal use of bio-inputs.

Sustainable Supply Chains: Build resilient and eco-friendly supply chains for bio-products, ensuring quality, affordability, and accessibility, especially for smallholder farmers.

Policy Incentives: Implement policies that incentivize the adoption of bio-control and bio-stimulants, including subsidies, certification schemes, and market linkages.

Challenges and Future Outlook

Technological advances in bio-control and bio-stimulants are pivotal to shaping a sustainable bio-agri model under the evergreen revolution. Through genomics, nanotechnology, precision agriculture, and data analytics, these bio-based solutions are becoming more effective, accessible, and environmentally friendly. The roadmap for a sustainable bio-agri future hinges on robust R&D, supportive policies, farmer engagement, and integrated technology adoption. Embracing this holistic approach will enable agriculture to meet the growing global food demand sustainably, ensuring ecological balance, climate resilience, and economic viability for future generations.



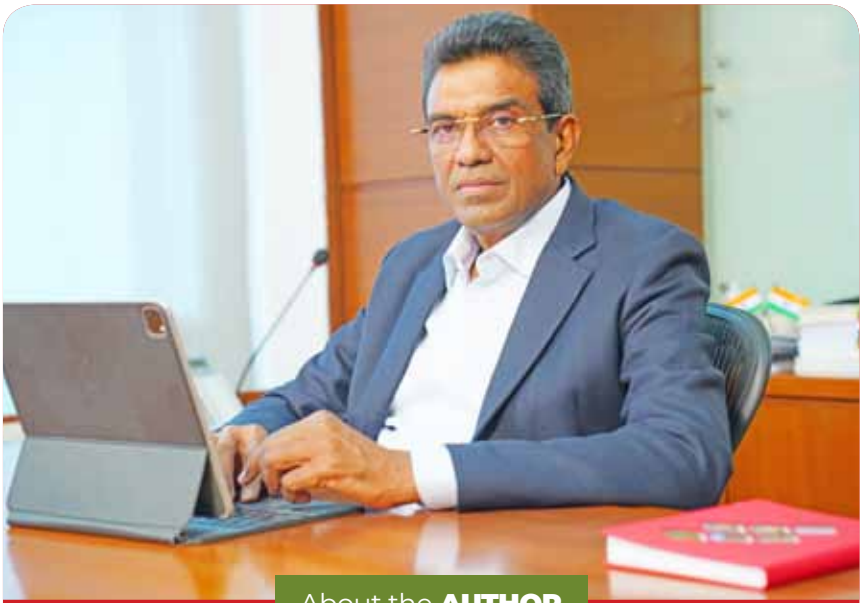
TRANSFORMING FARMER COMMUNICATION

From Paper Leaflets to QR Codes

In a progressive move toward enhancing agricultural productivity and sustainability, the Department of Agriculture and Farmers Welfare (DAFW), Government of India, has introduced a new directive emphasizing the dissemination of crop cultivation information through QR codes on seed packets. This shift from traditional printed leaflets to digital information systems marks a significant evolution in supporting farmers with real-time, accessible, and sustainable agricultural practices.

Importance of Information on Packages of Practices (PoPs)

Before seeds are released to farmers, they undergo rigorous trials across various agro-ecological zones to ensure their suitability for specific regions. Providing farmers with accurate and comprehensive information about the recommended Package of Practices (PoPs) is critical. It ensures the scientific adoption of agronomic techniques, enhancing crop yields, promoting sustainable resource use, improving farmer knowledge and skills, and ultimately contributing to food



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security and economic growth .

To this end, DAFW had earlier mandated that Bt Cotton seed packets must be accompanied by printed leaflets in local languages, Hindi, and English. These leaflets provided detailed guidance on cultivation practices to ensure better productivity, fibre quality, and income.

Challenges with Paper-Based Leaflets

Despite their usefulness, printed leaflets present significant challenges:

- Accessibility Issues: Farmers often lose or discard the leaflets during sowing activities, losing valuable guidance for crucial stages like irrigation and fertilization.
- Operational Difficulties: Printing multilingual leaflets tailored to different states is cumbersome, especially within the limited window between seed packing and market dispatch.
- Readability Concerns: In smaller seed packets, the leaflet fonts must be extremely small, making them difficult to read for farmers.
- Environmental Impact: Mass printing contributes to deforestation and resource waste, conflicting with India's sustainable development goals (SDGs).
- Cost Inefficiency: The process adds operational costs without guaranteeing consistent farmer engagement with the material .

The Advent of QR Code-Based Information Systems

Recognizing these challenges, the DAFW revised its guidelines through a Circular dated 11th April 2025, mandating the inclusion of QR codes on every seed packet. These QR codes would link farmers to crop-specific PoPs in vernacular languages while still requiring printed leaflets for packets above 100 grams.

The transition to QR codes aligns with India's rapid digitalization journey:

- Widespread Mobile Penetration: 93.3% of households now have at least one mobile device, and 95.08% of villages have 3G/4G coverage.

The industry collectively emphasized that, had the advisory been issued a few months earlier, it would have allowed adequate lead time for seamless integration

- Instant Access to Information: Scanning a QR code provides farmers real-time access to critical agricultural information.
- Sustainability: Reduces the dependency on paper, promoting eco-friendly practices.
- Product Authentication: Advanced QR systems also enable farmers to verify the genuineness of seeds, thus combating the menace of counterfeit seeds in the market.

Implementation Process

The QR code system is designed for ease of use:

- Scan: The farmer scans the QR code on the seed packet.
- Location-Based Content: Upon granting location access, the system presents the PoP information in the regional language along with Hindi and English.
- Verify Authenticity: Farmers can verify the seed's authenticity by entering their name and mobile number, receiving confirmation via WhatsApp.
- Access Multimedia: The system offers additional resources, including detailed literature and product videos via simple links .

Industry Response and Challenges

While the seed industry fully supports the government's intention, the sudden timing of the advisory has created operational challenges. Most of the packing material that is utilized during kharif gets designed and printed by the end of March every year. Almost 20-25% of the seed for many early planted crops is already packed and much of it is dispatched to the markets in the first week of April. Some companies already print QR codes on packets while others attach printed copies with each seed packet. Smaller companies who do not have mechanization in their plants prefer to drop printed handbills in the secondary packaging and also ensure display of handouts on points of purchase.

Each company, in some or the other form, ensures the right package of practice required to grow their seed reaches their customer. Some of the more advanced companies are one step ahead and leveraging modern mobile technology for product authentication as well as to deliver product information and existing user farmers experiences to the new customers.

The industry collectively emphasized that, had the advisory been issued a few months earlier, it would have allowed adequate lead time for seamless integration. There is now an appeal for temporary flexibility, allowing companies to choose either QR codes or printed leaflets for the 2025 kharif season.

In the long run, the department should encourage the QR code method to ensure dissemination of information in an environmentally sustainable manner. This will not only save a lot of expenditure on printing paper and capital expenditure to create infrastructure for insertion of paper leaflets in packing material but also pave the way for implementation of product authentication along with track and trace on similar lines as the fertilizer industry thereby reducing the risk of spurious seeds entering the ecosystem.

The National Seed Association of India (NSAI) and other seed organizations have committed to act as catalysts for driving this transition within an agreed timeframe, ensuring that the farming community benefits from both innovation and reliable crop information.

GREEN TO EVERGREEN

THE NEED FOR A BIO-BASED PARADIGM

The future of agriculture lies not just in growing more, but in growing better. As the world grapples with the twin crises of climate change and environmental degradation, there is a pressing need to transition from input-intensive farming to ecologically sustainable models. Central to this shift are biocontrol agents and biostimulants, backed by cutting-edge technologies that enhance their precision, efficacy, and integration into modern farming systems.

The Green Revolution introduced high-yielding varieties and chemical inputs that boosted production but also led to soil degradation, reduced biodiversity, and chemical resistance in pests. According to FAO, about 33% of global soils are degraded, and over 500 species of pests have developed pesticide resistance. The Evergreen Revolution seeks to increase yields without ecological harm, and biocontrol and biostimulants are central to this mission.

Biocontrol: Innovations Shaping Sustainable Plant Protection

Unlike chemical pesticides, biocontrol agents (BCAs) are ecosystem-compatible, target-specific, and do not leave harmful residues. Recent technological advances have transformed biocontrol from a niche practice to a mainstream solution

1. Genomics and Metabolomics

High-throughput sequencing technologies have enabled the identification of novel microbial strains from rhizosphere and phyllosphere ecosystems. Genome mining allows for the detection of genes responsible for producing antifungal, antibacterial, or insecticidal metabolites, streamlining the selection of elite biocontrol strains.

2. Synthetic Biology and CRISPR

CRISPR/Cas-based genome editing and synthetic biology approaches are now used to enhance the efficacy of BCAs by improving their stability, sporulation rate, and bioactive compound production. For example, engineered Bacillus subtilis strains with overexpressed biosynthetic gene clusters have shown increased pathogen suppression.

3. Smart Formulations

Another key shift is the move from single-strain solutions to microbial consortia, which mimic natural communities and offer broader spectrum activity. AI and machine learning are playing a pivotal role in designing these consortia, predicting interactions, and optimizing formulations for different crops and agro-climatic zones.

Biostimulants: Boosting Plant Physiology Naturally

Biostimulants stimulate plant physiological processes, improving nutrient use, stress tolerance, and overall vigor. This sector is evolving rapidly due to multidisciplinary innovations:

1. Multi-Omics Validation

Proteomics, transcriptomics, and metabolomics are enabling deep insights into plant-biostimulant interactions. Such studies help identify molecular markers for improved root architecture, chlorophyll synthesis, or hormonal regulation induced by biostimulants like seaweed extracts or humic acids.

2. Targeted Formulations

Precision agriculture tools and field data analytics allow the tailoring of biostimulant formulations for specific crops and agro-climatic conditions. AI-enabled platforms can now correlate soil health metrics with crop responsiveness to biostimulants.

About the **AUTHOR**

Dr. Prashant Khare is a renowned scientist with a wealth of experience and knowledge in all domains of life sciences. He currently serves as the Director of R&D at Xenesis, India.

3. Novel Sources and Fermentation

New bioactives are being derived from extremophiles, fungi, and plant endophytes. Advanced fermentation technologies—such as submerged fermentation (SmF) and solid-state fermentation (SSF)—enhance the yield and purity of biostimulant compounds like amino acids, polyamines, or volatile organic compounds (VOCs).

Integration with Digital Agriculture Tools

The synergy between biological inputs and digital agriculture is reshaping the operational landscape. Technologies like drone spraying, remote sensing, and IoT-based soil sensors facilitate precision application of biostimulants and biocontrol agents, minimizing waste and maximizing impact. Decision-support systems (DSS) guided by real-time environmental and crop health data ensure optimal timing and dosage

Despite the promise, regulatory challenges remain a bottleneck for market expansion. Standardized frameworks for efficacy testing, microbial strain authentication, and safety profiling are critical. Global moves like the EU Biological PPP (Plant Protection Product) framework and India's draft bio-stimulant regulation under the FCO amendment are positive steps.

A decentralized production and distribution model involving FPOs (Farmer Producer Organizations) and cooperatives can ensure the timely availability of bio inputs at affordable prices

Roadmap for a Sustainable Bio-Agriculture Model

To realize the vision of an evergreen revolution, a coordinated strategy must be adopted:

1. Research and Innovation Hubs

Public-private partnerships should focus on developing region-specific biocontrol and biostimulant products using local microbial diversity and indigenous knowledge.

2. Farmer-Centric Demonstrations

Massive field demonstrations and model plots showcasing biological input efficacy are essential to build farmer confidence and break chemical dependency.

3. Smart Agriculture and Digital Technologies

Integrating digital technologies, such as IoT sensors, data analytics, and precision agriculture tools, can optimize the use of biocontrol agents and biostimulants. For example, sensors can monitor soil conditions and pest pressure, allowing for targeted application of biocontrol agents and biostimulants only when and where they are needed

4. Financial and Policy Incentives

Subsidies, tax incentives, and inclusion in crop insurance schemes can encourage the adoption of bio-agriculture inputs. Mandatory soil health card-based prescription systems can also guide responsible use.

5. Strengthening Supply Chains

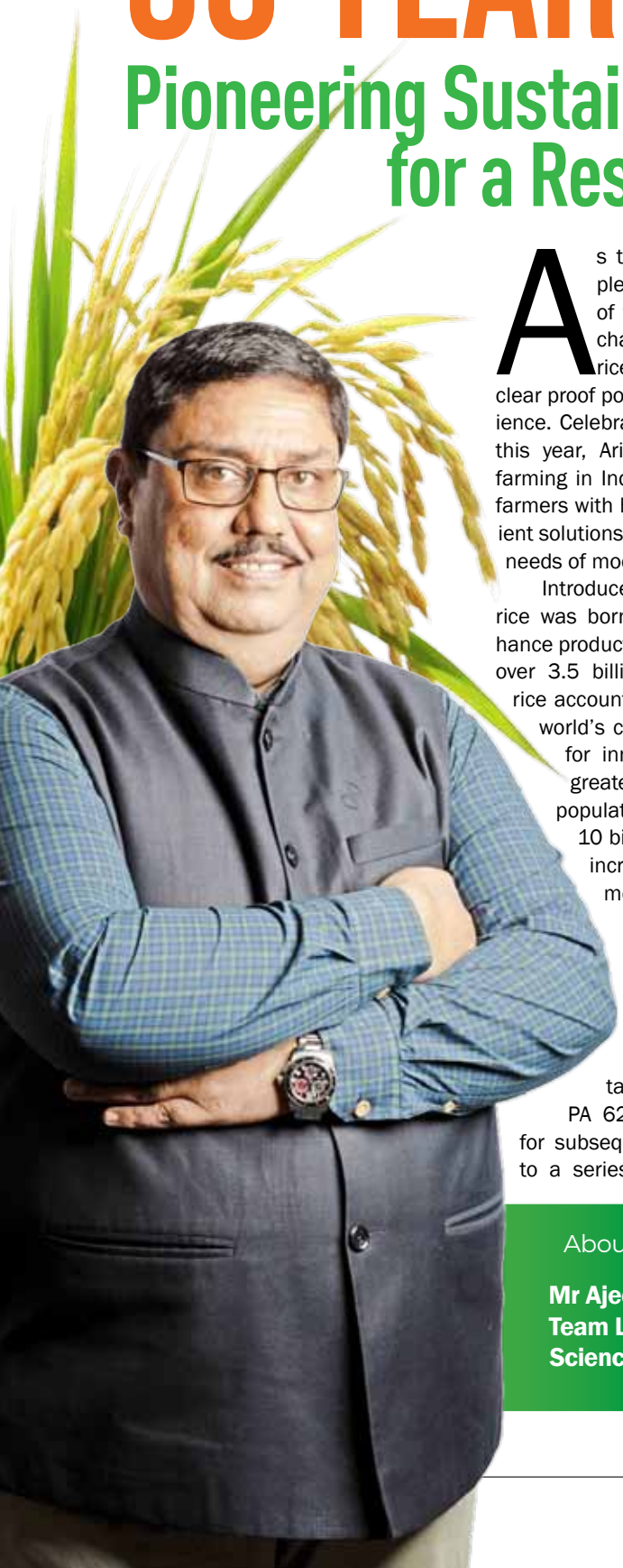
A decentralized production and distribution model involving FPOs (Farmer Producer Organizations) and cooperatives can ensure the timely availability of bio-inputs at affordable prices.

Technological advances in the biocontrol and biostimulant sectors are no longer just eco-friendly alternatives to chemical inputs but are paving the way for a more sustainable and resilient agricultural future. Building on that, our goal at INERA is to push the boundaries of biological innovation by creating adaptive, high-efficacy solutions based on one of the world's largest microbial datasets. The mission is further accelerated by the work of XENESIS, which powers INERA with cutting-edge research in synthetic biology, microbial engineering, and biomolecule discovery.

By harnessing the power of nature and integrating cutting-edge technologies, we can create a bio-agri model that enhances crop productivity, reduces environmental impacts, and ensures food security for generations to come. Future research should be committed to drive such innovations from lab to land—empowering farmers, restoring ecosystems, and paving the way for a climate-resilient and inclusive global food system.

30 YEARS OF ARIZE

Pioneering Sustainable Rice Cultivation for a Resilient Future



As the world we live in grapples with the dual challenges of food security and climate change, Bayer's Arize hybrid rice brand stands out as a clear proof point of innovation and resilience. Celebrating its 30th anniversary this year, Arize has transformed rice farming in India and beyond, providing farmers with high-yielding, climate-resilient solutions that address the pressing needs of modern agriculture.

Introduced in 1995, Arize hybrid rice was born out of the need to enhance productivity in a sector that feeds over 3.5 billion people globally. With rice accounting for nearly 20% of the world's calorie intake, the urgency for innovation has never been greater. By 2050, the global population is projected to reach 10 billion, necessitating a 25% increase in rice production to meet rising demand.

Bayer recognized these challenges early on and set out to develop hybrids that could thrive in diverse climatic conditions while ensuring sustainability. The first hybrid, PA 6201, laid the groundwork for subsequent innovations, leading to a series of successful launches that have significantly improved yield potential and farm profitability.

About the **AUTHOR**

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Milestones in innovation

The journey of Arize has been marked by several key milestones that underscore Bayer's commitment to agricultural innovation:

- **2002:** The launch of PA 6444, which quickly became a favorite among farmers for its exceptional yield
- **2008:** Launch of 1st BLB Tolerant hybrid "Arize Dhani"
- **2011:** Launched Arize 6444 Gold – a top-selling hybrid in the industry
- **2013:** Establishment of the Chandipa Rice Breeding Station, reinforcing Bayer's dedication to research and development.
- **2017:** Introduction of the first dual trait hybrid, AZ8433 DT, designed to combat both bacterial leaf blight and brown planthopper, showcasing Bayer's focus on developing resilient varieties.
- **2020:** Arize hybrids enriched the lives of 3 million smallholder farmers, a testament to their widespread acceptance and impact.

Addressing key challenges in rice production

Despite its significance, rice production faces formidable challenges. Water scarcity is a pressing concern, with rice cultivation consuming 3,000-4,500 liters of water per kilogram of rice produced. Additionally, labor shortages due to urban migration have escalated production costs, making traditional farming methods increasingly unsustainable.

Moreover, rice farming contributes

significantly to greenhouse gas emissions, accounting for 12% of global methane emissions. As climate change intensifies, farmers are experiencing more extreme weather patterns, with projections indicating a potential decline in global rice yields by 10-35% by 2050.

Bayer's commitment to sustainability

In response to these challenges, Bayer has implemented a multi-faceted approach to create a sustainable rice ecosystem. The company is advancing food security through its portfolio of innovative hybrid rice varieties while also focusing on sustainable agricultural practices.

Advancing food security

Bayer's Arize hybrids deliver up to 25% higher yields compared to traditional varieties, enabling shorter crop cycles and facilitating multi-cropping practices. This not only maximizes land use but also enhances farmers' income potential.

Promoting Direct Seeded Rice (DSR)

Bayer is also championing the Direct Seeded Rice (DSR) method, which reduces water usage by 30-40% and cuts greenhouse gas emissions by up to 45%. The Bayer Direct Acres program has already expanded to 14,000 hectares, with ambitious targets to scale further.

Bayer has implemented a multi-faceted approach to create a sustainable rice ecosystem

Bayer understands that sustainable transformation requires collaboration. The company has partnered with organizations such as the Indian Council of Agricultural Research (ICAR) and the International Rice Research Institute (IRRI) to enhance research, training, and policy advocacy. These partnerships enable Bayer to leverage expertise and resources, ensuring that the benefits of Arize hybrids reach more farmers.

The introduction of Bayer's non-GM, herbicide-tolerant rice hybrids by 2030 is further expected to improve weed management and labor efficiency in rice cultivation.

Additionally, Bayer's initiatives, such as The Good Rice Alliance (TGRA), promote climate-smart rice farming practices, engaging over 10,000 farmers and reducing carbon emissions significantly.

As Bayer celebrates 30 years of Arize, the company remains committed to innovation and sustainability. The focus on developing climate-resilient rice varieties, enhancing farmer training, and implementing sustainable practices positions Bayer as a leader in the agricultural sector.

The integration of technology, digital advisory tools, and mechanization support through initiatives like the FarmRise platform and the "Ask Deena" chatbot empowers farmers with real-time agronomic advice, optimizing their practices and improving yields.

Bayer's holistic approach to building a sustainable rice ecosystem ensures that the transition to climate-smart farming is scientifically sound, farmer-friendly, and scalable. As the world faces increasing pressures from climate change and population growth, the legacy of Arize hybrid rice will continue to play a crucial role in securing food for future generations.

By marrying innovation with sustainability, Bayer is not only transforming rice cultivation but also paving the way for a resilient agricultural future.

THIS IS OUR GREEN GOLD

EMPOWERING FARMERS AND ADVANCING SUSTAINABLE ETHANOL WITH BAMBOO

For its 2024-25 budget, the Maharashtra government announced Atal Bamboo Samruddhi Yojna. The decision was taken after deliberation for over a year that led to the constitution of a task force. This was a very significant move. Bamboo farming can serve as a powerful tool for fighting climate change and enhancing the livelihoods of rural communities in the state. Bamboo plantations can provide significant economic benefits to rural areas by stimulating rural economic growth in Maharashtra.

The Atal Bamboo Samruddhi Yojna is a comprehensive initiative aimed at addressing the escalating problem of rising temperatures linked to climate change. This was the first time such a thoroughly researched program was incorporated into the state's annual financial plan.

The scheme targets the plantation of bamboo across 10,000 hectares statewide, with a specific allocation of 1.2 hectares in the tribal district of Nandurbar. Participating farmers will receive financial support totaling Rs 7 lakh over a period of three years to assist with both planting and maintaining bamboo crops. Funding for the scheme is structured so that 90% comes from the central government and 10% from the state government, while in tribal regions, the central government will cover the entire cost.

The Burning Era

The period of rising temperatures has ended. We have now entered the "burning era." If this is not swiftly addressed, it will have severe consequences for humanity. To meet these urgent goals, it is essential to reduce reliance on diesel, petrol, and coal. Simultaneously, we must launch large-scale tree plantation drives.

Bamboo stands out as both an environmentally and economically practical crop. It matures rapidly, reaching full growth within three years of planting, unlike Peepal or Banyan trees, which typically require a decade or more to become fully developed. This swift growth enables more frequent harvesting and a steady income for farmers, making bamboo a reliable source of livelihood and job creation in rural areas.

Environmentally, bamboo is highly

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efficient at carbon sequestration, absorbing more carbon dioxide than many other plants-studies indicate mature bamboo can capture up to 12–15 tons of carbon dioxide per hectare annually. It also releases substantial amounts of oxygen, contributing to improved air quality. Planting bamboo near roadsides or residential areas can lower ambient temperatures, thanks to its dense foliage and transpiration, which helps cool the surrounding environment. Bamboo's rapid growth, high carbon absorption, and ability to thrive with minimal inputs make it a powerful tool for climate mitigation and rural economic development.

Role In Stimulating The Rural Economy

Bamboo cultivation and its related industries can greatly benefit diverse regions across India. Bamboo's versatile applications can stimulate the rural economy. The uses of bamboo are wide ranging, from growing vegetables and producing pickles, jams, and rice, to manufacturing ethanol, textiles, and cutlery. The micro, small, and medium enterprises (MSMEs) are showing good interest in the bamboo furniture sector. This shall offer substantial employment opportunities and shall also foster skilled craftsmanship in rural communities.

This aligns with the state's broader vision outlined in the Maharashtra Budget 2025-26, which includes Rs 4,300 crore investment in bamboo plantation projects to boost bamboo-based industries. The new Industrial Policy targets attracting investments worth Rs 40 lakh crore and generating 50 lakh jobs over five years, with bamboo industries playing a vital role in this economic expansion. The focus on bamboo shall boost environmental sustainability. It shall also promote rural development by creating a robust value chain involving farmers, MSMEs, and large-scale processing units.

Bamboo offers a promising alternative to traditional resources like coal and iron, which are major contributors to environmental degradation. Reducing reliance on thermal power plants is crucial, and bamboo can serve as a superior biomass alternative due to its higher calorific value compared to conventional biomass sources.

Bamboo thrives nationwide, adaptable from Kashmir to Kanyakumari, with minimal upkeep and low water demands. Bamboo processing generates 200 liters per ton, offering superior efficiency

India is planning to establish 300 bamboo-based refineries to harness this potential, building on the example of the first such refinery already operational in Assam. Bamboo biomass is being explored as a green reductant in iron production, offering a low-carbon-emission substitute that can significantly reduce greenhouse gas emissions in steel-making processes. Bamboo's rapid growth, high biomass density, and excellent fuel properties make it highly suitable for bioenergy production, with carbon sequestration benefits comparable to tree plantations but with faster annual regeneration.

Addressing Environmental Challenges

Technologies like bamboo charcoal kilns provide eco-friendly, cost-effective alternatives to traditional fuels, supporting rural energy needs while mitigating deforestation. The shift to bamboo-based bioenergy not only addresses environmental challenges but also supports rural economies by creating new jobs and sustainable livelihoods. This comprehensive approach aligns with global efforts to transition from fossil fuels to renewable biomass energy, positioning bamboo as a key resource in securing a greener future.

The integration of bamboo plantation under MGNREGA ensures assured wages for rural workers while creating a foundation for large-scale bamboo-based industries that bridge rural and urban economies.

Bamboo thrives nationwide, adaptable from Kashmir to Kanyakumari, with minimal upkeep and low water demands. While sugarcane consumes two crore liters per hectare, bamboo requires merely 20 liters, flourishing in 3.5-foot soil with drip irrigation. Ethanol production yields 80 liters per sugarcane ton, but bamboo processing generates 200 liters per ton, offering superior efficiency.

Bio-Agriculture

AN OPTION FOR SUSTAINABLE AGRICULTURE IN INDIA

India, the most populous country in the world, with a population of 1.46 billion (17.5% of the world population) occupying only 2.5% of the total landmass, reports that its agricultural productivity has outpaced the population growth with high productivity for crops that feed the masses such as rice, wheat, and pulses. Indian agriculture is at its peak, according to a recent news report (Indian Express, 2025) based on the sales of tractors, fertilizers, and seeds.

India has the youngest population globally with a median age of 29 years, compared to most other developed or developing countries and with demonstrated technological prowess, especially in computers, artificial intelligence, and biomedicine at the global level has an added advantage. From the agbiotech point of view, India just unveiled the world's first genome-edited (non-GMO) rice variety which promises 25-30% increased yield. India is well-positioned to be a major player to feed the world. Despite its laudable achievements, India must continue to enhance its agricultural productivity and try even harder to protect what it produces.

Indian Agriculture – The Strengths, The Challenges

As an agrarian economy, agriculture has been the foundation of Indian civilization, culture, and livelihood for over 6,000 years since agriculture started. Though the growth of non-farm sectors has gained considerable momentum during the past few decades, agriculture continues to be the lifeblood of the economy. With approximately 50% of its total land area under agriculture, India has the second largest arable land after the USA. Indian agriculture is, however, very diverse, not organized, and severely subject to the vagaries of the environment. Agriculture remains the backbone of its society, employing at least 60% of the population currently.

India has one of the largest agricultural R&D systems with its nationally organized Indian Council of Agricultural Research (ICAR), its state affiliates, and the state/regional academic or governmental agencies in terms of personnel, expenditure, and number of institutions; yet the extension systems and adoption of technologies remain a challenge.

About the **AUTHOR**

Dr Prem Warrior is a senior executive currently advising multiple agbiotech ventures globally. He served in leadership roles in the bioag sector at Valagro, Valent and at the Bill & Melinda Gates Foundation

While there has been remarkable growth in domestic food production, the progress in post-harvest management remained subdued, resulting in supply chain inefficiencies and substantial loss and wastage of food. The agriculture sector faces significant challenges, such as water scarcity, fluctuating weather patterns, pest/disease incidences, post-harvest losses, and most importantly fragmented landholdings or predominantly smallholder farming in India.

Novel Biological Solutions: A Sustainable Alternative

Biologicals, including biofertilizers, bio stimulants, and biopesticides offer a sustainable alternative to traditional chemical inputs. These products leverage the power of nature and natural processes to improve plant and soil health, boost crop resilience, manage plant diseases and pests, improve crop productivity, and enhance quality. Multiple nature-based alternatives to chemical pesticides popular in developed regions of the world have already found application in Indian agriculture. Microbial interventions such as Plant Growth Promoting Rhizobacteria (PGPR), novel mycorrhizal strains/formulations, phosphate solubilizers, nutrient mobilizers, nitrogen fixers, biofertilizers, and biostimulants are already being used to promote plant growth. Bioprotectants or biological control agents have found their applications for decades and complement or even re-

place chemical pesticides though not as effectively yet.

Innovations continue to improve efficacy, and applicability in global agriculture through increased use of active ingredients based on microbial, plant and seaweed extracts. Though the sources may not have increased, there has been an increase in the discovery and identification of biomolecules with novel modes of action, and the use of combinations or consortia of microbial (e.g. BioConsortia, Inc. USA) as also improvement in formulations and delivery of actives.

Technologies such as RNAi based pesticides (Greenlight Biosciences, USA) coupled with delivery mechanisms such as the one developed by AgroSpheres®, offer game-changing, targeted tools to protect the active ingredients thus offering novel weapons against pests and disease including those resistant to chemical pesticides. In addition to the continued growth of microbials, newer technologies in the bio-sector such as novel pheromones for insect control, peptides, and RNAi for control of pests and diseases continue to be developed and adapted globally for various markets.

Cutting Edge Technologies

While Indian companies such as Biostadt India has pioneered the development and use of biostimulant products, the multinationals such as Bayer, BASF, FMC, and Syngenta continue to expand their offerings through their existing crop protection channels. Seed dressing of biostimulant and biopesticidal actives is one of the most efficient methods of delivering optimal doses at the critical stages of plant growth and often provides the best return on investment.

A similar approach tailored for combining with pre- or post-plant fertilizer treatment is Phytacoat®, with active ingredients that trigger plant nutrient uptake and stress response, offered by Sea6energy®, a Bangalore-based entrepreneurial company that has pioneered novel mechanized sea-farming in the Asian region. This unique offering of "value-added fertilizer" composition should go a long way to enhance the uptake and optimization of fertilizer use.

The future of bio-agriculture in India is bright; in addition to the political will, what the agritech sector needs is continued yet disciplined innovation in technology specifically targeted at smallholder farmers

Multiple examples of innovative companies based in India include Bioprime®, KanBiosys®, offering multiple biological products such as phosphate solubilizing bacteria, plant and algae-based crop protectants. StringBio®, a brilliant example of innovation, developed novel technology for conversion of methane into agricultural products (CleanRise® for rice production), and other feed and food ingredients addressing the consumer needs while achieving the sustainability goal of reducing methane emissions.

Reduce Environmental Contamination, Promote Biodiversity

Compared to chemicals, these biological products reduce environmental contamination and promote biodiversity. Despite the obvious advantages they offer, biologicals have faced significant barriers to adoption. Due to their innate nature and unique modes of action, the biologicals are slow(er) to act and need to be applied carefully; often, these need education and training at the farm level.

There can also be challenges to production formulation and management at the distribution level since many of these living entities may need controlled storage and strong quality control measures, all of which need improvement. The biggest challenge that India faces is the weak regulatory environment which allows contamination, even intentional in many instances, with harmful chemicals thus undermining the overall trust in the use of biologicals and affecting the credibility of the industry itself.

Today's India is dynamic, embracing novel disruptive technologies; modernization of Indian agriculture is in progress and the ever-changing global technology landscape and India's unique leadership position in driving this change is an opportunity for agriculture. The timing is right for Indian agriculture to engage in "precision agriculture" led by innovative companies such as Absolute, Cropin, and a host of other entrepreneurs, to overcome the challenges in the scaling and adoption of the bio-agriculture tools.

The use of artificial intelligence (AI) to help the farmer make informed decisions relating to water/nutrient management, crop protection, and harvest/ postharvest management is also under development. In the context of predominantly rain-dependent farming, irrigation technologies such as micro-irrigation, fertigation, and sensor-based farm management systems developed by private sector players and promoted by various governmental policy initiatives can help. Removing barriers to innovation is essential, but it needs to be consciously monitored and promoted through governmental policies with investment models to promote innovation and incentivize successful startups on their path to profitability.

The future of bio-agriculture in India is bright; in addition to the political will, what the agritech sector needs is continued yet disciplined innovation in technology specifically targeted at smallholder farmers in India along with novel, scientifically credible biological products that are compatible with existing agricultural practices including chemistries, strong enforceable regulatory policies and extension support from the governmental agencies, and public/private sector funding initiatives to ensure that India can cater to the needs of its farmers and feed its population sustainably.

TRACEABILITY OF SEED

Idea needs to be fully baked

The Government of India plans to roll out a nationwide seed traceability system called SATHI (Seed Authentication, Traceability and Holistic Inventory), likely from 2026 onwards. This centralized digital platform aims to enhance the traceability and quality assurance of seeds across the country.

SATHI will allow farmers to trace the origin of seeds, from production fields to processing, distribution, and final purchase, ensuring authenticity and reducing the risk of poor-quality or spurious seeds. The system will build a complete digital ecosystem, including mobile-based field inspections, registration of seed growers, and real-time mapping of seed inventory across locations, providing the government with a comprehensive view of seed availability.

Another key feature under consideration is the mandatory certification of all seeds by the Seed Certification Agency, integrated into the traceability system to further ensure quality standards.

India's responsible seed industry supports this move, as it helps distinguish credible suppliers from those offering substandard or counterfeit products.

The Issue

India's agriculture sector faces a persistent challenge of spurious and low-quality agri inputs, especially seeds and crop protection products. Estimates suggest that such products may account for 10% to 30% of what farmers purchase. Varying levels of farmer awareness and differing market maturity across regions further complicate the issue, making some areas more vulnerable to fake inputs.

The seed industry is fragmented, with over 400 companies, many of which may not follow ethical or legal standards. While some have long-term credibility, others don't. Some also operate informally or as fly-by-night players, often flooding the market with poor-quality seeds during times of shortage, when prices surge and regulatory oversight weakens. In such cases, state governments struggle to identify the source of non-performing seeds.

The problem is compounded by the fact that most seeds sold in India are "truthfully labelled" and not officially registered, unlike certified seeds. This leaves a major gap in the government's ability to track production, stock, and availability.

As India aims to expand its agricultural exports, traceability is becoming critical. International markets increasingly demand transparency about the origin of food, and that traceability must begin at the seed stage.

To address these challenges, the Government of India is exploring seed traceability as a systemic solution. Whether it will be a comprehensive fix remains to be seen—but building this capability is fast becoming a necessity, not a choice.

Points of debate

Seed Licensing system

All seed sellers in India are required to obtain a license from the respective state governments, which means a database of registered companies, distributors, and dealers already exists. Yet, unethical and illegal seed sellers continue to operate freely. Why are state governments unable to act?

Consider the example of unauthorized GM cotton seeds. An estimated 70 lakh packets, around 15% of the market, are sold annually, mostly in western states. Valued at over Rs 600 crore, these illegal seeds are sold without accountability. If a farmer faces a problem, there's no one to hold responsible. What's shocking is that this happens openly, despite the states' regulatory authority. It's hard to believe that governments in 3–4 major states lack the power or capacity to stop this. A seed traceability system could help. By tracking each seed packet from production to sale, it would expose unauthorized supply chains, enable enforcement, and ensure that only approved, accountable products reach farmers. Traceability may finally give governments the tool to act where they've long been ineffective.

About the **AUTHOR**

Mr Ram Kaundinya is Adviser to Federation of Seed Industry of India.

Informal Seed System

The formal seed market is about Rs 30,000 cr (estimate) but it is estimated that almost an equal value of informal market exists in the country. Most of the informal market is through farm saved seed which does not cause problems in terms of supply of low quality and spurious seeds. But there are seed aggregators at village levels who undertake production through seed growers, aggregate the production and sell them to farmers mostly without any branding and definitely without licenses. This supply system will continue with no check and no quality control. How will the traceability system bring them to book?

Certification of seed.

If certification is made mandatory, do states have the necessary manpower and infrastructure? Hybrid seed is produced in a few states but supplied nationwide, while OP seed production is more decentralized. Timely quality checks, packing, and transport, especially for Kharif sowing, are critical. Between March and June, the seed industry operates at full capacity, and an overstretched certification system could lead to dangerous delays.

Is it wise to risk disrupting 90% of a well-functioning system to fix a 10% problem? Truthful labelling has supported industry growth and met rising demand for quality seeds over the past three decades. The seed industry deserves recognition for its vital role in India's agricultural progress

Confidentiality of data

A lot of the seed production data is confidential to the company. Seed production capability is one of the competitive advantages of a seed company. As such seed production is becoming tougher day by day due to vagaries of weather. In such a situation what a company is producing with which seed grower is a confidential data. How will the system protect this data being stolen by competitors?

Seed production system

India's seed production system has functioned reasonably well but lacks professional structure. Seed growers are typically registered only with individual companies and rarely have formal contracts. Even when contracts exist, enforcement is weak due to political interference. Many companies rely on local middlemen or 'organizers,' who control production but often operate with low ethical and legal standards.

This unorganized setup leads to issues like parent line pilferage, IP loss, and poor compliance, especially among smaller players. While some responsible companies maintain strict controls, many do not. Professionalizing this system would benefit both the industry and the country. But how will a traceability system navigate such a fragmented and informal network?

Distribution system

Agri inputs, particularly seeds are sold in the remotest corners of the country in a timely fashion. Especially during monsoon time it is a humongous task. The seed suppliers, both public and private, have done an outstanding job of storage and logistics to achieve this. Most of the retailers are not qualified persons and are pure traders. In some remote parts of the country, especially in the East, seed is sold in loose from gunny bags! Some of the retailers become conduits for selling low quality and spurious seed at high prices to gullible farmers. This system, although needs seed license from state government, is a highly vulnerable link in the chain.

Seed Quality Control System

Seed inspectors of the state governments pick up samples of seed from retail counters and send them to seed testing laboratories of the government for checking. This is supposed to be random sampling but it is seen that most of the times they pick up samples of good companies, leaving those supplying low quality seeds outside. The seed testing laboratories infrastructure, manpower and processes need upgradation. This leads to a situation it is mostly the good and responsible companies are harassed through the system.

Way Forward

The seed traceability system is a good measure and it must be implemented. However certain measures are required to be taken.

Mandatory Scanning at Sale: Full traceability is only possible if seed packs are scanned at the point of sale and linked to the purchasing farmer. Though challenging during peak season, this must be made mandatory.

Digital Registration of Seed Growers and Contracts:

a) Each seed grower and their geotagged land must be registered on a national platform with a unique ID.

b) All seed production should be based on registered contracts between growers and companies, with each seed lot assigned a unique ID. This enables tracking through the entire supply chain. Data must be secure but accessible to the government for real-time insights into seed availability and market trends.

Additionally, nurseries, especially in horticulture, must be registered, and each sapling tray should carry a traceable code scanned at sale.

Farmer Notification System: A centralized system should notify farmers via SMS when they purchase genuine seed, post-scan at retail.

Recognition of Reputed Companies: A national recognition program like Beej Ratna, as proposed by FSII, should reward long-term, research-focused seed companies. The One Nation – One License system will also help in differentiating quality players and improving business ease.

End-to-End Scanning: Scanning of seed codes must be enforced at every level—from factory to distributor to retailer—to ensure transparency, traceability, and tax compliance.

Passage of the New Seed Bill: The long-pending Seed Bill must be passed to mandate variety registration and instill discipline in the sector.

The intention of the government is good. However unless the total plan is thought through thoroughly and a food proof system is developed it will not serve the purpose. This is an opportunity to digitize the total seed supply system which will give long term benefits for responsible seed companies, the country and most importantly the farmers.

(Views expressed are personal)

BUILDING SUSTAINABILITY, RESILIENCE, EQUITY

The Indian agricultural sector is at a critical crossroads, facing the twin challenges of increasing productivity to feed a growing population and ensuring environmental sustainability. With the negative impacts of chemical-intensive farming becoming more evident—such as soil degradation, water pollution, loss of biodiversity, and health concerns—there is a growing shift towards sustainable agriculture. In this context, bio-control agents and bio-stimulants are emerging as key enablers of a green transition in Indian agriculture.

The Rise of Bio-Control and Bio-Stimulants

Bio-control agents are natural organisms (like bacteria, fungi, viruses, and insects) used to control pests, weeds, and diseases. They offer a safer and more targeted alternative to chemical pesticides, with minimal environmental side effects. Bio-stimulants, on the other hand, are substances or microorganisms applied to plants to enhance nutrient efficiency, abiotic stress tolerance, and crop quality—without being nutrients themselves.

In recent years, both sectors have witnessed significant technological innovation:

1. Genomic and Microbiome Research: Advances in genomics have allowed scientists to better understand plant-microbe interactions. This has led to the development of next-generation bio-stimulants that are crop- and region-specific, offering precision in application.
2. Nano-Formulations: Nanotechnology is being used to improve the efficacy and delivery of bio-agents. Nano-encapsulation allows for the slow release of active ingredients, better targeting of pests, and reduced degradation in the environment.
3. Artificial Intelligence (AI) and IoT: AI-driven platforms are helping farmers monitor crop health and pest outbreaks in real-time. Integrated with Internet of Things (IoT) sensors, these technologies ensure timely application of bio-products, increasing efficiency and reducing waste.
4. CRISPR and Genetic Engineering: Genome editing tools like CRISPR are being explored to engineer beneficial microbes for higher effectiveness against crop diseases or for enhanced nutrient uptake in plants.
5. Bioreactors and Fermentation Technology: Innovations in industrial biotechnology are allowing for the large-scale, cost-effective production of high-quality bio-control agents and bio-stimulants, making them more accessible to farmers.
6. Blockchain and Traceability: The use of blockchain for monitoring the production and application of bio-agents is enhancing transparency and ensuring quality assurance, which is especially important for export markets.

About the **AUTHOR**

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Benefits for Indian Agriculture

The benefits of bio-control and bio-stimulants are particularly relevant for India:

- Environmental Protection: These products are biodegradable and non-toxic, preserving soil health and water quality.
- Farmer Income Security: Reduction in input costs, combined with improved yields and quality, translates to better returns for farmers.
- Climate Resilience: Bio-stimulants improve plant resilience to drought, salinity, and temperature extremes—key as climate change disrupts weather patterns.
- Export Potential: Organic and residue-free produce is in high demand globally. Adoption of biologicals helps Indian produce meet stringent export standards.
- Sustainable Intensification: India needs to grow more food on the same or even shrinking land base. Biological inputs help intensify agriculture sustainably.

Challenges to Scale

Despite their promise, several barriers hinder the large-scale adoption of bio-inputs in India:

- Lack of Awareness: Many small and marginal farmers are unfamiliar with the benefits and use of biologicals.
- Inconsistent Quality: An unregulated market has led to variable product quality, which can erode trust among users.
- Limited R&D: While startups are innovating, public sector investment in bio-agri R&D remains modest.
- Distribution Gaps: Last-mile delivery of bio-products is hampered by cold chain requirements and lack of rural infrastructure.
- Policy Gaps: Absence of a comprehensive national bio-agriculture policy leaves the sector fragmented and without strategic direction.

A Roadmap for a Sustainable Bio-Agri Model

To realize the full potential of bio-agriculture and usher in an Evergreen Revolution—one that combines productivity with sustainability—India needs a holistic and coordinated approach:

A well-structured roadmap that brings together science, policy, infrastructure, and community participation is key to achieving an Evergreen Revolution

1. Policy and Regulatory Reforms:
   - Establish a national policy on bio-agriculture with clear standards and guidelines.
   - Accelerate registration of bio-products through simplified and science-based protocols.
   - Provide subsidies and incentives for verified bio-inputs, similar to chemical fertilizers.
2. Research and Innovation Ecosystem:
   - Strengthen collaboration between ICAR, universities, startups, and private firms.
   - Increase investment in public research for region-specific bio-agents and delivery systems.
   - Encourage open data platforms for sharing research findings and efficacy results.
3. Capacity Building and Farmer Awareness:
   - Launch nation-wide extension programs focused on biologicals through Krishi Vigyan Kendras (KVKs).
   - Train rural youth as “bio-agri entrepreneurs” to promote localized production and supply of bio-inputs.
4. Robust Infrastructure and Supply Chain:
   - Invest in rural cold storage and logistic networks for bio-products.
   - Promote decentralized bio-input production units, especially in tribal and semi-arid areas.
5. Public-Private Partnerships (PPP):
   - Encourage PPPs for field trials, quality assurance, and market linkages.
   - Develop crop-specific bio-input packages with pricing support through digital platforms.
6. Digital Enablement:
   - Integrate bio-input advisories in government apps like AgriStack.
   - Leverage remote sensing and AI to create predictive pest and disease maps for targeted interventions.

India stands at the threshold of a transformative phase in agriculture. While the Green Revolution of the past brought food security, it came at an ecological cost. The path forward must be guided by the principles of sustainability, resilience, and equity. The integration of advanced bio-control and bio-stimulant technologies into mainstream farming can serve as the backbone of this transformation.

BIOSTIMULANTS

KEY TO SUSTAINABLE BIO-AGRI MODEL FOR EVERGREEN EVOLUTION

Robust physiology and metabolic processes in any living being is highly pivotal to convert potential energy to kinetic energy, plant life is no exception.

Knowing that 65% Approx yield losses are counted on the account of Abiotic Stresses in plants, whereas 35% loss with Biotic stresses. Unfortunate part is even 75 to 85%+ cost of cultivation is towards managing Biotic stresses whereas hardly 15to 25%% to Abiotic stress management. This depicts that we only talk about internal body mechanism of fighting with external factors might be biotic or abiotic but on belief side, we don't rely on it.

Feputed scientist Magdolf & Weil say, "Pathogens are not real cause of plant disease, they only attack to unsuitable varieties or improperly grown crops. Their true role in Agriculture is that of censor for pointing out the crops which are imperfectly nourished. Disease resistance seems to be the natural reward of healthy and well-nourished protoplasm."

Rightly said that farmers don't grow crops, they only create an environment where crops can grow.

Empowering Action

Biostimulants, as the name suggests, stimulate the biology of soil and plants in ways that empower them-and, in turn, empower us. By definition, biostimulants are substances or microorganisms applied to plants or soil to enhance natural processes, ultimately improving plant growth, nutrient uptake, stress tolerance, and crop quality. They work independently of their nutrient content, stimulating processes such as root development and nutrient efficiency. These factors enable soil and plant biology to function optimally.

About the **AUTHOR**

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Biostimulants can be categorized as microbial, non-microbial, or waste-derived. Microbial biostimulants include beneficial bacteria and fungi, while non-microbial biostimulants encompass humic substances, protein hydrolysates, and algal extracts. Waste-derived biostimulants are a recent addition to this category, incorporating substances like chitin derivatives and plant endophytes.

Microbial Biostimulants

These involve beneficial microorganisms such as plant growth-promoting rhizobacteria (PGPRs), mycorrhizal fungi, and other beneficial bacteria.

Non-Microbial Biostimulants

This category includes:

- Humic Substances: Humic acids and fulvic acids, derived from the decomposition of organic matter, improve nutrient uptake and stress tolerance.
- Protein Hydrolysates: Derived from animal or vegetal sources, these contain amino acids and peptides.
- Algal Extracts: Extracts from seaweed and other algae contain various bioactive compounds that can improve plant growth and stress resilience.
- Inorganic Compounds: Substances such as silicates and phosphates can enhance nutrient efficiency and tolerance to abiotic stresses.
- Other Biopolymers: Examples include chitosan, derived from chitin, which can act as a biostimulant and protect plants from various stresses.

Waste-Derived Biostimulants

This emerging category includes biostimulants derived from agricultural waste or industrial byproducts, such as plant endophytes.

Biostimulants are claimed to offer several benefits: preserving the health of natural resources, managing biotic and abiotic stresses, and reducing the cost of production without adversely impacting crop yields. Biostimulants do not supply nutrients to plants or directly control pests and diseases; instead, they stimulate natural processes within plants and soil microbiota. By triggering molecular adjustments and physiological, biochemical, and anatomical modifications within plants, biostimulants enhance the plants' capacity to withstand both biotic and abiotic stresses.

Biostimulants directly and indirectly support soil and plant life mechanisms, augmenting their proper functioning and playing a vital role in sustainable and healthy bio-agriculture

Biostimulants increase crop growth and yield by modifying the physiological and biochemical responses of plants, such as increasing root and shoot development, improving organic carbon content, stimulating cation exchange, enhancing nitrogen metabolism, promoting microbial activities, boosting antioxidant activities, and increasing water-holding capacity.

Biostimulants like seaweed extract contain plant hormones such as auxin, cytokinin, kinetin, zeatin, gibberellins, glycine betaine, and choline chloride. These hormones enhance crop growth and tolerance during environmental stress by accelerating the mobilization of photosynthates from leaves to stems and increasing photosynthetic pigments. Biostimulants can modify the primary and secondary metabolism of plants, leading to the synthesis and accumulation of micronutrients and antioxidant molecules. They significantly increase photosynthesis, maintain relative water content, reduce electrolyte leakage and lipid peroxidation, increase proline content, reduce reactive oxygen species (ROS), and improve the activity of antioxidant enzymes, all of which help plants cope with the harmful effects of abiotic stress.

Multiple Benefits

Additionally, biostimulants promote the production of heat shock proteins, phenolics, amino and organic acids, dehydrins, and ACC-deaminase, all of which are vital in imparting resistance to abiotic stresses. The functional mechanisms of biostimulants and their impact on various indicators of sustainability suggest that biostimulants improve crop yield and product quality, reduce the external application of fertilizers, enhance water-use efficiency, and improve crops' ability to tolerate abiotic stresses.

Given the growing negative externalities of intensive agriculture on natural resources, human health, and the environment-as well as predictions of increasingly severe climate conditions-there is a need to focus more on basic and applied research on biostimulants. Combining modern technologies with traditional farming practices is one of the most efficient pathways to improving the sustainability of agriculture.

Biostimulants play a crucial role in sustainable agriculture by enhancing natural plant processes to improve crop yield, quality, and stress tolerance, while also reducing reliance on synthetic fertilizers and pesticides. They achieve this by boosting nutrient uptake efficiency, promoting a healthier soil microbiome, and improving plant resilience to environmental challenges. Biostimulants directly and indirectly support soil and plant life mechanisms, augmenting their proper functioning and playing a vital role in sustainable and healthy bio-agriculture, thereby creating efficient pathways to improve the sustainability of agriculture.

MITIGATING ENVIRONMENTAL & CLIMATE CHANGE CONCERNS VIA BIOLOGICAL AGRI-INPUTS: GOI SUPPORTIVE INITIATIVES

The Government of India is actively promoting organic farming through several schemes, notably the Paramparagat Krishi Vikas Yojana (PKVY), a component of the Pradhan Mantri Rashtriya Krishi Vikas Yojana (PM-RKVY), which includes implementation in Kerala. PKVY offers comprehensive support to organic farmers, from production and processing to certification and marketing, using a cluster-based approach. The scheme prioritizes small and marginal farmers, helping them form organic clusters and build supply chains.

INITIATIVES TO ENCOURAGE ADOPTION OF BIO-AGRI INPUTS

Promotion and Registration of Biopesticides

The Government encourages the use of biopesticides, biocontrol agents, and botanical formulations as alternatives to chemical pesticides. The Central Integrated Pest Management Centres (CIPMCs), Krishi Vigyan Kendras (KVKs), and State Agriculture Departments conduct training programs to promote these alternatives and ensure the safe use of chemical pesticides only as a last resort. The Central Insecticide Board & Registration Committee (CIB&RC) registers pesticides only after verifying their efficacy and safety.

About the **AUTHOR**

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Quality Control and Research on Biopesticides

Insecticide Inspectors, appointed under the Insecticides Act, 1968, regularly sample products from manufacturing units and sales points to check for substandard or counterfeit products. The Indian Council of Agricultural Research (ICAR) and State Agriculture Universities (SAUs) develop and test biopesticides through coordinated research projects. Numerous biocontrol laboratories and production units have been established nationwide to support the development, production, and dissemination of biopesticides, aiming to improve efficacy and reduce production costs.

Encouragement of Biofertilizer Use

The Government also promotes biofertilizer use through PKVY and the Mission Organic Value Chain Development for North Eastern Region (MOVCDNER). Under PKVY, farmers receive financial assistance of Rs. 15,000 per hectare over three years for organic inputs, including biofertilizers. MOVCDNER provides Rs. 32,500 per hectare over three years for similar purposes in the North Eastern Region.

Organic Farming Schemes Across States

PKVY is implemented in all States and Union Territories (except the North Eastern States, which are covered by MOVCDNER). Both schemes provide

end-to-end support, including production, processing, certification, marketing, post-harvest management, training, and capacity building. Under PKVY, assistance of Rs. 31,500 per hectare over three years is provided, with Rs. 15,000 directly transferred to farmers for organic inputs. MOVCDNER offers Rs. 46,500 per hectare over three years, including Rs. 32,500 for organic inputs and Rs. 15,000 as direct benefit transfer.

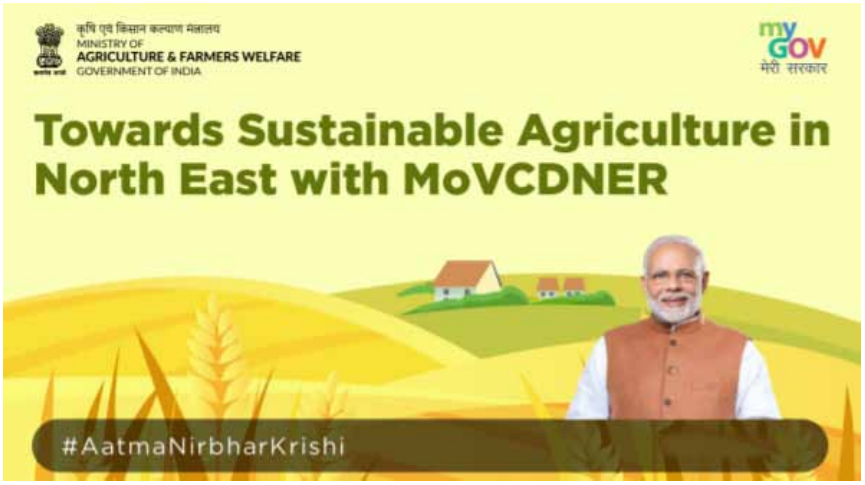
Support from Ministry of Jal Shakti and Market Development Assistance

The Ministry of Jal Shakti, through the Swachh Bharat Mission (Grameen) Phase II, supports biogas plants and the production of Liquid Fermented Organic Manure (LFOM) and Fermented Organic Manure (FOM) under the GOBARdhan initiative. Market Development Assistance (MDA) of Rs. 1,500 per metric tonne is provided for FOM, LFOM, and Phosphate Rich Organic Manure (PROM) to encourage their production and use. Of 81 Compressed Bio Gas (CBG) plants, 43 are registered on the iFMS portal, with Rs. 16.01 crore disbursed to eligible beneficiaries.

PM-PRANAM and Support for Start-ups in Agriculture

The "PM Programme for Restoration, Awareness, Nourishment and Amelioration of Mother Earth (PM-PRANAM)" incentivizes States and Union Territories to promote alternative and balanced use of fertilizers. Under this programme, 50% of subsidy savings are granted to States for promoting organic and natural farming.

Start-ups in agriculture are supported through the "Innovation and Agri-Entrepreneurship Development" programme under RKVY-DPR. This initiative provides financial and incubation support to start-ups in agriculture and allied sectors, with five Knowledge Partners and 24 Agribusiness Incubators implementing the programme. Financial support includes Rs. 5 lakh at the idea/pre-seed stage and Rs. 25 lakh at the seed stage. To date, 1,749 start-ups have received Rs. 124.96 crore in grants.



Start-ups are supported under the "Innovation and Agri-Entrepreneurship Development" programme of Rashtriya Krishi Vikas Yojana through financial assistance and incubation to promote innovation and agri-entrepreneurship

Certification Systems to Promote Organic Produce

To help farmers obtain better prices for certified organic produce, two certification systems are promoted: the Participatory Guarantee Certification System (PGS India) and the third-party National Programme for Organic Production (NPOP). These systems are implemented under PKVY and MOVCDNER, covering a total organic area of 59.74 lakh hectares.

National Mission on Natural Farming (NMNF)

Approved in November 2024 with an outlay of Rs. 2,481 crore, the National Mission on Natural Farming (NMNF) aims to form 15,000 natural farming clusters over 7.5 lakh hectares. The scheme will create 10,000 Bio-input Resource Centres (BRCs) and establish 2,060 Model Demonstration Farms for hands-on training. Trained farmers practicing natural farming can receive an output-based incentive of Rs.4,000 per acre per year for up to two years for adopting natural farming practices and preparing or purchasing natural farming inputs.

Impact and Reach of Organic Farming Schemes

To date, 25.30 lakh farmers have benefitted from PKVY, and 2.19 lakh farmers from MOVCDNER, reflecting the significant reach and impact of these initiatives.

Soil Health & Fertility Initiatives

The Government is also implementing the Soil Health & Fertility scheme, having issued 24.77 crore Soil Health Cards nationwide, including 1.77 crore in Karnataka. The Soil and Land Use Survey of India (SLUSI) has completed detailed soil surveys over 36.86 lakh hectares in Karnataka using remote sensing and GIS. The scheme provides detailed soil characterization and classification, along with interpretative groupings for land capability, irrigation suitability, and hydrologic soil grouping, supporting better soil health and land use planning.

Disclaimer: The above views are excerpts from the Q&As response in the Lok Sabha. Compiled and shared in the interest of broader stakeholder outreach.

ROTO PUMPS

A Journey of Innovation, Legacy, and Sustainable Growth

Roto Pumps, established in 1968, stands as India's pioneering manufacturer of progressive cavity pumps with a rich legacy spanning over five decades. Renowned for its cutting-edge technology, robust manufacturing infrastructure, and strong global presence across more than 50 countries, the company delivers efficient and reliable pumping solutions to diverse industries including wastewater, renewable energy, and mining. With continuous R&D investments and a commitment to sustainability-evident in its expanding solar power initiatives-Roto Pumps is recognized as a top 10 global player in positive displacement pumps.

A Third-Generation Entrepreneur's Perspective

I am proud to be part of the third generation leading Roto Pumps, a company deeply rooted in innovation and indigenous engineering. Our story began with my grandfather, Mr. Ram Ratan Gupta, whose visionary approach transformed the landscape of pumping technology in India. During the 1950s and 60s, he was a user of progressive cavity pumps in his coal mines in Kanpur. At that time, these pumps were imported from the UK, specifically from Monopumps, to dewater the mines. When the mines were nationalized, he saw an opportunity to develop this technology locally. Despite not being a formally qualified engineer, his technical insight and determination led to the invention of a unique manufacturing process for the intricate profiled rotor-the heart of the progressive cavity pump. This breakthrough gave birth to Roto Pumps over 55 years ago and established a legacy of "in-house" product development and manufacturing technology.

About the **AUTHOR**

Mr Anurag Gupta is Joint Managing Director, Roto Pumps

Building a Legacy of Indigenous Innovation

My grandfather's philosophy of self-reliance and continuous investment in research and development shaped the company's DNA. From the outset, Roto Pumps focused on creating quality products at competitive costs, avoiding reliance on imports. This approach enabled us to pioneer the manufacture of progressive cavity pumps in India, a technology that became synonymous

with our brand. Over the decades, we expanded our product range and manufacturing capabilities, establishing state-of-the-art facilities in Noida and Greater Noida, and setting up ultra-modern R&D centres.

Diversifying into Solar-Powered Pumping Solutions

Our core expertise lies in positive displacement pumps, widely used in municipal and industrial wastewater treatment. As environmental sustainability became a global priority, we recognized the potential of applying our helical rotor pump technology to the renewable energy sector, specifically solar-powered pumping systems. This diversification aligns with our commitment to providing sustainable and efficient solutions.

Solar pumping technology has two main types: progressive cavity (helical rotor) pumps and centrifugal pumps. We specialize in the former, which is ideal for small to medium capacities and challenging pumping conditions. By integrating our pumps with solar drives, motors, and control systems, we have developed robust solar pumping solutions under the brand "Roto Rudra," named after the Vedic solar deity, symbolizing our blend of tradition and innovation.

Our dedicated solar manufacturing plant in Noida is nearing completion and will serve as the hub for these solutions, enabling us to meet growing demand domestically and internationally6.

Expanding Global Footprint and Ambitious Growth Plans

Today, Roto Pumps operates globally with subsidiaries in the US, South Africa, the UK, Germany, Dubai, Malaysia, and Australia. About two-thirds of our business comes from exports, reflecting our strong international presence. Our main competition comes from a major German company, but we continue to lead in India and are steadily expanding our global footprint.

Our solar business is managed through our wholly-owned subsidiary, Roto Energy Systems Ltd., with Roto Rudra as the flagship brand. Launched just last year, this segment is a key driver of our growth strategy. As we approach our 60th anniversary, our goal is to become a $100 million company, with a target of Rs100 crores in solar segment revenue within the next 4-5 years.

As we embrace new technologies and markets, we remain dedicated to delivering solutions that meet the world's pressing needs for water and energy

Addressing Water Scarcity with Technology

One of the most rewarding aspects of our solar pumping solutions is their ability to address critical challenges such as water scarcity and limited electricity availability. Solar pumps are ideal for remote and rural areas where traditional power infrastructure is lacking. They can extract water from deep underground, providing reliable irrigation for agriculture and clean water for livestock and domestic use.

Our systems support government initiatives like the Jal Jeevan Mission, which aims to provide potable water to every rural household. By enabling access to clean water in thousands of villages, our technology contributes directly to improving quality of life and promoting sustainable development.

Sustaining Excellence Through Generations

As a third-generation leader, I look forward to the possibility of the fourth generation joining the business in due course. They are currently pursuing their studies, but I am confident they will bring fresh perspectives and global insights when the time comes.

Our commitment to innovation remains unwavering. We continue to invest heavily in R&D to enhance our pump technologies, focusing on reliability, efficiency, and environmental sustainability. Our goal is to maintain Roto Pumps' position as a trusted global leader in positive displacement pumps while expanding our impact in renewable energy and water management.

Power Of Indigenous Innovation and Visionary Leadership

Roto Pumps' journey is a testament to the power of indigenous innovation, visionary leadership, and a steadfast commitment to sustainable growth. From my grandfather's pioneering spirit to our current global ambitions, we have continuously evolved while staying true to our founding principles. As we embrace new technologies and markets, we remain dedicated to delivering solutions that meet the world's pressing needs for water and energy.

THE CLIMATE ACTION STRATEGY TO SAFEGUARD OUR FUTURE

As the world searches for greener solutions in agriculture, India stands at a crossroads. Traditional farming methods, once the backbone of our food security, now face the dual challenge of environmental degradation and diminishing returns. At FarmWatt Innovations Private Limited, we believe that the answers lie not in chemicals or quick fixes, but in nature itself—through bio-based practices that nurture the soil, empower farmers, and protect our air, water, and ecosystems.

Our journey began with a simple but urgent goal: to stop the harmful practice of crop residue burning and convert that waste into wealth. Across paddy-dominant regions of Madhya Pradesh, Uttar Pradesh, and Chhattisgarh, thousands of tonnes of agricultural residue are burned every year, releasing massive amounts of particulate matter and greenhouse gases.

At FarmWatt, we are reversing this damage. This year alone, we aim to collect over 3 lakh metric tonnes of agri-residue through organized baling and transportation systems. This biomass is used to produce Compressed Biogas (CBG)—a clean, renewable fuel that replaces fossil energy in industries and transport.

Our agri-waste collection model is not just a logistical solution; it is a climate action strategy.

Every tonne of crop residue we collect prevents harmful emissions from stubble burning, reducing air pollution and protecting community health. This approach is transforming what was once seen as farm waste into a valuable energy resource. By diverting biomass from open fires and landfills, we are helping India move closer to a circular economy, where nothing is wasted and everything has a role in healing the planet. Our work ensures that rural landscapes become greener, air quality improves, and the planet is preserved for future generations.

Biomass Crop

Our work goes far beyond waste management and clean fuel. We are reimagining rural ecosystems as hubs of green innovation.

One of our key strategies is the promotion of Napier grass—a fast-growing, high-biomass crop that enhances soil structure, supports microbial activity, and sequesters carbon. Cultivated across our farms in Kakinada (Andhra Pradesh) and now expanding into Gujarat, Rajasthan, and Madhya Pradesh, Napier acts as a natural bio-stimulant. It supports long-term soil fertility while also supplying

About the **AUTHOR**

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biomass to CBG plants, completing a sustainable loop.

Another area we are scaling is biochar production—a carbon-rich material made by heating farm waste in controlled conditions. Biochar, when added to soil, improves its ability to retain nutrients and water, supports beneficial soil organisms, and acts as a bio-control agent by suppressing pathogens. It is an ancient method being revived with modern science, offering farmers a powerful tool to regenerate their land while also helping to store carbon in the soil.

Looking ahead, we plan for scaling up biochar production as a key element of our green agricultural model. By returning stable carbon to the soil, biochar plays a direct role in carbon sequestration, supporting climate goals while also improving crop yields and soil resilience.

We are actively exploring the wider environmental potential of biochar and its future applications. As we pursue these avenues, FarmWatt stays firmly committed to innovation that delivers tangible ecological benefits, making our villages cleaner, our farms more resilient, and our industries more climate-conscious.

India needs an evergreen revolution—one that feeds our population without harming the environment. This future must be rooted in bio-agriculture

What truly makes this model inclusive and sustainable is our focus on rural employment and skill-building. Every step of our value chain—from baling crop residue to operating biogas plants—relies on a trained rural workforce. We actively recruit and train local youth as machine operators, logistics staff, and plant technicians, creating meaningful employment in villages where opportunities are limited.

Through these efforts, we are not only generating livelihoods but also nurturing a new generation of green-skilled professionals.

Our teams regularly conduct awareness campaigns in farming communities to explain the benefits of residue management, sustainable cropping, and the long-term value of soil health. These village-level programs, often held during harvesting and sowing seasons, are helping shift the mindset from chemical dependency to natural, bio-based practices. We have seen how a well-informed farmer becomes a change-maker—not only in the field but also in the wider rural community.

The impact is visible. Cleaner air during harvest months. Fields enriched with organic matter. Villagers working in local jobs instead of migrating to cities. And most importantly, a growing awareness that agriculture can be both productive and planet-friendly.

India needs an evergreen revolution—one that feeds our population without harming the environment. This future must be rooted in bio-agriculture: solutions like Napier grass, biochar, and CBG that work with nature, not against it. FarmWatt's roadmap connects science, sustainability, and social inclusion to make this possible. We're proving that the future of farming is not just about higher yields, but about smarter systems, greener villages, and stronger rural economies.

The path to a sustainable bio-agri model is not a distant dream—it is already under construction, one field, one farmer, and one trained rural worker at a time. At FarmWatt, we are proud to walk this path, knowing that every step brings us closer to a future where agriculture heals the Earth instead of harming it.

AGRI-BIOTECH FOR TOMORROW'S FARMS

Across the world, farmers are facing growing pressure to adopt sustainable practices that protect the environment and ensure long-term food security. For ensuring more sustainable and productive agriculture, we must accelerate the use of biological solutions - naturally derived and engineered products that help crops grow stronger, use nutrients more efficiently, and better withstand pests, diseases, and changing weather.

These solutions are not only safer for the environment but also have the potential to reduce reliance on chemical inputs. But many farmers still lack access, awareness, or the support needed to use them effectively. Addressing these barriers through targeted policy interventions, robust extension frameworks, and investment in research and development is essential to unlocking their full potential.

Smarter Formulations

As agriculture faces increasing pressures from climate change, unpredictable weather patterns, and soil health degradation, the demand for more precise and effective solutions has increased.

Advancement in plant science, molecular biology, and high-throughput screening have led to the development of highly specialised biostimulants that go beyond broad-spectrum approaches. These innovative formulations are carefully characterized compounds with known modes of action. They are designed to target specific plant physiological responses, under defined conditions such as drought, salinity, or temperature extremes.

The development of such targeted formulations relies heavily on integrative platforms that combine plant physiology, omics (including metabolomics and transcriptomics), bioinformatics, and rapid screening methods. These platforms allow researchers to identify and validate bioactive compounds capable of triggering specific pathways in plants—such as stress-response signaling, enhanced nutrient uptake, or root architecture development. This new generation of bio stimulants are not only crop- and stage-specific but also complement other agricultural inputs effectively. Farmers now have access to formulations that can support early root establishment, improve flowering and fruit set, enhance shelf life, and build resilience against abiotic stress, all through a scientifically grounded approach.

These advancements are shaping a new generation of bio stimulants, designed to enhance crop resilience and performance in the face of today's agricultural challenges.

Extraction and Multi-Functionality

Advancements in bio stimulant development have centered around extraction techniques and diversified modes of action. The effectiveness of bio-stimulants hinges on how their valuable compounds are extracted from natural sources. The cold extraction process ensures that there are close to 40% more bioactive compounds in the extract. This extraction process is designed to

About the **AUTHOR**

Dr. Renuka Diwan is Co-founder and CEO, BioPrime

get secondary metabolites, which have proven efficacy against the modern-day agricultural challenges like stress management & improvement in quality. Selecting the optimal extraction method is crucial to ensure that these compounds are preserved in their purest and most active form, leading to consistent and noticeable benefits for crops.

Modern agriculture demands bio stimulants that are not only effective but also stable, scalable, and easy to integrate into existing farming systems. Recognizing the evolving needs of modern agriculture, researchers are developing multi-functional bio-stimulants. These advanced products combine various active compounds such as seaweed extracts, botanical extracts, humic acids, to address multiple plant needs, offering a comprehensive approach to plant health and productivity.

The efficacy of bio stimulants, biofertilizers and biocontrol solutions are closely tied to the diversity and adaptability of the microbial strains used. One of the most promising approaches to improving biocontrol outcomes involves building comprehensive microbial libraries sourced from a wide range of agro climatic zones. Such collections offer access to microbial strains with unique, naturally evolved traits, ranging from antagonism against specific pathogens to resilience under drought or salinity stress.

Research efforts must be directed toward creating location-specific solutions suited to India's diverse agro-climatic zones and cropping systems

By studying these microbes in detail, researchers can identify and develop targeted biocontrol agents that are better suited to local cropping systems and environmental conditions.

Microbes and biomolecules extracted from different sources representing various agro climatic zones carry unique traits that help plants deal with local challenges like pests, diseases, drought, and poor soil conditions. Each of these microbial strains or biomolecules has the potential to be developed into novel formulations aimed at solving critical agricultural pain points. These novel offerings have the potential to be used as seed coatings, soil conditioner, abiotic stress tolerance solutions or nutrient use efficiency products.

The Road Ahead

Despite mounting environmental concerns, shifting consumer preferences, and technological advances, many farmers remain hesitant to adopt sustainable agricultural practices. This reluctance often stems from a lack of awareness, perceived risks, and limited access to reliable information, credit, and markets—challenges that are especially acute for smallholder farmers. There is need for integration of ecological principles into the development and dissemination of agricultural technologies.

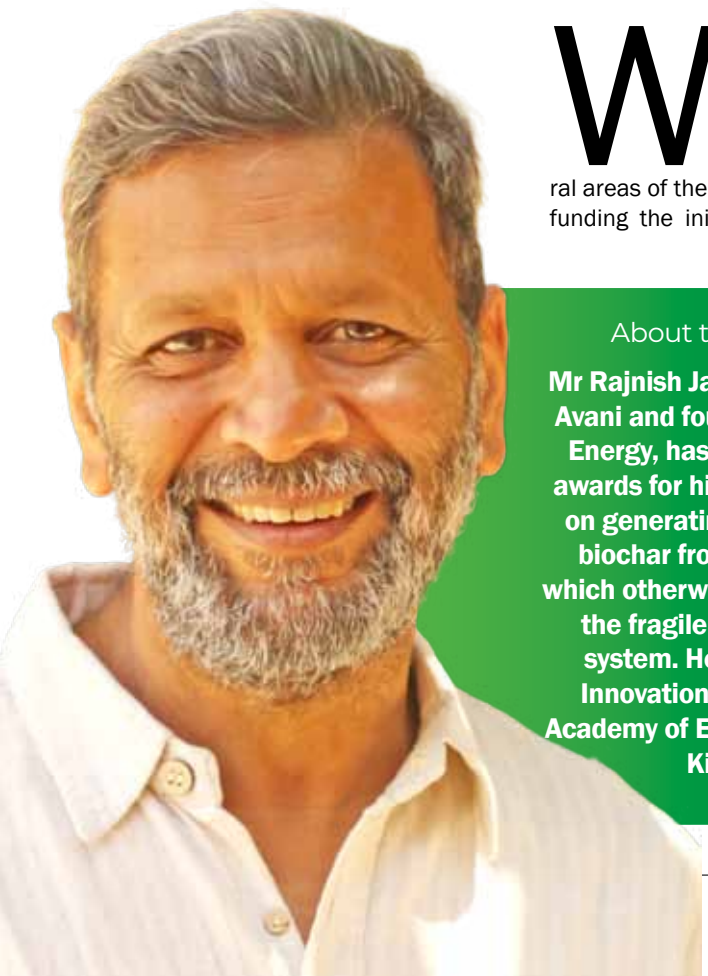
This approach hinges on several vital elements: primarily, embracing Integrated Pest Management (IPM) with a focus on biological solutions; secondly, implementing water harvesting and efficient irrigation; thirdly, diversifying crops and farming methods for greater resilience and healthier soil; and finally, employing strong lab-to-land extension programs to share knowledge and technologies with farmers.

Facilitating collaboration and partnerships with corporates, farmer cooperatives and networks can play a pivotal role in spreading knowledge, enhancing bargaining power, and promoting best practices.

The exciting advancements in biotechnology, including genomics and genetic engineering, hold immense promise for developing the next generation of bio-based agricultural inputs. Increased public-private partnership can fuel the development of these cutting-edge technologies.

Research efforts must be directed toward creating location-specific solutions suited to India's diverse agro-climatic zones and cropping systems. Studying the synergistic effects of various biomolecules could unlock more effective, integrated approaches to pest management and plant health.

Redefining Farmer Prosperity With Biochar



We are developing a business model for the decentralized production of biochar and its use in agriculture in the rural areas of the Uttarakhand Himalayas, funding the initiative through sales of carbon credits generated in the process.

About the **AUTHOR**

Mr Rajnish Jain, a co-founder of Avani and founder of Avani Bio Energy, has received several awards for his pioneering work on generating electricity and biochar from pine needles, which otherwise are threatening the fragile Himalayan ecosystem. He is a Livelihood Innovation Fellow at Royal Academy of Engineering, United Kingdom

Background

Recurrent forest fires, spread by pine leaf litter (commonly known as pine needles), have caused significant loss of biodiversity and ecosystem services, on which rural communities depend. This situation inspired us to find a solution to forest fires by utilizing pine needles for economic activity. Our natural response was to harness this energy for household use. We developed production systems for generating electricity-to be fed into the grid-and biochar fuel briquettes for use by village households.

However, frequent grid failures and the grid's inability to absorb the generated electricity created problems for this business model, which depended on revenue from electricity sales. Additionally, the perception of free fuelwood-despite substantial unmonetized labor inputs in its collection-being available from the forests rendered the business

model completely unviable.

The Shift to Biochar

We have responded by increasing biochar production as the main source of revenue instead of electricity and shifting the use of biochar from fuel to farm manure. This biochar amends soil ecology by retaining nutrients and moisture and providing a surface for microbial populations, leading to increased farm productivity and permanent carbon storage in the soil.

Our biomass gasification systems, which allow continuous biomass feeding and biochar removal, deliver over 40% of the fed pine needles as highly stable biochar while utilizing producer gas to continue electricity production. This approach is an effective method of carbon removal, producing high-value Carbon Dioxide Removal certificates (CDRs), which serve as the main source of revenue for those involved in collecting and converting pine needles.

Innovative Biochar Production Method

Our technology offers innovation in biochar production from pine needles, a material that is difficult to process but abundantly available in the area. The continuous raw material feeding and biochar removal/collection mechanism is unique, enabling easy conversion of this challenging biomass into biochar.

Additionally, our innovative technology uses flue gases in the biochar production process-gases that would otherwise be emitted and contribute to non-CO_2 greenhouse gas emissions-to produce clean electricity for household or other uses. This eliminates harmful non-CO_2 emissions, benefiting the atmosphere and generating additional revenue for the business.

Besides processing pine needles, this technology can also process various crop residues such as coffee husks, wood, bamboo chips, etc., to obtain biochar and fuel gases. Instead of generating electricity, these gases can also be used in thermal applications, such as crop drying.

Biochar primarily aims to increase agricultural productivity by 1.5 to 2 times while improving soil health for the long-term sustainability of agriculture

Funding Through Climate Finance

Our excellent-quality biochar, with an H/C ratio of 0.32 and an O/C ratio of 0.068, is highly stable and can be stored in soil for more than 1,000 years. It significantly contributes to soil amendment by increasing the soil's capacity to hold water and nutrients and providing surface area for microbial populations, leading to better soil ecology and greater, sustained productivity. This stable biochar stored in soil generates Carbon Dioxide Removal certificates (CDRs).

We are developing a financing mechanism using carbon funding to scale this technology across pine-dominated geographies through sales of accredited CDRs-at no or insignificant cost to farmers.

Impact on Ecology and Rural Communities

This business model not only builds climate-resilient agriculture, removes carbon dioxide to mitigate climate change, and generates clean electricity but also creates jobs in rural areas and protects biodiversity by eliminating pine needle-induced forest fires.

Use of Biochar in Farming

Biochar contributes directly to building soil ecology. It is a carbon-rich form of charcoal known to increase soil fertility. The high pore volume and surface area per gram of biochar help it absorb and retain water and nutrients in the soil, releasing them to plants during times of stress, leading to higher growth and productivity in agriculture. When mixed with growing media, biochar supports the growth of soil microbes, which are essential for making nutrients available to plants and maintaining soil ecology.

The Agroecological Outcomes of Using Biochar

Resilience:

Production and application of biochar to soils make agriculture climate-resilient by improving soil conditions. This helps crops cope with water and nutrient stress by maintaining higher moisture and nutrient levels in the soil. Biochar acts as a host to soil microbes-crucial for soil health-due to its high pore volume and surface area. Rebuilding robust soil ecology leads to sustained incremental agricultural productivity and climate-resilient farming, enabling efficient responses to climatic stress and ensuring sustainable income for farmers.

Efficiency:

Biochar primarily aims to increase agricultural productivity by 1.5 to 2 times while improving soil health for the long-term sustainability of agriculture. It also reduces input costs by decreasing water and nutrient requirements. Additionally, the production of electricity from flue gases makes efficient use of biomass.

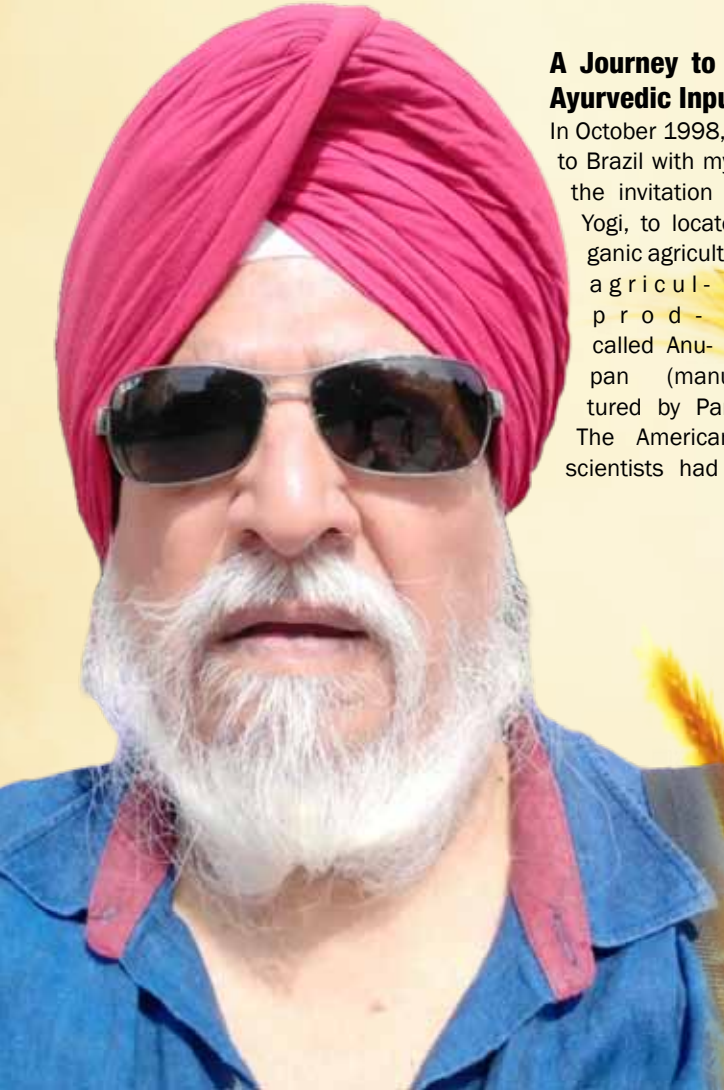
EMPOWERING FARMERS WITH AYURVEDIC SCIENCE

A New Era in Organic Agriculture

The present era is influenced by the power of Ayurveda, thanks to Covid-19. Ayurveda has had 100% success, and we all know the rest. There is a great similarity between human treatment and the treatment of other living organisms. Agriculture falls into the same category.

About the **AUTHOR**

Mr Harpal Singh Grewal is an organic farmer who follows Ayurvedic principles and has been widely awarded for achieving excellence in farming practices



A Journey to Brazil: Introducing Ayurvedic Inputs in Agriculture

In October 1998, I volunteered for a trip to Brazil with my friend, Dr. Hooda, on the invitation of Maharishi Mahesh Yogi, to locate suitable land for organic agriculture. I took an Ayurvedic agricultural input product called Anupan (manufactured by Parnanetra). The American agricultural scientists had treated citrus in such a way that citrus canker (cancer) spread on a mass scale, and our team happened to be there at the right time while the IFOAM event was going on. I met some citrus growers there and gave Anupan to one of the farmers. I met this farmer again at Biofach in Germany in February. I asked about the results, and as per my expectations, a few of his plants recovered. Those times marked just the beginning of the agriculture Ayurvedic approach.

Scientific Validation and Growing Recognition

One professor from Cambridge University took samples from me and asked for its formulation. We gave samples to the head of agronomy at Munich University for testing. The very next year, we were told by the same scientist that just by treating vegetable seeds, the yield increased by 10%.

Challenges and

Opportunities in Ayurveda-Based Agriculture

We were being questioned about approval from agricultural universities, whereas Ayurveda-based agriculture was a new concept and the related universities had no clue about it. One of our learned microbiologists, whose family had been Ayurvedacharyas for generations, met me in my first organic company, IOF, in the year 2000. I encouraged him to research Ayurvedic agricultural inputs in accordance with present scientific principles and validate them. To our good luck and pleasant surprise, he has created many products such as nano organic stimulants and organic bio control. The company name is Myodelphia. They are exporting their bio-stimulants and bio-control products to the USA with extraordinary results. The company exports nanomaterials, and the US counterpart multiplies them (according to instructions) and sells them. Many other agricultural scientists have developed good products. The need of the hour is to be self-reliant, not only in inputs but also in approach and thought process. Our education system must be put on the path of Ayurveda.

Ancient Wisdom Meets Modern Science

Our ancient Rishis (scientists) conducted great research with scientific validation, which had about 40 parameters, whereas present science has only 4 parameters for the recommendation of medicines. I have been repeatedly emphasizing the need to club AYUSH and organic. The entire scenario of approach will change. Presently, the so-called modern scientific community is not letting the Ayurvedic concept enter the minds of policymakers and political leadership. If there is any seminar regarding health or agriculture, not even a single Ayurvedic expert is given a chance to present his point of view. I think the draconian law of magic medicine needs to be quashed. Ayurveda treats up to the conscious level.

We can make or multiply our own bio-stimulants and bio-controls. A change of mindset is required.

Innovations at Heavenly Farms and the Biodynamic Farming Connection

We make many of our own concoctions for biocontrol at Heavenly Farms. Biodynamic farming started with four lectures from Rudolph Steiner, an anthropologist from Europe, who learned this method of farming from India. The Europeans worked on it and created proper research data about biodynamic farming and presented it to the world. Why doesn't the government hold a brainstorming session on the subject by inviting experienced organic farmers and the present scientific community? Farmers should be provided IT assistance for making presentations, as we have done a lot of work that needs to be validated and presented to the masses for its beneficial utilization.

Technological Breakthroughs in Paddy Cultivation

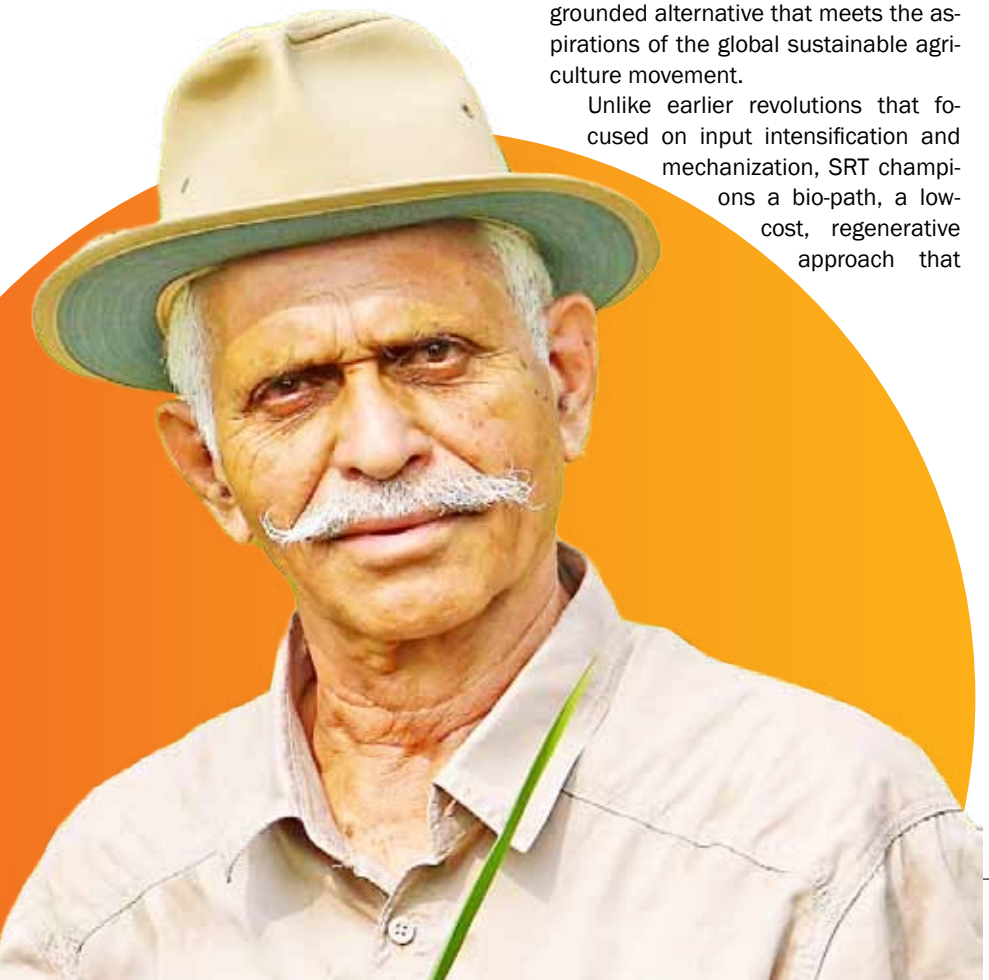
We have perfected a technology that compensates for the nitrogenous requirements of the paddy crop without any outside input. In India, we sow (plant) approximately 49.5 lakh hectares of paddy. Imagine the savings-not only of urea, but also of costly, poisonous, and carcinogenic sprays and inputs in paddy. I am ready to introduce the technology, but government willingness or blessing is required. We perfected another input that completely controls whitefly. There are many simple findings that can boost the actual nutritional yield of crops instead of the gross weight of agricultural output laden with all sorts of carcinogenic chemicals. Nowadays, agricultural universities also mention gross weight as yield. No one bothers about compliance with the Food Law Amendment 2011. Every recommendation of inputs by agricultural universities needs to be authenticated by FSSAI in light of the Food Law Amendment 2011 before it is recommended to farmers.

The Need for a Paradigm Shift in Farming Practices

Mother Nature produces ailments and cures at the same time, but our Western system of education ignores this. Farming starts with Panchang (area-specific), and since we have devised ways for timely moisturizing (irrigation), like tubewells with different disciplines of moisturization, we can get assured yields using bio-stimulants and bio-controls. The indiscriminate use of boosters (so-called fertilizers) disturbs the C&N ratio of the plant, which starts the negative cycle of pests, insects, fungus, and unwanted weeds. We can make or multiply our own bio-stimulants and bio-controls. A change of mindset is required.

SRT: THE BIO-AGRI MODEL FOR INDIA'S NEXT GREEN REVOLUTION

As India stands at the crossroads of escalating agricultural distress and environmental degradation, the call for a new green revolution is loud and urgent. But this time, the path forward is not paved with synthetic inputs or high-tech machinery—it lies in the embrace of biology, ecology, and farmer well-being. The Saguna Regenerative Technique (SRT) presents a sustainable, scalable, and scientifically grounded alternative that meets the aspirations of the global sustainable agriculture movement.



Unlike earlier revolutions that focused on input intensification and mechanization, SRT champions a bio-path, a low-cost, regenerative approach that is both farmer-friendly and ecosystem-positive. It does not demand high investment or specialized equipment. Instead, it draws from the very principles that traditional Indian agriculture once revered—working with nature, not against it.

A Ray of Hope for the Small Farmer

At the heart of SRT is a clear mission: reviving the confidence and prosperity of small and marginal farmers. These are the cultivators who have often been left behind by modern agritech solutions. For them, SRT is not just a technique; it's a revival of faith in farming itself.

By eliminating tillage, preserving crop residues, and promoting natural soil regeneration, SRT restores both soil health and farmer dignity. It empowers the farmer to reduce dependence on expensive inputs while boosting productivity and profits.

About the **AUTHOR**

Mr Krushiratna Krushibhushan Chandrashekhar Bhadsavle is Founder President - Saguna Rural Foundation (SRF)

Redefining Agricultural Economics: High Yields, Low Costs

One of the most remarkable outcomes of SRT adoption has been the simultaneous increase in yields and decrease in costs. Traditional methods often require heavy applications of fertilizers, pesticides, and irrigation, all of which escalate financial risks. SRT flips this model on its head.

By using natural processes like mulching, microbial stimulation, and minimum soil disturbance, SRT reduces the need for:

- Insecticides and chemical fertilizers
- Excessive labor for weeding and land preparation
- Fossil fuels used in repeated tillage and mechanized operations

This leads to higher net profits and a more resilient farming model—especially critical during periods of climate unpredictability.

Soil Health and Ecosystem Regeneration

The cornerstone of SRT lies beneath our feet—in the living soil. Years of intensive agriculture have turned soil into inert substrates, devoid of life and structure. SRT reverses this damage through:

- Improved water infiltration: This reduces runoff and increases groundwater recharge, ensuring longer-lasting water availability in wells and aquifers.
- Increased soil organic carbon: Farmers adopting SRT report that their soils become soft, fragrant, and rich in life within a few seasons.
- Better soil aggregation: This naturally reduces erosion and improves the soil's resistance to compaction.
- Lower bulk density: Which enhances both air and water movement, critical for root respiration and nutrient uptake.
- Thriving biological activity: Earthworms, fungi, and beneficial microbes proliferate in SRT fields, creating a self-sustaining soil ecosystem.

This biological resurgence not only enhances productivity but also contributes to climate resilience and carbon sequestration.

It is time to shift the narrative from "how much we can extract" to "how much we can regenerate"

A Climate-Smart Agriculture Model

SRT's ecological benefits extend beyond the farm. In crops like rice, SRT eliminates the flooded field conditions that are typically associated with methane emission—a potent greenhouse gas.

By avoiding anaerobic decomposition and encouraging aerobic microbial life, SRT enables climate-smart rice cultivation that is both water-efficient and environmentally friendly.

This positions SRT as a ready-made solution for nations and institutions striving to meet their climate commitments and SDGs (Sustainable Development Goals).

Human-Centered Agriculture: Joyful and Stress-Free Farming

Beyond the biological and economic outcomes, SRT brings about a transformation in the psychology of farming.

Many farmers practicing SRT report to be tension-free, more confident, and happier. This is no small feat in a sector plagued by uncertainty, debt, and distress. The simplicity and self-reliance embedded in SRT reduce dependency on external advice, suppliers, or consultants.

This emotional and mental well-being is the often-overlooked cornerstone of a truly sustainable agri-model.

From Pilot Plots to a National Movement

SRT has already demonstrated scalable impact across varied agro-climatic zones in India—from the cotton fields of Vidarbha to the rice belts of Konkan. Hundreds of farmers have witnessed regeneration in real-time, both in their soils and in their lives.

As governments and policy-makers look for agricultural models that are inclusive, low-carbon, and economically viable, SRT stands out as a homegrown innovation with global relevance.

The Future of Agriculture is Biological

The world continues to aspire toward a farming model that is productive, regenerative, and inclusive. With SRT, this aspiration is no longer distant—it is within reach.

By making use of local resources, encouraging biological processes, and putting the small farmer at the center, the Saguna Regenerative Technique offers more than a method—it offers a movement toward a new, bio-agri green revolution.

It is time to shift the narrative from "how much we can extract" to "how much we can regenerate." And in doing so, SRT shows us that the future of agriculture is not just sustainable—it is thriving.

BIOCONTROL AND BIOSTIMULANTS

Pioneering Sustainable Solutions for Modern Agriculture

Regulatory, Technological, and Economic Roadmaps for Sustainable Agriculture

The agricultural sector faces mounting challenges, including climate change, soil degradation, water scarcity, and the need to feed a growing global population while reducing environmental impacts. Traditional agricultural practices relying heavily on synthetic chemicals are being reconsidered as we move toward more sustainable approaches. The emerging biocontrol and biostimulant sectors represent promising alternatives that align with agricultural productivity and environmental sustainability goals.

Biocontrol: Nature's Defence Force

Biocontrol refers to using natural enemies, such as beneficial microorganisms, insects, or nematodes, to suppress pests and diseases in crops. Technological advancements are enhancing the effectiveness and accessibility of biocontrol methods through:

Improved Identification and Characterisation: Advanced molecular techniques allow for more precise identification and action of beneficial organisms, which leads to the development of more targeted and effective biocontrol agents.

Enhanced Production and Formulation: Innovations in fermentation, formulation, and delivery systems are making it easier and more cost-effective to produce, store, and apply biocontrol agents on a large scale.

About the **AUTHOR**

Mr Ajay Bhartiya has pioneered the introduction of several high-efficiency fertilisers in India and is actively involved in developing next-generation fertiliser solutions

Integration with Digital Agriculture: Precision agriculture technologies, such as drone-based monitoring and data analytics, can help identify pest outbreaks early and optimise the timing and application of biocontrol agents.

Genetic Enhancement of Biocontrol Agents: Biotechnology is exploring ways to enhance the natural pest-fighting abilities of beneficial organisms, making them even more effective.

Biostimulants: Boosting Plant Resilience

Biostimulants are substances or microorganisms that enhance plant growth, nutrient uptake, and tolerance to abiotic stresses like drought, salinity, and extreme temperatures. Technological progress in this area includes:

Discovery of Novel Compounds and Microbes: Ongoing research is uncovering new natural compounds (e.g., humic substances, seaweed extracts, amino acids) and beneficial microbes (e.g., mycorrhizal fungi, plant growth-promoting bacteria) with biostimulant properties.

Understanding Mechanisms of Action: Advanced omics technologies (genomics, transcriptomics, metabolomics) are helping to elucidate how biostimulants interact with plant physiology at a molecular level. This knowledge guides the development of more effective products.

Precision Application Strategies: Similar to biocontrol, biostimulants can be applied with greater precision using modern irrigation systems and other targeted delivery methods, maximising their impact and minimising waste.

Tailoring Biostimulants to Specific Needs: Research is focusing on developing biostimulant formulations that are tailored to specific crop types, soil conditions, and environmental challenges.

The Synergy for Sustainable Agriculture

The combined use of advanced biocontrol and biostimulant technologies

The biocontrol market is projected to grow from approximately $5 billion in 2023 to over $12 billion by 2030, while the biostimulant market is expected to expand from $3 billion to around $8 billion in the same period

contributes to sustainable agriculture in several key ways:

Reduced Reliance on Synthetic Inputs: By providing natural alternatives for pest and disease management and enhancing nutrient efficiency, these technologies decrease the need for chemical pesticides and fertilisers, minimising environmental pollution and health risks.

Enhanced Resource Use Efficiency: Biostimulants improve nutrient uptake and water utilisation, leading to more efficient use of these critical resources.

Improved Soil Health: Many biocontrol agents and biostimulants promote beneficial soil microbial communities and improve soil structure and fertility over time.

Increased Crop Resilience: By enhancing plants' natural defence mechanisms and tolerance to stress, these technologies contribute to more stable and reliable crop yields, even under challenging environmental conditions.

Support for Biodiversity: Sustainable agriculture practices that incorporate biocontrol and biostimulants can help create more diverse and resilient agroecosystems.

Digital Agriculture and Biocontrol/ Biostimulant Integration

- Remote sensing to identify biotic/abiotic stress before visible symptoms appear
- Precision application systems for targeted biocontrol deployment
- Predictive models integrating weather data, crop development, and pest emergence

Formulation Technologies

- Microencapsulation techniques provide extended shelf life and controlled release
- UV protectants and adjuvants enhancing field persistence
- "Stacked" products combining multiple biocontrol organisms or biosimulants

BEYOND THE APP

WHY AGRITECH NEEDS MORE THAN THE INTERNET

As the globe started to recover from the COVID-19 pandemic in 2021, discussions about food systems, how our food is produced, how it gets to us, and whether supply can keep up with demand, became more urgent. The focus shifted to farming, which was long thought to be traditional and low-yield in terms of returns. As a potential remedy for long-standing inefficiencies in the farm-to-fork process, using technology to enhance agricultural results started to gain popularity.

India appeared to be ripe for innovation, with more than half of its people working in agriculture. According to FSG, the industry brought in $1.28 billion in investment in that one year alone. Solutions from startups ranged from tools for climate resilience to supply chain traceability and agricultural monitoring systems. There was hope that agri-tech will change farming in the future.

From Quick Development to Market Reversal

However by 2023, investment in industry had drastically decreased, falling 45% to $706 million. This contraction was a component of a larger worldwide trend that was impacted by tightening credit markets, rising prices, and geopolitical unrest. As operational inefficiencies, unsustainable business models, and overvaluation were revealed, agri-tech encountered more difficulties. Agri-tech was not an exception to the grim reality check that swept across the tech industry after the post-pandemic euphoria.

The Indian agri-tech industry is still expected to develop after 2027, when it was last estimated to reach a $34 billion market size. The worldwide agri-tech market, for example, is projected to increase from USD 23.5 billion in 2022 to over USD 79.7 billion by 2030, indicating a notable rising pattern.

About the **AUTHOR**

Ms Yashasvini Kumar is Group COO, Innoterra

Agri-Tech: A Specific Concern

Although it's easy to compare agri-tech to industries like fintech or edtech, this comparison is incorrect. Following India's campaign for demonetization and digital payments, fintech took off. The popularity of edtech was hastened by the pandemic, but it had been developing for years. However, agriculture is highly contextual, reliant on weather, seasons, and terrain. Farmers must develop trust over time; they cannot embrace new equipment suddenly.

There are still gaps in the basic infrastructure, accurate land records, localized weather data, and trustworthy databases. Without these, even the most advanced technology cannot yield appreciable benefits.

Unlike digital platforms that expand rapidly through user acquisition, agri-tech requires physical infrastructure, including cold storage facilities, transportation networks, food testing labs, and a skilled field workforce. These are tough to scale since they need a lot of cash and are sluggish to produce.

The Requirements for Agri-Tech Development

Building a strong agri-supply chain from farm to fork is a completely different undertaking than developing a mobile application, which could take several months. With uncertain weather, pest outbreaks, and limited water supplies, over 93 million Indian farmers work on small plots and suffer significant hazards. One poor season can have disastrous consequences. It takes years of relationship-building in addition to instruction to persuade them to embrace new technologies.

Agri-ecosystems are also closely related. Farmers frequently collaborate with dependable local middlemen, including lenders, buyers, and sellers from many generations. To be accepted, newcomers must fit in with these networks and show that they are valuable in the long run.

At the same time, customer expectations are evolving, with growing demand for traceable, organic, and health-conscious food, though meeting these expectations can be time-consuming.

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