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JUST AGRICULTURE™
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FUTURE HARVEST:
AN ARTIFICIAL INTELLIGENCE FOR HORTICULTURE

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FROM THE FOUNDER & CEO's DESK

Dear Readers,

Welcome to the latest issue of Just Agriculture—a publication dedicated to empowering, informing and inspiring the agricultural community. The landscape of agriculture continues to evolve, we are witnessing significant advancements in technology, sustainability practices, and global trends that are reshaping the way we produce, consume, and think about food, from precision farming to the integration of AI in crop management, innovation is at the heart of the agricultural revolution.

However, alongside these opportunities, challenges like climate change, supply chain disruptions and labor shortages remain pressing concerns that require our collective action and resilience.

At Just Agriculture, we are committed to being a bridge between these emerging technologies and the farmers, agribusinesses and stakeholders who will shape the future of agriculture. In this issue, we delve into topics that matter most: sustainable farming practices, the rise of agri-tech and the crucial role of policy in ensuring a thriving agricultural ecosystem. We also highlight success stories from across the globe, demonstrating how adaptability and innovation are driving positive change.

I believe that the future of agriculture is bright, but it requires all of us—farmers, scientists, policymakers and consumers—to work together toward a common goal: ensuring food security, environmental sustainability and the well-being of future generations.

Thank you for your continued support and for being a part of this incredible journey. I hope this issue inspires you as much as it has inspired us to bring it to you.

Dr. D.P.S. BADWAL
Founder & CEO,
Just Agriculture-the Magazine

Publisher & Editor:
Dr. D.P.S. Badwal on behalf of Just Agriculture Communications Group & printed at Just Agriculture Publications, Jalandhar.

FROM THE CHIEF EDITOR's DESK

Dear Readers,

It gives me immense pleasure to present the September 2025 issue of Just Agriculture, a special edition dedicated to highlighting one of the most transformative movements in recent times — the Viksit Krishi Sankalp Abhiyan 2025. As India steps firmly on the path of becoming a developed nation, this ambitious campaign under the Ministry of Agriculture & Farmers' Welfare is shaping a new era of progressive, sustainable, and inclusive agricultural growth.

This initiative is not merely a government program; it is a collective resolve to reimagine Indian agriculture through innovation, technology, and the unwavering commitment of our farming community. Across the country, we are witnessing a renewed energy in the fields, backed by strong institutional support from ICAR, agricultural universities, Krishi Vigyan Kendras, and allied departments, all working in synergy to turn vision into action.

In this issue, we bring to light the latest developments and success stories emerging from the heart of this national campaign. One of our lead features presents a comprehensive review of solar energy applications in agriculture, exploring how farmers are adopting clean and renewable energy solutions for irrigation, cold storage, drying, and protected cultivation. Solar energy is fast becoming a cornerstone of self-reliant and climate-smart farming.

We also cover vital topics such as cotton farming advancements, aquaponics as an emerging integrated farming system, and the role of

research and extension in spreading modern, science-backed agricultural practices to even the most remote corners of India. The issue captures the pulse of change and the spirit of innovation being nurtured under Viksit Krishi Sankalp Abhiyan.

At Just Agriculture, we remain committed to serving as a bridge between knowledge and practice, policy and ground-level impact. Through this edition, we hope to inform, inspire, and ignite further dialogue among students, researchers, farmers, policymakers, and agri-entrepreneurs who are contributing to the evolving narrative of Indian agriculture.

I invite you to engage deeply with the stories, research, and perspectives shared in this issue. Together, let us move forward with the shared vision of a "Viksit Krishi"—empowered, enlightened, and ever-evolving.

Dr. Sushila
Chief Editor,
Just Agriculture-the Magazine

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Baby corn (*Zea mays* L.):

The Wonder Crop to Increase the Farmer's Income

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INTRODUCTION

Baby corn (also known as young corn, cornlettes, child corn or baby sweet corn) is a cereal grain taken from corn (maize) harvested early while the stalks are still small and immature. It typically is eaten whole—including the cob, which is otherwise too tough for human consumption in mature corn—in raw, pickled, and cooked forms. Baby corn is common in stir fry dishes. Maize occupies third position as cereal crop after rice and wheat. Maize is also known as "Queen of Cereals". Maize provides nutrition to human and as a fodder crop to animals. Growing of maize as vegetable crop increases its value in cropping system along with its applications in industries with different range of products. Among all the cereals, maize has the highest production potential. Young corn has a small growth period. Hence farmers can cultivate 3 or more than 3 crops in a year. Due to more crop cycle farmers economy can be improved.

Amongst the cultivated maize crops, the most promising one is baby corn. It is the most exquisite one as it provides the increased range of production, value addition as well as increased income. It belongs to the family Gramineae and originated from Central America. The grains are used as food, feed as well as industrial raw materials. It contains carbohydrate in the form of starch (up to 80%) and crude protein (up to 10%). According to Thava Prakash, 100gm of baby corn contains required moisture (89.0%) moisture, fats (0.2 gm), protein (1.9 gm), carbohydrate (8.2 mg), ash (0.06 gm), calcium (28.0 mg), potassium (86.0 mg). Despite of human nutrition the other benefits of baby corn are the utilization of its husk, silk and stover as green fodder.

In China, Baby corn was used as vegetables crop and further it was gradually spread to all over the world to accept it for cultivation. Now baby corn is cultivated all over the world. Thailand is the highest producer of baby corn and the production value is nearly $64 million US. Baby corn cultivation has already started in India and major states are going for its cultivation at larger scale. In India, it is cultivated on 9.43 m ha land. In India total production is 24.35 m t and productivity is 2583 kg/ha. Consideration by different group of researchers is currently more focussed towards investigating its potential in India for acquiring outside trade other than higher financial incomes to the farmers. The cultivation of baby corn is higher in many parts of India including Meghalaya, Uttar Pradesh, Haryana, Maharashtra, Karnataka and Andhra Pradesh.

NUTRITIONAL VALUE OF BABY CORN

Baby corn has nutritional value very related to vegetables like cauliflower, cabbage and tomatoes etc. (Baby corn nutritional value per 100 grams).

S. No.	Nutrients	Quantity
1	Energy	26 calories
2	Carbohydrates	3.1 g
3	Fibre	1.7 g
4	Protein	2.5 g
5	Sodium (Na)	300 mg
6	Calcium	95 mg
7	Magnesium	345 mg
8	Phosphorous	898.62 mg

Besides all of these nutrients, it also contains iron, vitamin A, B and folic acid in very less quantity. Studies have showed that its one cup meets about of recommended daily intake of Fe and vitamin A and 4% of recommended daily intake of vitamin C.

Health benefits

- Reduction in body weight
- Maintain blood sugar level
- Improve digestion
- Source of nutrients
- Improve vision
- Prevention of neural-tube birth defects

Uses of baby born

- The entire short ear of baby corn is edible. Baby corn can be eaten raw or cooked.
- It is used in variety of traditional and continental dishes besides being canned.
- It is used as decorative, crispy vegetable in salad, soup, pickles, pakoras, vegetable biryani, mixed vegetable, pasta, chutney, cutlets chat, dry vegetable, kofta curry, Manchurian, raita, candy, jam, murabba, burfi, halwa, kheer, deep fried baby corn with meat and rice and other favorite dishes.
- It can also be used after boiling and blanching. Except corn, its whole plant can also be used as fodder for cattle, which is nutritious. Moreover straw, dry leaves and cob covering can be used as good fuel.

CHALLENGES OF BABY CORN IN INDIA

Perishability and Short Shelf Life

- Baby corn has a very short harvest window (1–2 days for optimum quality) and spoils quickly without proper cold storage.
- Limited cold chain infrastructure in rural areas leads to post-harvest losses.

Labour-Intensive Cultivation

- Requires frequent harvesting (every 2–3 days), which increases labour requirements and cost.
- Skilled labour is needed to harvest at the correct maturity stage.

Market Awareness and Demand Fluctuations

- Consumer awareness about baby corn's nutritional value and culinary uses is still low in many regions.
- Seasonal demand from hotels, restaurants, and export markets can be unstable.

Lack of Standardized Varieties

- Many farmers grow baby corn from normal maize hybrids rather than specialized baby corn hybrids, leading to inconsistent yield and quality.

Infrastructure and Processing Gaps

- Limited facilities for processing (blanching, canning, freezing) restrict expansion into processed food markets.
- Poor packaging leads to damage during transportation.

Price Instability

- Farmers often face fluctuating prices due to oversupply during peak seasons and lack of organized procurement.
- Pest and Disease Management
- Baby corn is susceptible to maize pests like stem borers, armyworms, and fungal diseases, requiring careful management.

SCOPE OF BABY CORN IN INDIA

High-Value Crop for Diversification

- Can be cultivated throughout the year in many parts of India, providing an additional income source for farmers.
- Short duration (60–70 days) allows it to fit well into multiple cropping systems.

Export Potential

- Growing international demand for baby corn in South-East Asia, Middle East, and Europe for fresh and processed forms.
- India's climatic diversity allows off-season production, giving a competitive advantage.

Value Addition Opportunities

- Baby corn can be processed into canned, frozen, and pickled products for retail and export.
- Potential for integration with food processing industries and ready-to-eat food segments.

Nutritional and Culinary Appeal

- Low calorie, high fibre, and rich in vitamins and minerals.
- Increasing health-conscious consumer base and demand from restaurants, hotels, and fast-food chains.

Employment Generation

- Labour-intensive cultivation offers employment opportunities in rural areas for harvesting, grading, packaging, and processing.

Government and Institutional Support

- Inclusion in horticulture development programs under MIDH, NHM, and state horticulture missions.
- Potential for contract farming with organized buyers and food processing companies.

Agro-Industrial Linkages

- Can be integrated with dairy farms (as the stalks are excellent fodder) and poultry feed production.
- By-products have economic value, reducing waste.

IMPORTANT VARIETIES AND HYBRIDS OF BABY CORN:

S. No.	Name of varieties	Institute of Release	Characteristics
1. Public Sector Varieties			
1	VL Baby Corn 1	VPKAS, Almora	Short duration (60–65 days), uniform cobs, good tenderness.
2	HM 4	IARI, New Delhi	High yield potential, good cob size, suitable for spring and kharif seasons.
3	G-5414	PAU, Ludhiana	High number of cobs per plant, good sweetness, suitable for fresh and processing.
4	PEHM 2	IARI, Pusa	Medium duration, good for both baby corn and fodder.
5	African Tall		Mainly a fodder maize variety, sometimes used for baby corn in dual-purpose systems.
2. Private Sector / Hybrid Varieties			
1	PAC 792	Advanta	Uniform small cobs, good market acceptance.
2	Sweet Gold	Advanta	Attractive colour, tender texture, sweet taste.
3	Prakash	Private hybrid	High yield, uniform maturity, disease tolerant.
4	Golden Baby	Private hybrid	Suited for fresh market, good sweetness, high recovery after husking.
3. Sweet Corn Hybrids Used as Baby Corn: Some sweet corn hybrids viz., Sugar 75, Madhuri, and Priya are harvested early for baby corn. **Note:** Many baby corn growers use normal maize hybrids (grain maize) harvested at 1–3 days after silk emergence. Specialized baby corn hybrids are preferred for uniform ear size, tenderness, and higher number of ears per plant.			

THE FUTURE PROSPECTS OF BABY CORN IN INDIA:

Expanding Domestic Market

- Urban lifestyle changes are driving demand for exotic and health-focused vegetables.
- Hotels, restaurants, and fast-food chains (HORECA sector) increasingly use baby corn in salads, stir-fries, soups, and snacks.
- Rising health-conscious consumer base is pushing baby corn into supermarkets and online grocery platforms.

Export Opportunities

- India has a climatic advantage to produce baby corn year-round for fresh and processed export.
- Major importing countries: Thailand, Vietnam, UAE, UK, and other European markets.
- Processed baby corn (canned, frozen, pickled) has growing demand in Middle East and EU due to long shelf life and convenience.

Integration with Food Processing Industry

- Baby corn has high value addition potential:
- Canning, freezing, vacuum-packing, pickling.
- Ready-to-eat and ready-to-cook packaged products.
- Government's PLI Scheme for food processing and Operation Greens can promote processing units.

Role in Crop Diversification

- Fits into short-duration cropping

systems (60–70 days) and can be grown between major crops.

- Suitable for peri-urban agriculture where proximity to markets reduces transport and storage costs.
- By-products (stalks, husks, tassels) provide quality green fodder, enhancing farm profitability.

Technology & Research Potential

- Development of specialized high-yielding baby corn hybrids with uniform cobs and pest/disease resistance.
- Protected cultivation (polyhouse/ net house) for premium off-season production.
- Cold chain and logistics improvement to reduce post-harvest losses.

CONCLUSION

Baby corn in India has strong future potential as a niche, high-value, short-duration crop especially if linked with processing industries, export chains, and modern retail. With research backed varieties, organized marketing, and cold chain development, India can emerge as a major global supplier. Further, for grab baby corn industry, regional co-operation for swap of information and germplasm, regional testing of selected hybrids and varieties, joint meetings and visits, human resource growth, collaborative efforts for research, development and sensitization of policy makers for reaching at adoption of appropriate baby corn output and processing technology would be highly desirable.

BIOCHAR :
BLACK GOLD FOR SUSTAINABLE AGRICULTURE

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INTRODUCTION

Sustaining soil quality is the most effective method for ensuring sufficient food to support life. By soil quality, we meant the suitability or limitation of a soil for a particular use. Some scientists defined it as the 'fitness for use' and others as the capacity of the soil to function. For improving and ensuring soil and water quality, the main considerations should be the identification and development of suitable methods to measure their quality. Then, the management-sensitive key indicators of soil and water quality should be identified and used for monitoring and predicting the changes periodically.

SOIL QULAITY AND SOIL DEGRADATION

Soil is a natural finite resource base which sustains life on earth. It is a three-phase dynamic system that performs many functions and ecosystem services and highly heterogeneous. Soil biota is the biological universe which helps the soil in carrying out its functions. Often, the soil health is considered independently without referring to interlinked soil functions and also based on soil test for few parameters. Physical condition of soil and biological fertility are overlooked in soil health management which needs revisiting of soil users. Recognizing the importance of soil health in all dimensions, 2015 has been declared as the International Year of Soils by the 68th UN General Assembly. Food and Agriculture Organization of the United Nations has formed the Global soil partnership with various countries to promote healthy soils for a healthy life and world without hunger. India, the second most populous country in the world, faces severe problems in agriculture. It is estimated that out of the 328.8 M. ha of the total geographical area in India, 120.4 M. ha are degraded, producing less than 20% of its potential yield.

Soil is the essence of life on earth. It serves as a natural medium for the growth of plants that sustains human and animal life. Healthy soils provide us with a range of ecosystem services such as resisting erosion, receiving and storing water, retaining nutrients and acting as an environmental buffer in the landscapes. Soils have undergone unabated degradation at an alarming rate by wind and water erosion, desertification and salinization resulting from misuse and improper farming practices. Soil quality, antonym for soil degradation, has deteriorated due to the natural and anthropogenic activities particularly with the advent of the intensive management practices.

SOIL HEALTH

Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land use boundaries. The functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal and human health.

SOIL QUALITY INDICATORS

Soils have chemical, biological and physical properties that interact in a complex way to give soil its quality of capacity to function of performs. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators.

There are three types of indicators :

Chemical

- Soil organic carbon
- Top soil pH
- Cation exchange capacity (CEC)
- Anion adsorption capacity
- Base saturation

B. Biological

- SOC (Soil organic carbon)
- Microbial biomass carbon
- Soil biomass
- Microbial diversity index and enzyme assays

C. Physical

- Integrated air capacity
- Texture
- Bulk density
- Aggregation
- Pore size distribution and continuity
- Available water capacity
- Non-limiting water range
- Infiltration rate
- Effective rooting depth
- Soil temperature

D. Visual

- Soil colour
- Ephemeral gullies
- Ponding
- Runoff
- Plant response
- Weed species

BIOCHAR FOR ENHANCING SOIL HEALTH

The technique for discovery of biochar was first described by Spanish explorer Francisco de Orellana in the 1540s (where biochar is known as terra preta). Biochar is substance which is created by heating biomass (organic matter) in a limited oxygen conditions, a process known as pyrolysis. It is commonly defined as charred organic matter, deliberately applied to soils to sequester carbon and improve soils physical, chemical and biological properties. Biochar application in soil has received a growing interest as a sustainable technology to improve highly weathered or degraded soils. It guarantees a long term benefit for soil fertility and productivity. It can enhance plant growth by improving soil physical characteristics (i.e. bulk density, water holding capacity, infiltration, porosity), soil chemical characteristics (i.e. pH, nutrient retention, nutrient availability), and soil biological properties (i.e. microbial biomass carbon), all contributing to an increased crop productivity. The major quality of biochar that makes it attractive as a soil amendment is its highly porous structure which is responsible for improved water retention and increased soil surface area.

BENEFIT OF BIOCHAR

Biochar process is not carbon neutral, but carbon negative. The major benefits of biochar are impressive because it reduces leaching of soil nutrients, increases soil pH and thus reducing the need for lime, enhances nutrient availability for plants, reduces toxicity of aluminum to plant roots, increases water quality of runoff, reduces dependency on fertilizers, reduces bioavailability of heavy metals and thus works as bioremediation, decreases N_2O and CH_4 emissions from soils, thus further reducing GHG emissions.

NUTRIENT VALUE OF BIOCHAR

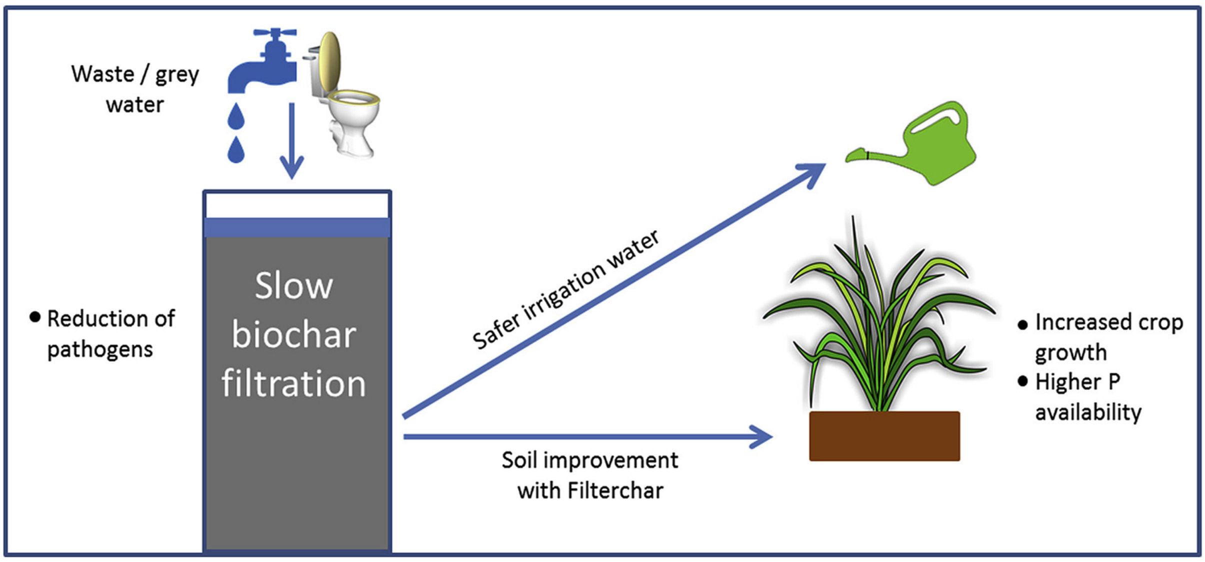
Biochar is able to improve soil fertility as well as productivity directly and indirectly.

Direct: Biochar itself contains some amount of nutrients which is available directly to plants. Positive yield responses as a result of biochar application to soils have been reported for a wide range of crops and plants in different parts of the world by improving soil quality, with consequent improvement in the efficiency of fertilizer use. From an agronomic perspective it is suggested that biochar could improve soil health by improving nutrient retention, particularly in coarsely textured soils.

Indirect: The indirect responses due to biochar application were attributed to either nutrient savings (in term of fertilizers) or improved fertilizer-use efficiency. Biochar being high C/N ratio can immobilize nitrogen which sometimes results in reduced N availability for short duration. This is the ability of biochar to retain applied fertilizer against leaching which results in increase in fertilizer use efficiency.

BIOCHAR AND WATER AVAILABILITY

Biochar increases water quality and plant available water capacity (PAWC). Biochar addition in soil increases water holding capacity and plant available water in sandy soils. In dry areas where water quantity and quality is extremely variable, it would contribute a significant benefit. Biochar has a high surface area with increased micro pores and improves the water holding properties of porous sandy soils. Therefore, biochar application for soil water benefits is maximized in sandy soils. Thus, there are enormous benefits of biochar in cropping areas where cost of water is very high such as dry areas.



EFFECT OF BIOCHAR ON SOIL pH

Soil pH is an important factor for plant growth because nutrient availability in soils depends on soil pH. Most of the macronutrients are available in neutral soils. To neutralize acidic soils, farmers apply thousands of tons of lime to farm soils at great expense. Biochar have an effect on soil pH. It can react similarly as agricultural lime do (by increasing soil pH). If a soil has a low cation exchange capacity, it is not able to retain nutrients and the nutrients are often washed out by leaching. Biochar in its pores having large surface area develops some negative charges and thus provides more negatively charged sites for cations to be retained when added to soil.

EFFECT OF BIOCHAR ON SOIL PHYSICAL PROPERTIES

Biochar application improved the saturated hydraulic conductivity of the top soil and xylem sap flow of the rice plant. It increases water holding capacity in sandy soil. Peanut hull biochar have ability to reduce moisture stress in sandy soil. It improves soil physical condition for earthworm populations. Application of 6.6 metric tons cassia biochar/ha is enough to initiate C-accumulation, which reflect in an increase in organic matter and a net reduction in soil bulk density.

EFFECT OF BIOCHAR ON SOIL CHEMICAL PROPERTIES

Biochar contributes some quantity of nutrients in soil through the negative charges that develops on its surfaces. This negative charge can easily buffer acidity in the soil (as does organic matter). Due to its high alkalinity nature it has been demonstrated to reduce aluminum toxicity in acid soils. Application of biochar to acidic soils can avoid significant amounts of direct and indirect costs by avoiding GHG emissions. Application of biochar in soil increases soil pH, EC, CEC and decreased exchangeable acidity.

EFFECT OF BIOCHAR ON SOIL BIOLOGY

Biochar is able to enhance soil microbial biomass carbon and carbon mineralization. It stimulates the activity of a variety of agriculturally important soil microorganisms and can greatly affect the microbiological properties of soils. The pores in biochar provides a suitable habitat for many microorganisms by protecting them from predation and drying while providing many of their diverse carbon (C), energy and mineral nutrient needs. The intrinsic properties of biochar and its ability to form complex with different soil type, can have an impact on soil-plant-microbe interactions. Thus, modifications in the soil microbial community can subsequently influence changes in nutrient cycling and crop growth in biochar-amended soil. Biochar application increase Co adsorption which lead to increase in local nutrient concentrations for microbial community species and enhanced water retention.

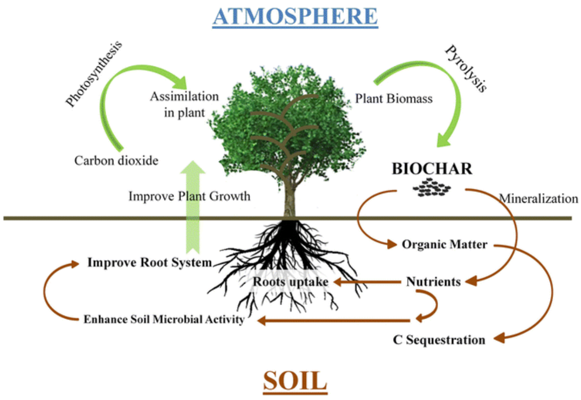
Dehydrogenase activity and microbial biomass carbon are enhanced due to biochar application in soils.

Table 1. Effect of biochar on different soil properties

Factor	Impact
Bulk density	Soil dependent
Soil moisture retention	Upto 25% increase
Liming agent	1 unit t pH increase
Cation exchange capacity	50% increase
Nutrient use efficiency	10-20% increase
Crop productivity	30-100% increase
CH4 emission	90% decrease
N2O emission	50% decrease
Biological nitrogen fixation	50% increase
Mycorrhizal fungi	30% increase

APPLICATION OF BIOCHAR IN SOIL

There are different methods for application of biochar in soil like broadcasting, deep banding, band application, spot placement, etc. However, method of biochar application in soil mainly depends on farming system, labour and available machinery. Generally farmers apply biochar in their own field by hand only. But due to prolonged contact with airborne biochar particulates, it is not viable on large-scale considering human health. Broadcasting application needs large amount to cover whole field. Suitable method of application deposits biochar directly into the rhizosphere, and may be viable for perennial cropping systems, and previously established crops. Deep banding of biochar has been successfully implemented in several wheat fields. Mixing of biochar with composts, manures and other organic input may reduce odours, colour and improve nutrient performance over time due to slower leaching rates. Mixtures may be applied for uniform topsoil mixing without incorporation.



APPLICATION RATES OF BIOCHAR

Application of biochar in soils is based on its properties like agricultural value from enhanced soils nutrient retention and water holding capacity, carbon sequestration and reduced GHG emissions. There is no specific rate of application of biochar in soil. It depends on many factors including type of biomass used, the types and proportions of various nutrients (N, P, etc.), the degree of metal contamination in the biomass, and also climatic and topographic factors of the land. It was found that rates between 5-10 t/ha (0.5-1 kg/m^2) have often been found better. Due to variability in biochar materials, nature of crop and soils, farmer should always consider testing several rates of biochar application on a small scale before setting out to apply it on large areas. Even low rates of biochar application can significantly increase crop productivity assuming if the biochar is rich in nutrients. Biochar application rates sometimes also depend on the amount of dangerous metals present in the original biomass.

SOIL HEALTH MANAGEMENT USING BIOCHAR

Biochar can act as a soil conditioner by improving soil physical, chemical and biological properties. Benefits from biochar application rates can be maximized only if the soil is rich in nitrogen or if the crops are nitrogen-fixing legumes. Researchers found that application of biochar to soils in a legume-based (e.g. peanut and maize) rotational cropping system, clovers and lucernes is more beneficial. Significant changes in soil quality, including increase in pH, organic carbon and exchangeable cations were observed at higher rates of biochar application, i.e. > 50 t/ha. When mixed with organic matter, biochar can result in enhanced retention of soil water as a result of its pore structure which contributes to nutrient retention because of its ability to trap nutrient rich water within the pores. Biochar is able to strongly adsorb phosphate, even though it is an anion. It is reported that the higher BNF with biochar additions is due to greater Mo and B availability. These properties make biochar a unique substance, retaining exchangeable and plant available nutrients in the soil, and offering the possibility of decreasing environmental pollution by nutrients and improving crop yields. Thus, biochar application could provide a new technology for both soil fertility and crop productivity improvement, with potential positive and quantifiable environmental benefits.

BIOCHAR AND LAND RESTORATION/RECLAMATION

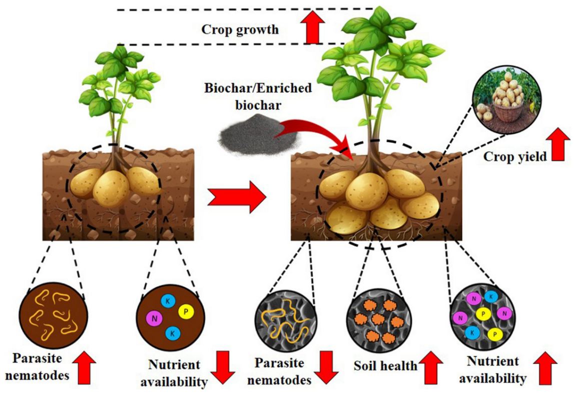
Biochar has received considerable attention in recent years as soil amendment for both sequestering heavy metal contaminants and releasing essential nutrients like sulphur. Biochar are porous with a polar and aromatic surface. They have a high surface to volume ratio and a strong affinity to non-polar substances such as polycyclic aromatic hydrocarbons (PAHs), dioxins, PBDEs, furans (PCDD/Fs), and PCBs. Through the intervention of biochar, groundwater could be protected from the hydrophobic herbicide, insecticide and fungicide. Biochar applications have the potential to absorb pollution by adsorbing ammonia to reduce ammonia volatilization in agricultural soils.

BIOCHAR AND HEAVY METAL SORPTION

The use of biochar to remove contaminants such as organic contaminants or metals is a relatively novel and promising technology. Biochar made from bagasse and other agricultural residues is effective alternative, low-cost environmental sorbents of lead or other heavy metals. Several studies have reported the effective removal of lead by biochar sorbents. Like many other traditional sorbents, the high affinity for lead and other metal ion species bound by biochar may be controlled by other mechanisms as well, including complexation, chelation, and ion exchange. Application of maize stalk biochar is useful to ameliorate chromium (Cr) polluted soils and reduce the amount of carbon produced due to biomass burning.

EFFECT OF BIOCHAR ON CROP PRODUCTION

Biochar applications to soils have shown positive responses for net primary crop production, grain yield and dry matter. Application of wheat straw biochar along with NPK significantly increase the yield of maize than either crop residue incorporation (CRI) or crop residue burning (CRB). Higher agronomic nitrogen use efficiency was recorded with application of biochar. The combined application of biochar along with organic/inorganic fertilizer has the potential to increase crop productivity, thus providing additional incomes, and may reduce the quantity of inorganic fertilizer use and importation. The impact of biochar application is seen most in highly degraded acidic or nutrient depleted soils. Low biochar application in soil has shown marked impact on various plant species, whereas higher rates seemed to inhibit plant growth. So, moderate additions of biochar are usually beneficial.



EFFECT BIOCHAR AND ON NODULATION AND NITROGENASE ACTIVITY

Biochar addition increase root nodule number, localized N_2 fixation per nodule, nitrogenase activity in legumes, mycorrhizal colonization and plant-growth promoting organisms in the rhizosphere. Increased nodulation following biochar application could increase sustainable N input into agro ecosystems. Biochar applications also increase nitrogen fixation rates. Increased micronutrient availability (e.g. Mo and B), together with the liming effect on soil pH following biochar application has been proposed as the mechanisms for increased biological N_2 fixation of pot grown beans. Symbiotic association between biochar and mycorrhizal association showed that biochar could influence mycorrhizal abundance. Rice biochar showed greater microbial activities than other biochar because of its higher liability.

EFFECT OF BIOCHAR ON CARBON SEQUESTRATION

A more efficient way to increase and maintain a high soil organic matter content would be to apply more stable C products such as biochar. Future political agreements may make it profitable for farmers to add biochar to soil. Large amounts of carbon in biochar may be sequestered in the soil for long periods estimated to be hundreds to thousands of years. Terra preta soils suggest that biochar can have carbon storage permanence in soil for many hundreds to thousands of years. Biochar mineralizes in soils in a little fraction and remains in a very stable form which provides it the potential to be a major carbon sink. About 12% of the total anthropogenic carbon emissions by land use change (0.21 Pg C) can be offset annually in soil, if the slash-and-burn system is replaced by the slash-and-char system. Compared with other terrestrial sequestration strategies, such as afforestation or re-forestation, carbon sequestration in biochar increases its storage time. The principal mechanisms operating in soils through which biochar entering the soil is stabilized and increase its residence time in soil are due to formation of interactions between mineral surfaces, intrinsic recalcitrance and spatial separation of decomposers and substrate.

BIOCHAR AND CARBON CREDIT

Application of higher amounts of biochar to soils may increase the carbon credit benefit to the farmers. Carbon added to the fields in the form of biochar could give farmers C credits that can be sold on a C credit market for additional income. Increasing the C sink in soil will help reduce the amounts of CO_2, CH_4, and N_2O.

BIOCHAR TECHNOLOGY ON CLIMATE CHANGE

Biochar technology is called as geo-engineering solution that has potential to actively reduce the atmospheric concentrations of green house gases. As it results in the removal of CO_2 from the atmosphere and increases level of long wave radiation leaving the planet, it is considered as a long wave geo-engineering option for climate change mitigation. A biochar system, where agricultural crops are grown, and subsequently pyrolyzed to produce biochar, which is then applied to soil, is a carbon sink. This means CO2 from atmosphere is sequestered as carbohydrates in the growing plant and conversion of the plant biomass to biochar stabilizes this carbon. The stabilization of carbon in biochar delays its decomposition and ensures that carbon remains locked away from the atmosphere for hundreds to thousands of years. In addition, gases released in the process of creating biochar can be used to make bio fuels. If we want to tackle climate change challenges, we must emphasize the potential of soil to sequester carbon. Sustainable biochar can be used now to combat global warming by holding carbon in soil and by displacing fossil fuel use.

SUMMARY

Soil amendment with biochar has attracted a fair amount of research interest due to its abundant usage and wide potential, which includes enhancing crop production by improving soil fertility, decreasing greenhouse gas emissions and increasing soil carbon sequestration. Use of biochar in agricultural systems is one viable option that can improve the soil quality, increase carbon sequestration in soil, reduce farm waste. However, to promote the application of biochar as a soil amendment and also as a climate change abatement option, research, development and demonstration on biochar production and application is very vital.

SUSTAINABLE PRACTICES IN INDIAN AGRICULTURE: ORGANIC AND ZERO-BUDGET NATURAL FARMING

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INTRODUCTION

Agriculture is the backbone of India, but the sector faces severe challenges—soil degradation, falling water tables, rising input costs, and climate change. To overcome these issues, farmers are increasingly turning to **sustainable practices**. Among the most discussed approaches today are **organic farming** and **Zero-Budget Natural Farming (ZBNF)**. Both focus on reducing dependency on chemical inputs, protecting soil health, and ensuring long-term food security.

WHAT IS ORGANIC FARMING?

Organic farming is a system that avoids synthetic fertilizers, pesticides, and genetically modified organisms (GMOs). Instead, it relies on natural inputs like compost, green manure, crop rotation, and biological pest control.

Key Features:

- Uses farmyard manure, biofertilizers, and compost.
- Encourages biodiversity and crop rotation.
- Prohibits chemical fertilizers and pesticides.

Benefits:

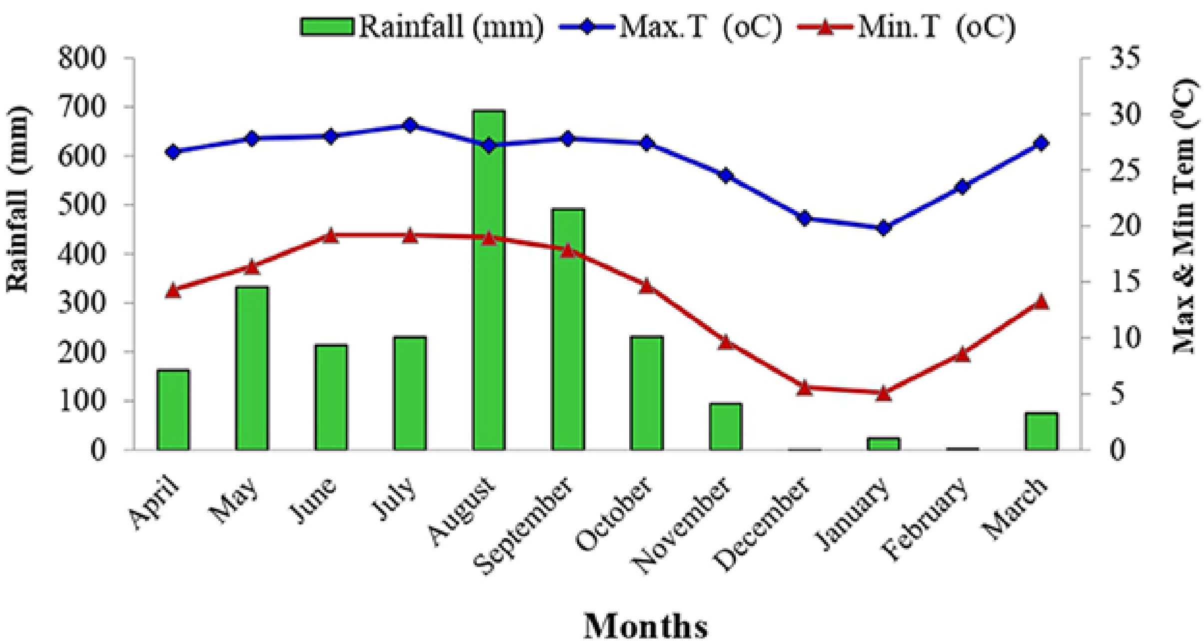
- Improves soil fertility and structure.
- Produces chemical-free, healthier food.
- Enhances long-term farm sustainability.

India has made notable progress in this field. India ranks among the top 10 countries in organic farming, with 4.4 million hectares under organic certification. States like Sikkim have already gone 100% organic, inspiring others.

CASE STORY 1 – SIKKIM'S SUCCESS:

In 2016, Sikkim became the world's first fully organic state. Farmers there shifted completely to natural manures and pest-control practices. Initially, yields dipped, but within three years, they bounced back. Today, Sikkim not only produces healthy food for its people but also attracts organic tourism, boosting farmer incomes through both agriculture and allied sectors.

Monthly average data of experimental site (2015-16 to 2019-20), Meghalaya,



What is Zero-Budget Natural Farming (ZBNF)

ZBNF, popularized by Subhash Palekar, is a method that promises farming with "zero external cost." The idea is to produce crops without relying on purchased chemical fertilizers or pesticides. Instead, farmers use natural concoctions made from locally available materials.

Core Principles of ZBNF:

- **Jeevamrutha** – A microbial culture made from cow dung, urine, jaggery, pulse flour, and water, used to enhance soil fertility.
- **Beejamrutha** – A seed treatment mixture to protect from seed-borne diseases.
- **Mulching** – Covering soil with crop

residues to preserve moisture and improve fertility.

- **Whapasa** – Reducing irrigation by maintaining soil moisture and aeration balance.

Advantages:

- Drastically reduces input cost.
- Revives soil biology and fertility.
- Makes farming profitable even for small and marginal farmers.

States like Andhra Pradesh and Karnataka have promoted ZBNF widely. Andhra Pradesh, in particular, has set a goal of scaling ZBNF across 8 million hectares by 2030.

Challenges of Organic & ZBNF

While promising, both practices face challenges:

- **Yield Gap:** Initially, yields may drop when farmers shift from chemical-intensive to natural practices.
- **Certification & Marketing:** Organic certification is lengthy and costly, limiting farmer access to premium markets.
- **Awareness & Training:** Many farmers still lack proper training on preparing bio-inputs or managing organic systems.

CASE STORY 2 – ANDHRA PRADESH'S NATURAL FARMING

Andhra Pradesh's Natural Farming Drive Ramaiah, a small farmer from Anantapur district, once struggled with debts due to high fertilizer and pesticide costs. After joining the state's ZBNF program, he began preparing Jeevamrutha using cow dung and urine from his two cows. Within two seasons, his costs dropped by 60%, and he reported better soil health and stable yields of groundnut. "For the first time in years, I saved money instead of borrowing," he says proudly.

Andhra Pradesh's Estimated Cost for Five Years

Categories	Cost per Gram Panchayat (In Rs)	Cost of converting one farmer household (In Rs)
Capacity building	50,80,000	12700
Institution building and finds to farmers' institutions	26,20,000	6550
one-time subsidy/support for access to inputs, tools etc, to farmers and farmers' institutions	4,00,000	1000
PGS Certification, Quality assurance, Tracking and Monitoring	11,60,000	2900
Marketing Capacity Building and Marketing Support	5,60,000	1400
Technical Support and Overall Programme	4,00,000	1000
Total	1,02,20,000	25,550

Data Source: Official Website of ZBNF Programme of Rythu Sadhikara Samstha, Government of Andhra Pradesh

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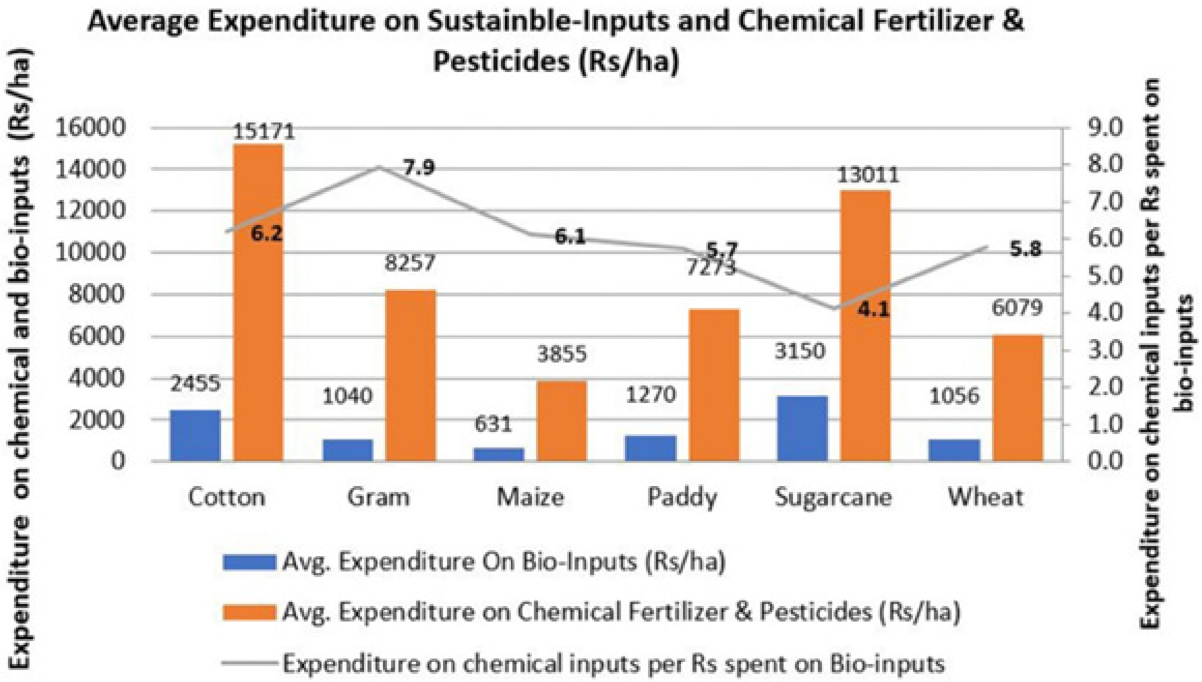
CASE STORY 3 – ORGANIC COTTON IN MAHARASHTRA

In Yavatmal, Maharashtra—often known for farmer distress—some cotton farmers switched to organic cultivation with NGO support. By pooling together and selling directly to textile companies, they now earn 20–25% higher prices compared to conventional cotton. Though certification was tough, collective marketing helped them overcome the challenge, offering hope in a region once dominated by debt and despair.

Future of Sustainable Farming in India

Despite challenges, the demand for sustainable food is growing rapidly. Urban consumers are increasingly willing to pay higher prices for organic produce. Government initiatives such as **Paramparagat Krishi Vikas Yojana (PKVY)** and **Bhartiya Prakritik Krishi Paddhati (BPKP)** are supporting farmers with subsidies, training, and market linkages. Experts believe a **hybrid model—**integrating the best of organic, natural, and modern scientific practices—could shape the future of Indian agriculture.



CONCLUSION

Organic farming and ZBNF are more than just techniques—they represent a movement toward ecological balance, farmer self-reliance, and healthy food production. If given proper policy support, training, and market access, these practices can transform Indian agriculture into a sustainable, resilient, and profitable system for generations to come.

Sustainable agriculture is not just an alternative—it is a necessity for India's future. Organic farming and ZBNF empower farmers to reduce costs, regenerate soil, and produce healthier food. The experiences from Sikkim, Andhra Pradesh, and Maharashtra demonstrate that with proper policy support, training, and marketing linkages, these practices can deliver both ecological and economic benefits.

The path ahead may involve integrating the best of traditional knowledge with modern innovations to create a hybrid, resilient model of farming. If scaled properly, sustainable practices could ensure food security, farmer prosperity, and environmental balance for generations to come.

THE YEAST FEAST: ENGINEERING MICROBES TO CONSUME ALL SUGARS FOR BIOFUEL PRODUCTION

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INTRODUCTION

The ethical shift from first-generation biofuels derived from food crops to second-generation biofuels from non-food lignocellulosic biomass has created a major technical hurdle for the industry. Lignocellulosic material, a complex composite of cellulose, hemicellulose, and lignin, yields a diverse mixture of fermentable sugars upon breakdown. While cellulose is a source of glucose, hemicellulose yields a variety of other sugars, predominantly the pentoses D-xylose and L-arabinose. The industrial standard for fermentation, Saccharomyces cerevisiae, is highly efficient at converting glucose into ethanol but is naturally unable to ferment non-conventional sugars like xylose and L-arabinose. It also metabolizes galactose with notable inefficiency. This inherent metabolic limitation means that without a metabolic overhaul, a significant portion of the energy in lignocellulosic biomass remains untapped, presenting a key bottleneck to commercial viability.

A NEW BLUEPRINT: METABOLIC ENGINEERING TO WIDEN THE MENU

Metabolic engineering is a scientific discipline focused on modifying a microbe's genetic code to introduce new capabilities or optimize existing ones. This process relies on a suite of sophisticated tools like CRISPR-Cas9, an "RNA-guided molecular scissor" that enables "more sophisticated, accurate, and cheaper gene editing". This technology accelerating the creation of complex genetic circuits that were previously very time-consuming to build. Another crucial partner is Adaptive Laboratory Evolution (ALE). While rational genetic design provides the initial blueprint, ALE complements this by subjecting engineered strains to gradually increasing stress over many generations. This process guides the microbe's evolution, allowing it to acquire beneficial mutations that fine-tune its performance. The combination of rational design with evolutionary fine-tuning is a powerful strategy for creating robust, industrially viable strains.

ENGINEERING A VERSATILE FERMENTER: THE SUGAR-BY-SUGAR SOLUTION

By applying this toolkit, researchers are systematically expanding the range of sugars that S. cerevisiae can consume, transforming it into a versatile microbial factory capable of maximizing biofuel yields from diverse feedstocks.

Unleashing Xylose Fermentation:

D-xylose is the second most abundant sugar in plant biomass, and its efficient conversion is a top priority. Scientists have tackled this challenge by introducing a heterologous metabolic pathway. The "isomerase pathway," which uses a single enzyme to directly convert xylose, is often preferred over the alternative "oxidoreductive pathway" because it avoids a problematic redox imbalance that can lead to wasteful by-product accumulation. Engineering efforts have been highly successful, with one engineered strain achieving a 2.6-fold increase in anaerobic growth rate and a high ethanol yield of 0.41 g per gram of xylose.

Unlocking L-Arabinose and Galactose:

L-arabinose is another significant pentose sugar in lignocellulosic biomass. Similar to xylose, engineers have introduced a bacterial isomerase pathway from organisms like Lactobacillus plantarum to enable its efficient metabolism. For galactose, a sugar that yeast can ferment inefficiently, the solution was not a new pathway but a regulatory rewrite. By knocking out the COX9 gene to block respiration, engineers forced yeast to

ferment galactose anaerobically, resulting in a 94% increase in ethanol yield and a 6.9-fold increase in productivity.

Tackling Cellobiose:

Cellobiose is a key intermediate in the breakdown of cellulose, but wild-type yeast cannot consume it. Engineers have addressed this by introducing genes for a cellodextrin transporter (CDT-1) and a β-glucosidase enzyme (GH1-1) from other organisms. This allows the yeast to directly import and ferment cellobiose, bypassing the need for expensive external enzymes and improving the overall efficiency of the process. In a notable example, an engineered strain was able to produce 16.8 g/L of ethanol from 40 g/L of cellobiose within 24 hours.

THE ROAD AHEAD: A MULTI-PRODUCT BIOECONOMY

The successful genetic engineering of yeast to consume this full spectrum of sugars is pivotal for the economic and environmental future of the biofuel industry. It allows biorefineries to use low-cost, abundant feedstocks and maximize the amount of fuel produced from every ton of waste.

The ultimate vision is a "biorefinery" model where a single stream of agricultural waste is converted not just into one fuel, but into a portfolio of high-value fuels, chemicals, and bioproducts. This multi-product approach, enabled by robust and versatile microbes, is critical for long-term economic viability. By engineering yeast to consume waste and produce designer molecules, we are building a new, sustainable bioeconomy where industrial biotechnology becomes a cornerstone of our energy, chemical, and materials production.

Future Harvest: An Artificial Intelligence for Horticulture

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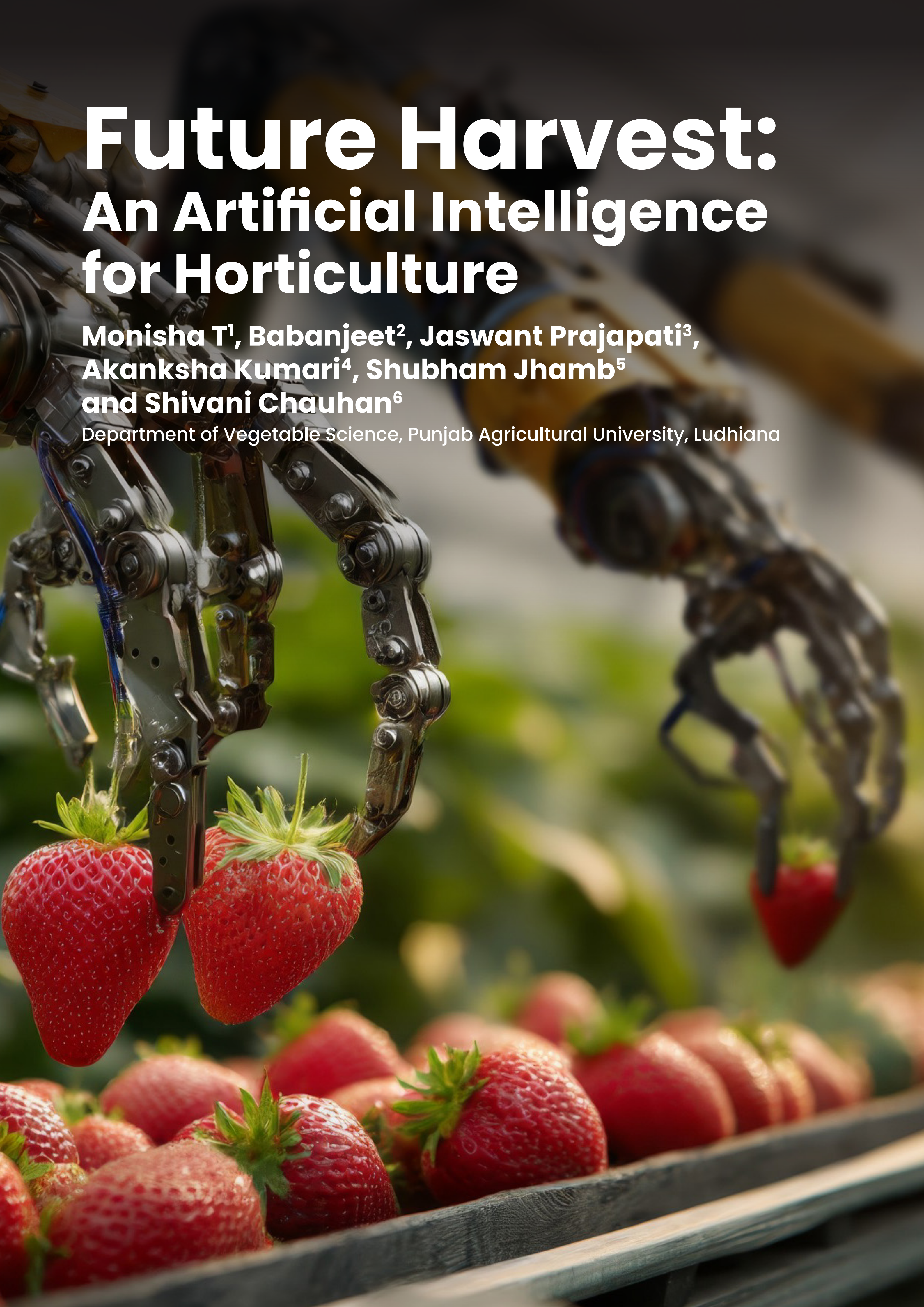


Artificial intelligence (AI) refers to the creation of intelligent machines capable of performing tasks that typically require human intelligence. It is a branch of computer science focused on developing both physical and virtual systems that can think, learn and act like humans, achieving comparable performance in cognitive tasks through logical reasoning. In horticulture, AI has a wide range of applications. It can detect plant diseases, improve crop yields, manage weeds, identify nutrient deficiencies and optimize fertilizer use. By learning from past data, AI enables fast and accurate decision-making. Machine learning, a subset of AI, develops tools and algorithms to solve such problems. For example, AI-based automated systems using computer vision and machine learning incorporating like features can identify the ripest fruits and vegetables for harvest. AI technology not only diagnoses issues quickly but also recommends precise corrective actions. It excels in monitoring data, finding solutions promptly and supporting precision agriculture. The ongoing digital transformation of agriculture and horticulture driven by industrialization, mechanization, networking and data management promises significant benefits for both producers and consumers. With the rise of digital agriculture, the next major revolution in farming is already underway.

Keywords: Horticulture, Artificial Intelligence (AI), Machine Learning Computer Vision, Precision Agriculture and Digital Transformation

INTRODUCTION

India has diverse soils, climates and agro-ecological zones support a wide variety of horticultural crops, including fruits, vegetables, medicinal, aromatic, and ornamental plants. These crops are vital for nutrition, medicine, aesthetics, and rural livelihoods, with fruits and vegetables making up 90% of production. India ranks second globally in fruit and vegetable output after China. Despite its economic importance, horticulture remains less digitalized and vulnerable to biotic and abiotic stresses. Modern technologies, especially artificial intelligence (AI), can enhance productivity by optimizing planting, irrigation, harvesting, and monitoring. AI offers real-time insights on weather, soil, pests, and crop conditions, improving efficiency, reducing labor needs, and strengthening the food supply chain.

ADVANTAGES OF AI IN THE HORTICULTURAL SECTOR

AI offers several key benefits for horticulture:

- Enables more efficient production, harvesting and marketing of essential crops.
- Detects defective produce early, thereby enhancing the chances of healthy crop yields.
- Strengthens agro-based businesses by improving operational efficiency.
- Supports applications such as automated machinery adjustments, weather forecasting and rapid identification of diseases or pests.
- Enhances crop management practices and provides solutions to challenges like climate variability, pest infestations and weed control factors that often reduce yields.
- Complements rather than replaces human labor, helping farmers improve processes instead of eliminating jobs.

APPLICATIONS

Produce Maturity Identification

Determining fruit ripeness involves capturing images of crops under white or UV-A light. This is particularly valuable for highly perishable horticultural products, where farmers can classify produce into different maturity grades based on the crop or fruit type and sort them accordingly before sending them to market. Harvesting at the optimal maturity stage not only improves quality but also extends post-harvest shelf life.

Automation in Irrigation

The integration of the Internet of Things (IoT) with artificial intelligence (AI) has transformed irrigation into a highly efficient and automated process. IoT-based smart irrigation systems use a network of soil moisture sensors, weather stations, and data analytics platforms to monitor soil water content, temperature, humidity, and other meteorological factors in real time. These systems can determine exactly when and how much water a crop needs, preventing both under- and over-irrigation. Irrigation is traditionally one of the most labor-intensive tasks in farming, requiring manual monitoring of field conditions and extensive physical effort. However, with AI, the process becomes far more streamlined. AI algorithms process historical weather patterns, soil quality data, and crop-specific water requirements to make predictive decisions. For example, if the system detects low soil moisture and forecasts no rainfall in the coming days, it can automatically trigger irrigation with the optimal amount of water needed. This level of automation not only conserves water resources but also reduces labor costs and ensures that crops receive consistent care, ultimately leading to higher yields and improved quality.

AI IN SHAPING THE FUTURE OF FARMS

Drones in Agriculture

Drones, or unmanned aerial vehicles (UAVs), have become indispensable tools in modern precision farming. Equipped with high-resolution cameras, multispectral sensors, and AI-powered analytical software, drones can conduct in-depth field analysis, perform long-range crop spraying, and provide high-efficiency crop monitoring. Using drone technology, farmers can:

- Assess soil conditions to determine if an area is suitable for planting or requires watering.
- Monitor crops for signs of stress such as dehydration, nutrient deficiencies, or pest infestations.
- Identify problem areas early, allowing for targeted interventions that save time and resources.

Cameras on drones are often trained with AI models to recognize visual anomalies, such as yellowing leaves (nutrient deficiency) or irregular patches (pest damage). All collected data is processed to predict the optimal harvest period, helping to avoid premature or delayed harvesting. Drones also excel at crop spraying—covering large areas quickly, evenly, and with minimal waste. Compared to conventional spraying equipment, aerial spraying with drones is up to five times faster, making them a cost-effective and time-saving solution. The ability to perform real-time scanning and adjust spraying patterns on the fly ensures that every plant receives the necessary treatment without excessive chemical use.

2. Robotics in Greenhouses

Greenhouses have also embraced automation through robotic arms and AI-driven systems. These robotic arms are capable of performing complex 3D movements with high precision, such as:

- Lifting potted plants from carriers.
- Placing them onto tables or trays in exact positions.
- Rearranging plants for optimal spacing and growth conditions.

Even when plants are misaligned, AI-guided robotic systems can adjust their grip and movement to handle them safely. This automation reduces the manual labor required for repetitive greenhouse tasks, increases operational efficiency, and ensures that plants are handled consistently and gently, reducing damage. Additionally, such systems can be integrated with environmental sensors to automatically adjust lighting, temperature, and humidity for optimal plant health.

3. Fruit Harvesting Robots

Fruit-picking robots represent one of the most advanced applications of AI and automation in horticulture. These robots must delicately remove fruit without damaging branches, leaves, or the produce itself. They achieve this through a combination of computer vision and mechanical precision:

Detection: Cameras mounted on the robot's arm capture images of the tree canopy. The AI system processes these images to differentiate between fruit and foliage based on color, shape, and size.

Verification: The detected color is compared to reference data stored in memory. If a match is confirmed, the robot moves to harvest the fruit.

Obstruction Management: If leaves block the view of the fruit, an air jet gently moves the foliage aside to allow for accurate identification.

Harvesting: The robotic gripper applies just enough pressure to detach the fruit without bruising it. The design of the gripper varies according to the type of fruit or vegetable being harvested

AI-POWERED ROBOTICS AND SYSTEMS IN HORTICULTURE

1. Lettuce Weeding and Thinning Robots

Specialized robots for lettuce weeding and thinning are being used to significantly enhance lettuce productivity. Equipped with high-resolution vision systems and advanced artificial intelligence algorithms, these robots inspect each individual plant with precision. The AI system then decides which plants should be retained for optimal growth and which should be removed to reduce overcrowding. By making these selective decisions in real time, the robot ensures that each plant receives adequate sunlight, nutrients, and space, thereby improving both yield and quality. Such automation also reduces the need for manual labor in repetitive, time-consuming tasks, allowing farmers to focus on higher-level management operations.

2. Automated Tractors

The agricultural tractor, a cornerstone of modern farming for over a century, is now undergoing a transformation into a fully autonomous machine. By integrating sensors, radar systems, GPS navigation, and sophisticated AI software, automated tractors can perform plowing, planting, and other field operations with minimal human intervention. These self-driving machines are capable of working long hours without fatigue, maintaining consistent accuracy, and reducing human error. Farmers will soon be able to delegate entire field preparation tasks to robotic tractors, improving efficiency and lowering operational costs.

AI IN HORTICULTURE: CURRENT APPROACHES AND ACHIEVEMENTS

A. Blue River Technology – Precision Weed Control

Weed management is a critical challenge for farmers, especially as more than 250 species of weeds have developed resistance to common herbicides. To address this, California-based startup Blue River Technology has developed the "See & Spray" robot, which uses computer vision and AI algorithms to identify weeds in real time and apply herbicides only where needed. This precision spraying approach can reduce herbicide use by up to 90%, minimizing environmental impact while cutting costs. In addition to weed control, the system can also target and apply fertilizers directly to individual plants, ensuring efficient nutrient management.

B. Crop Harvesting Solutions

Labour shortages in agriculture have caused substantial economic losses, particularly in labor-intensive crops such as strawberries. In response, Harvest CROO Robotics, in collaboration with Florida-based Wish Farms, developed an autonomous strawberry harvester capable of picking and packing strawberries directly in the field. First introduced in 2017, this machine uses AI to identify ripe strawberries, gently harvest them, and place them into containers, significantly reducing reliance on manual labor while ensuring timely harvesting to maintain fruit quality.

C. AI for Monitoring Crop and Soil Health – PEAT's Plantix

Berlin-based agricultural technology startup PEAT has created Plantix, a deep learning-based mobile application designed for diagnosing plant pests, diseases, and soil nutrient deficiencies. Using machine vision, farmers can simply take photographs of affected plants or soil samples, and the AI-powered system will analyze the images to detect possible problems. Plantix can identify nutrient deficiencies, pest infestations, fungal infections, and other crop health issues, providing farmers with recommendations for corrective measures. This enables faster decision-making, reduces crop losses, and supports sustainable farming practices by ensuring timely and targeted interventions.

D. Trace Genomics – Machine Learning for Soil Diagnostics

Trace Genomics, a California-based company, provides cutting-edge soil analysis services for farmers, using machine learning to diagnose soil defects. Similar in concept to the Plantix app, this system goes a step further by offering a comprehensive breakdown of a soil's health profile. The company, supported by Illumina as a lead investor, has developed a platform that analyzes soil samples sent by farmers. Once processed, users receive a detailed report outlining the

soil's strengths, weaknesses, and overall fertility status. This empowers farmers to make informed decisions about crop selection, nutrient management, and soil amendment practices.

E. Farm Shots – Satellite and Drone-Based Crop Monitoring

Based in Raleigh, North Carolina, Farm Shots specializes in analyzing agricultural data collected through satellite imaging and drone surveys. The company's primary goal is to detect plant diseases, pest infestations, and nutrient deficiencies before they cause significant yield losses. One of its major contributions is optimizing fertilizer usage—its software can pinpoint exactly where fertilizer is needed, potentially reducing fertilizer application by up to 40%. Farm Shots leverages hyperspectral imaging and 3D laser scanning to capture high-resolution data capable of distinguishing individual fields, plots, and even single plants. This high spatial resolution, combined with the temporal advantage of tracking changes throughout the growing season, provides farmers with unparalleled insights into crop health. These technologies are scalable, making it possible to monitor plant health across thousands of acres efficiently

F. aWhere – Satellite-Based Agronomic Intelligence

aWhere, headquartered in Colorado, uses a combination of satellite imagery and machine learning algorithms to deliver actionable insights to farmers. Their system monitors agricultural land to detect diseases, identify pests, forecast weather conditions, and evaluate the sustainability of crop production. The platform processes more than one billion points of agronomic data each day, covering variables such as temperature, rainfall, wind speed, and solar radiation. These measurements are compared with historical climate data from anywhere in the world, enabling highly localized and accurate decision-making.

EXPERT SYSTEMS IN AGRICULTURE

Agriculture today is a sophisticated and data-intensive industry that requires integrating knowledge from multiple disciplines. Farmers often rely on agricultural experts for guidance in crop management, pest control, soil health, and weather forecasting. However, in many cases, expert advice is not readily available when needed. To address this challenge, expert systems—also known as knowledge-based systems (KBS)—have been developed. An expert system is a specialized computer program designed to replicate the decision-making processes of a human expert. In agriculture, these systems integrate expertise from fields such as plant pathology, entomology, horticulture, agronomy, and agricultural meteorology into a unified decision-support platform. They can provide farmers with customized, situation-specific advice, even in the absence of direct expert consultation. Some notable expert systems developed for horticultural crops include:

- Cuptex – An expert system for cucumber crop production.
- Citex – Designed for the cultivation and management of orange orchards.
- Tomatex – Tailored for tomato production.
- Limex – A multimedia expert system for lime production.

These tools combine scientific knowledge, real-time field data, and AI-driven analytics to provide timely recommendations, thereby improving crop quality, optimizing resource use, and increasing farm profitability.

ARTIFICIAL INTELLIGENCE IN PROTECTED CULTIVATION

AI in Greenhouse Cultivation

Greenhouse farming is already automated, but AI takes it to new levels of precision by processing real-time crop and environmental data to adjust lighting, irrigation, temperature, nutrients, and ventilation. It predicts yields, improves quality, optimizes resources, and supports sustainabilityespecially important for large greenhouse networks facing labor shortages and rising demand. AI can also link growing conditions with post-harvest quality by adjusting parameters based on consumer feedback to extend shelf life.

Plant Phenotyping & Crop Sensors

Plant phenotyping measures traits like growth rate, architecture, and composition, now used in production to maintain crop health. Digital systems use cameras, depth sensors (e.g., Intel RealSense), and LiDAR to gather 3D plant data. To overcome dense crop occlusion, mobile platforms such as trolleys, drones, and robotic arms capture plants from multiple angles. AI then processes these images into accurate 3D models for analysis.

Digitalisation and AI for Crop Physiology Monitoring

Physiological performance, especially photosynthesis, is key to crop monitoring. Non-destructive tools like chlorophyll fluorescence imaging and thermal imaging can assess photosynthetic efficiency and detect stress early. Imaging spectroscopy further enables real-time, in-field chemical analysis of pigments, sugars, proteins, and water, replacing slow, destructive lab methods. AI-powered image segmentation enhances precision by automatically identifying and analyzing plant parts.

The Role of AI in Data Integration and Decision-Making

Spectral cameras and other high-resolution sensors generate enormous volumes of data, which can be difficult for human operators to process. AI techniques are therefore essential for extracting meaningful information from these datasets. AI algorithms can:

- Filter noise from raw data.
- Identify patterns and correlations between environmental conditions and crop traits.
- Combine outputs from multiple sensors into a unified decision-making model for growers.

LIMITATIONS OF ARTIFICIAL INTELLIGENCE IN HORTICULTURE

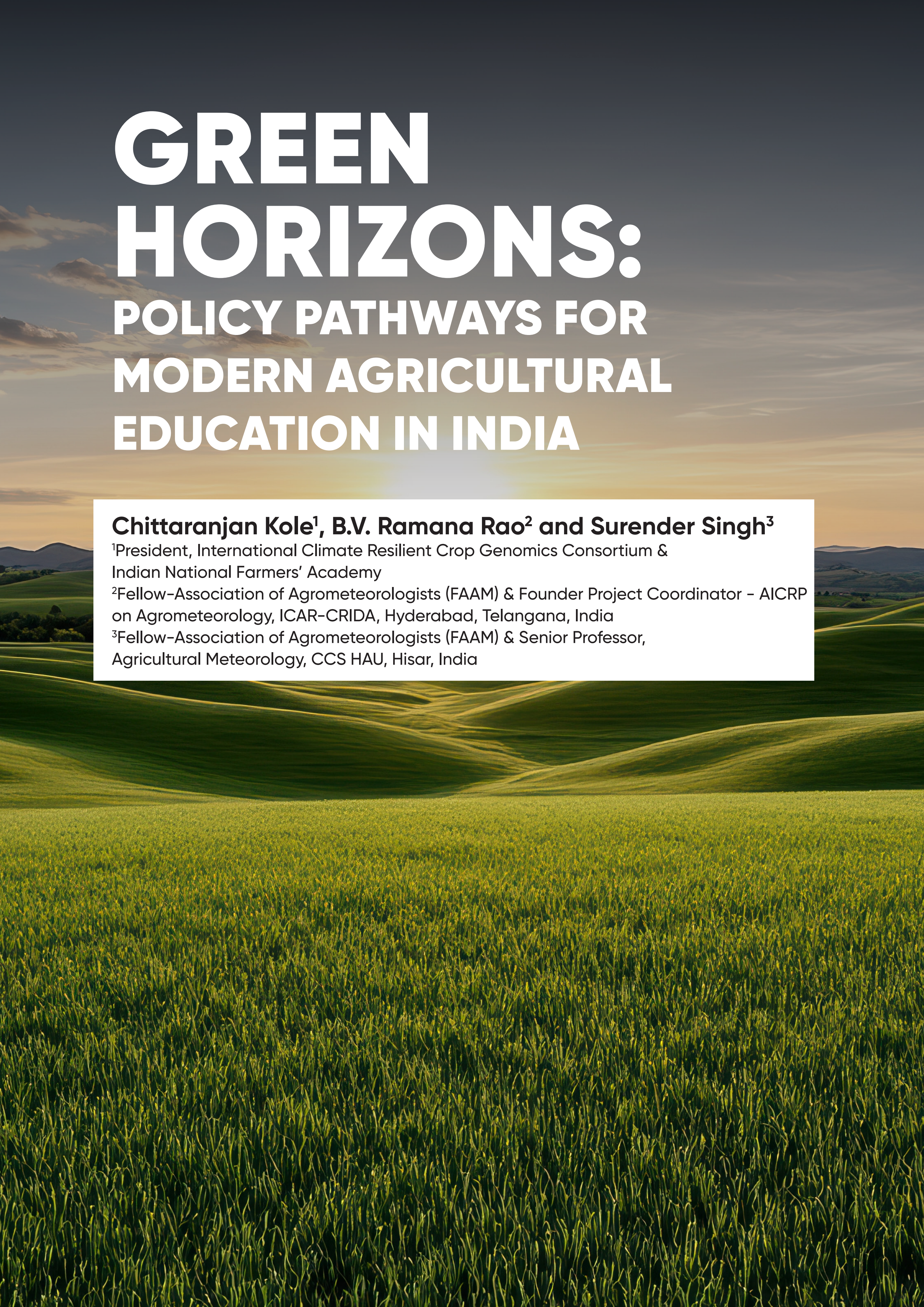
Despite its potential, the adoption of Artificial Intelligence (AI) in horticulture faces several challenges. In many parts of the world, farmers have limited exposure to advanced machine learning and AI-based solutions, making their acceptance and effective utilization difficult. The high initial cost of AI technologies is another significant barrier, especially for small and medium-scale farmers who may not have access to sufficient financial resources. Furthermore, AI systems require large volumes of high-quality data for training algorithms and ensuring accurate predictions. Collecting, storing, and processing this data can be technically demanding and expensive.

CHALLENGES AND FUTURE SCOPE

The horticulture sector continues to face pressing issues such as inadequate irrigation infrastructure, unpredictable temperature fluctuations, declining groundwater reserves, food shortages and post-harvest wastage. The future of sustainable horticulture depends heavily on adopting cognitive and digital solutions that can address these concerns effectively. However, the application of autonomous decision-making systems and predictive analytics in farming is still at a relatively early stage. AI can be used to forecast weather patterns, assess land quality, monitor groundwater levels, predict pest or disease outbreaks, and determine optimal crop cycles. AI-enabled sensors, when integrated into robotic harvesting equipment, can collect real-time data for better operational decisions. It is estimated that AI-powered advisory systems could potentially increase horticultural productivity by up to 30%. Nevertheless, farmers must adapt to the digital transformation trend, embracing AI to enhance efficiency and resilience in their practices. This transition marks the beginning of a new agricultural revolution—one that demands innovative, resource-efficient strategies to meet the needs of a growing global population.

CONCLUSION

Artificial Intelligence in agriculture and horticulture not only automates routine tasks but also facilitates precision farming, leading to higher yields, improved crop quality, and reduced resource consumption. Labour constitutes one of the largest expenses in horticulture—often exceeding 50% of total production costs due to the intensive care and skill required for high-value crops. AI technologies can optimize labour usage, ensure the efficient application of herbicides and fertilizers, and minimize crop losses by enabling timely harvesting. By integrating AI across various horticultural applications, farmers can boost productivity while reducing production costs. The use of AI will transform research and development in horticulture, promoting innovation in areas such as drone-based imaging, automated processing, and intelligent greenhouse systems. As AI-based solutions advance, they will bring more efficient, sustainable, and scalable approaches to crop production. Ultimately, AI represents a technological revolution in horticulture—a powerful tool to meet the food demands of the world's growing population. It will empower farmers with data-driven insights, challenge them to make better decisions, and contribute to a more sustainable agricultural future.



GREEN HORIZONS: POLICY PATHWAYS FOR MODERN AGRICULTURAL EDUCATION IN INDIA

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In the pursuit of a hunger-free and prosperous India, a nation where the vast rural population thrives and contributes equitably to the economy, a critical review of existing policy frameworks is not merely advisable but essential. The urgency of this challenge is underscored by stark statistics, most notably India's concerning position in the 2024 Global Hunger Index, where the nation ranked 105 out of 127 countries with a serious hunger level score of 27.3. Such data makes it abundantly clear that existing policies have not been sufficient to ensure food security or economic well-being for all citizens. Without a skilled human capital pipeline capable of fostering innovation, entrepreneurship, and sustainable practices, the promise of a revitalized agricultural sector remains unfulfilled. Thus, there is need for a comprehensive and critical examination of the present educational policy.

EVOLUTION OF AGRICULTURAL UNIVERSITIES IN INDIA

Dr. S. Radhakrishnan's University Education Commission (1948-49), in its report submitted shortly after India's independence, strongly advocated for a transformative approach to agricultural education to achieve national food self-sufficiency. The committee recognized that traditional educational models were inadequate to meet the monumental challenge of feeding a rapidly growing population. It proposed the establishment of a new kind of institution: agricultural universities based on the American land-grant model.

The committee's vision was to create institutions that were not just centers of academic learning but also engines of rural development. This model, exemplified by institutions like G.B. Pant University of Agriculture and Technology was built on three core pillars teaching, research and extension. This vision with the establishment of GBPUAT in 1960, served as a blueprint for other SAUs to train professionals with a holistic understanding of the agricultural ecosystem and to ensure that relevant research findings reached farmers. During the early years, SAU's were designed to provide comprehensive, integrated education. They brought together various discipline to train a new generation of professionals with a holistic understanding of the agricultural ecosystem, rather than a narrow, discipline-specific view. The land-grant model mandated that research should be directly relevant to the needs of the local farming community. Perhaps the most revolutionary aspect of this model was the emphasis on extension services. The universities were not only responsible for education and research but also for taking that knowledge directly to the farmers. With SAUs taking lead in extension work in their domain areas with close linkages with the state development departments, the Extension Division of ICAR is superfluous.

FRAGMENTATION OF AGRICULTURAL UNIVERSITIES

However, the land-grant model has faced significant challenges due to fragmentation. Over time, new SAUs have been carved out of existing ones, often in response to regional political demands. In addition to regional splits, there has been a trend of establishing separate, discipline-specific universities for subjects like horticulture, animal sciences, and fisheries. By separating disciplines, these universities create academic and professional silos. For example, a student specializing in animal husbandry may have little exposure to the challenges and opportunities in crop production, despite the fact that feed for livestock comes from crops. This makes it difficult to train professionals who understand the interconnected nature of modern farming systems, where crops, livestock, and fisheries are often integrated in practices like integrated farming systems. The overall result of this fragmentation is a diluted and less-integrated approach to agricultural education in India. Therefore, all states must have only land-grant type integrative SAU's by converging universities with fragmented mandate.

As on today there are 63 SAUs and 3 Central Agricultural Universities in the country. The establishment of Central Agricultural Universities (CAUs) in states already served by multiple State Agricultural Universities (SAUs) creates a potential for duplication of efforts and unhealthy competition, rather than fostering a complementary academic environment. While SAUs are designed to address the specific agricultural needs of their states, a CAU, with its national mandate and central funding, can inadvertently compete for resources, talent, and research priorities. This can result in a "race to the bottom" for student admissions and faculty recruitment, as both institutions compete for the same talent pool. Furthermore, government funding, a key resource, may be inefficiently split between institutions with overlapping mandates. It is better to transfer CAU's to respective states. For example, Uttar Pradesh has many agricultural universities and colleges, e.g. SHUATS, NDUAT, CSAUAT, SVPUAT, BHU, etc. Establishment of a CAU at Jhansi is perhaps redundant.

TEACHING PROGRAMS IN ICAR INSTITUTIONS

The Indian Council of Agricultural Research (ICAR), a premier body for agricultural research and education, has of late ventured into offering academic teaching programs in its research institutions that are largely indistinguishable from those already available at State Agricultural Universities (SAUs) and Central Agricultural Universities (CAUs). The primary role of ICAR has traditionally been to serve as the nation's premier agricultural research hub, focusing on high-impact projects that require specialized infrastructure and long-term commitment. Its scientists are hired for their expertise in specific, often niche, research areas. By diverting these scientists' time and energy to a full-fledged teaching curriculum, the ICAR system is compromising its core function. Teaching demands a substantial amount of time

for course preparation, lecture delivery, examination conduct, and student counseling. These are all activities that detract from the time available for laboratory work, field trials, data analysis, and publication—the very tasks for which ICAR was established. This duplication of teaching efforts is particularly problematic in a country with a well-established network of SAUs and CAUs. The ICAR should focus undertaking research in frontier areas of agricultural sciences and free itself from education and extension activities. The national agricultural agencies in the countries leading in agricultural research are focused exclusively on research except lending hands to the universities in taking specialized courses and even guiding research on specialized fields. One can cite examples of USDA, INRAE, ARO, EMBRAPA, etc.

AUTONOMY OF AGRICULTURAL UNIVERSITIES IS AN ILLUSION

The notion of autonomy for State Agricultural Universities (SAUs) is largely an illusion, primarily because their academic and operational freedom is significantly curtailed by the Indian Council of Agricultural Research (ICAR). While SAUs are formally under the jurisdiction of their respective state governments, their core functions—from curriculum design to examination patterns—are centrally dictated, leaving little room for independent thought or regional adaptation.ICAR designs and mandates a uniform syllabus for all academic programs across the country. This one-size-fits-all approach is a

major flaw, as it fails to account for the diverse agro-climatic zones and unique agricultural challenges of different states. For example, the curriculum taught at an SAU in Punjab, a state known for its grain production, is almost identical to the one taught in Kerala, which specializes in spices and plantation crops. ICAR's control extends to the examination system, prescribing a uniform pattern that all SAUs must follow. This standardized approach often prioritizes rote learning and a theoretical understanding of subjects rather than practical, hands-on skills or critical thinking. It removes the university's ability to experiment with more effective assessment methods, such as project-based learning or practical examinations that would better reflect a student's true competence.SAUs are not empowered to introduce new courses in response to local industry demands or emerging technologies. If a region requires expertise in a niche field like drone-based agriculture or hydroponics, the university cannot easily create a program for it without a lengthy and often bureaucratic approval process from ICAR. This lack of flexibility makes SAUs slow to adapt, leaving them perpetually behind the curve of rapid technological and market changes in the agricultural sector. For SAUs to become true drivers of rural development, a fundamental policy shift is required. ICAR's role should be redefined from a regulator to a facilitator and confine itself to lead research in frontier areas of agricultural sciences. The SAUs must operate with complete autonomy from the administrative control of the Indian Council of Agricultural Research (ICAR). This includes the freedom to select their own Vice Chancellors (VCs), design their curricula, and manage their finances without central interference. Each State Agricultural University (SAU) is situated in a unique agro-climatic zone with its own specific challenges and opportunities. A blanket curriculum and administrative approach, dictated by a central body like ICAR, cannot effectively address regional priorities.

ACADEMIC LEADERSHIP OF VICE CHANCELLORS

The selection of a Vice Chancellor (VC) is a critical factor in a university's success. When VCs are selected by a central body, the process can become politicized, and the chosen candidate may lack a deep understanding of the local context or the vision to lead the institution effectively. Granting SAUs the autonomy to select their own VCs would allow them to choose dynamic, visionary leaders with a clear plan for the university's development and a strong connection to the state's agricultural community. This, in turn, would help attract and retain top-tier faculty and researchers who are eager to work in an environment that values academic freedom and innovation. The disparity in the recruitment of Vice Chancellors for agricultural universities is a significant concern, as the selection process often falls short of ensuring that the chosen candidate is a true academic leader. The ideal Vice Chancellor must be an eminent scholar in agricultural sciences with experience in teaching as Professor for not less than ten years and proven record of quality research, not a bureaucrat or an individual lacking professional experience in academia. An effective Vice Chancellor of an agricultural university must embody a rare blend of academic excellence, visionary leadership, and administrative competence. Their qualifications should not be a checklist of formalities but a testament to their professional and intellectual capabilities.

EVALUATION OF SAU'S

The evaluation of State Agricultural Universities (SAUs) should be conducted by an independent body rather than the Indian Council of Agricultural Research (ICAR). This is essential to ensure objectivity, prevent conflicts of interest, and promote genuine, constructive feedback for the SAUs. ICAR, which also runs its own academic programs, is not an impartial evaluator of institutions with which it is in direct competition. A fundamental principle of effective evaluation is the absence of a conflict of interest. The evaluation metrics and criteria are often designed to favor a one-size-fits-all approach that ICAR itself promotes. This discourages SAUs from innovating or tailoring their programs to suit specific regional needs. For instance, an SAU in a coastal region might want to invest heavily in a specialized aquaculture program, but if the ICAR evaluation framework does not highly value such specialization, the university may be penalized. To ensure a fair and effective evaluation system, an independent body with no direct stake in running academic programs should be established. This body's mandate would be to evaluate SAUs based on transparent, outcome-oriented criteria, such as:

- **Graduate employability and entrepreneurship.**
- **The societal impact of research on local farmers and communities.**
- **The quality of faculty and infrastructure.**
- **The relevance of the curriculum to current industry needs.**

LEADING INDIA TO GREEN HORIZONS

To truly lead India toward new "Green Horizons," a profound and sustained evolution of its agricultural education system is indispensable. It's no longer enough to rely on the Green Revolution-era policies that focused on high-yield crops and chemical inputs. The new pathways must be designed to meet the complex and multifaceted challenges of a climate-constrained future, including soil degradation, water scarcity, and the need for greater biodiversity. Therefore, policy must shift its focus from a supply-driven, top-down approach to a demand-driven, farmer-centric model. This requires a comprehensive overhaul of the curriculum to integrate modern technologies like AI, machine learning, and data analytics with traditional, indigenous farming knowledge. Furthermore, fostering a culture of entrepreneurship and innovation is critical, as is ensuring that the education system can produce a new generation of agri-preneurs capable of creating market linkages and value-added products. This will not only boost rural incomes but also make the agricultural sector more resilient and attractive to young people. Ultimately, by empowering farmers with the right skills and knowledge, India can achieve its goal of sustainable food security while securing the long-term health of its ecosystems.

Digital Transformation in Agricultural Marketing: A NEW ERA FOR INDIAN FARMERS

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INTRODUCTION:

Agricultural marketing in India has traditionally been dependent on physical mandis (markets), middlemen and highly localized supply chains. This structure often resulted in inefficiencies, market information asymmetries and poor price realization for farmers. However, with the rapid penetration of the internet, smartphones and digital literacy, the agricultural sector has begun to embrace digital platforms as an innovative solution to bridge these longstanding gaps. Digital marketing in agriculture refers to the strategic application of digital tools such as e-commerce websites, mobile applications, cloud platforms, social media and SMS services to connect producers directly with buyers, input suppliers and service providers. These platforms enable data-driven decision-making, traceability, real-time price discovery and reduce the influence of intermediaries.

Prominent platforms like e-NAM, ReMS, e-Choupal, Agmarknet and NCDFI eMarket exemplify this transformation. For instance, e-NAM, launched by the Government of India, has created a unified national digital market by integrating 1522 mandis across the country. Similarly, ITC's e-Choupal initiative uses internet kiosks to connect farmers with buyers, while Agmarknet delivers daily commodity prices via SMS and apps.

KEY DIGITAL PLATFORMS AND INITIATIVES

1. National Agriculture Market (e-NAM)

The e-NAM platform, an initiative of the Government of India, was launched on April 14, 2016. It is managed by the Small Farmers Agribusiness Consortium (SFAC) under the aegis of the Ministry of Agriculture and Farmers' Welfare. The platform aims to provide farmers with better marketing opportunities through a transparent online price discovery system and an online payment facility, thereby reducing the influence of middlemen. The e-NAM portal has been celebrating 8 successful years.

e-NAM has successfully integrated 1,522 mandis across 23 states and 4 Union Territories. It offers a pan-India electronic trading platform, ensuring fair price discovery and increased market access. The platform's features include an online trading and payment system, quality assaying and produce grading, information on prices and arrivals, and a nationwide license for traders.

A significant advancement is the "Platform of Platforms" (POP) under e-NAM, an advanced initiative launched by the Ministry of Agriculture & Farmers Welfare. The POP aims to integrate multiple service providers into the e-NAM ecosystem. It brings together various agri-tech platforms, service providers, logistics, fintech, and warehousing into a single digital interface to serve farmers, traders, and other stakeholders more holistically. Services integrated under POP include quality assaying (real-time lab reports), logistics (trucks, storage, cold chain), ePayments (NEFT, DBT, UPI), eLearning/advisory, FPO linkage, and financial services. The introduction of e-NAM 2.0 and logistics integration is expected to bridge gaps and enable meaningful pan-India trade, addressing fragmentation and supporting long-distance market linkages.

The impact of e-NAM has been notable. A study by Yadav (2018) found that the marketing efficiency of tomatoes under the post-unification of e-NAM was 2.11, which was higher than the pre-unification efficiency of 0.58. The study also showed improvements in the farmer's selling price and the price received by the farmer. A different study revealed that a majority of respondents (72.50%) perceived the transparency in weighment of e-NAM as "good," ranking it first among process-related effectiveness items.

2. Rashtriya e-Market Services (ReMS)

The ReMS scheme was launched in February 2014 by the Government of Karnataka in collaboration with NCDEX e-Markets Limited (NeML). The initiative aims to transform agricultural markets by promoting transparency, efficiency, and fair trade practices. It unifies 162 main and 354 sub-APMCs and covers a total of 92 commodities.

A study by Fathima (2019) in Karnataka showed that among 80 farmers, 45% utilized the ReMS infrastructure to a medium extent, and 26.25% showed high utilization. The study also highlighted challenges faced by farmers, such as lack of computer knowledge (92.50%), poor internet connectivity (75.00%), and delay in payment settlements (60.00%). Suggestions provided by farmers included the provision of computer education (100%), awareness programs about ReMS (95.00%), and simplification of the process (93.75%).

3. e-Choupal

ITC Limited launched the e-Choupal initiative in June 2000. It links rural farmers directly via the internet for the procurement of agricultural and aquaculture products like soybean, wheat, and coffee. There are 6,100 e-Choupals in operation in 35,000 villages across 10 states, covering 4 million farmers. ITC aims to expand e-Choupal 4.0 to 10 million farmers by leveraging technology and widening regional coverage. Each kiosk is managed by a Sanchalak, a trained local farmer, who serves around 600 farmers in a 5 km radius.

A study on e-Choupal usage in Uttar Pradesh found that major constraints perceived by farmers were a lack of awareness (Garrett's Mean Score of 52.98), difficulty in accessibility (44.73), and the information not being provided in the local language (24.88).

4. Agmarknet

The Agmarknet portal, launched in March 2000 by the Ministry of Agriculture, Government of India, provides easy access to commodity-wise and variety-wise daily prices and arrival information for more than 2,000 varieties and about 350 commodities. It has covered 3,918 markets across the country. The portal is

accessible via web, mobile apps, and SMS, and provides analytical reports, including weekly and monthly trend analyses.

5. NCDFI eMarket

The NCDFI eMarket is the National Co-operative Dairy Federation of India's digital trading platform, launched on June 10, 2015. It is an internet-based electronic marketplace for dairy and allied commodities, aiming to improve price transparency, speed, and trade volume. The platform features forward and reverse auctions for products like dairy products, cattle feed, sugar, edible oils, and more. It also provides procurement solutions and e-auction services to the NCCF for trading pulses and other commodities under schemes like the Price Support Scheme (PSS) and Price Stabilization Fund (PSF). Operational modules include farmer registration, farmer procurement, inventory dispatch, and online farmer payments.

MOBILE APPLICATIONS FOR AGRICULTURAL MARKETING

Mobile applications are playing an increasingly crucial role in agricultural marketing, providing farmers with real-time information and tools for decision-making.

- **Krishify Agriculture Kisan App:** Farmers can sell their produce, and trade cattle and fertilizers, with their GPS location displayed.
- **AgriCentral:** This application provides market prices for nearby markets as well as for all of India. Farmers can see market trends for their crops to decide when and where to sell their produce.
- **Uzhavan:** This app provides information about market prices in major markets of Tamil Nadu. A study found that farmers faced challenges with this app, such as a lack of training (92.22%), inadequate agricultural news (84.44%), and the app only functioning in online mode (71.11%).
- **IFFCO Kisan:** Farmers can get access to mandi prices, market status, and price trends, and both buyers and sellers can register their requirements.
- **iKhedut:** This app provides information on government schemes, subsidies, farm inputs, and market details in the Gujarati language.
- **Amul Farmers App:** This app is designed for dairy farmers supplying

IMPACT ON FARMERS AND MARKET EFFICIENCY

Digital platforms have a demonstrable positive impact on farmers. A study on cotton farmers in Hubballi, Karnataka, found that online farmers had a net return of ₹2,718.01 per bale, which was 56.59% higher than the ₹1,735.69 per bale for traditional farmers. The B:C ratio also improved for online farmers (1.48) compared to traditional farmers (1.30). The study also found that marketing costs for online farmers were 28% lower than for traditional farmers.

Furthermore, research indicates a positive and significant correlation between a farmer's profile and their awareness of digital platforms. Education, annual income, training received, extension contact, innovativeness, mobile inclination, and decision-making ability were all found to be positively correlated with a farmer's perception of e-NAM and digital marketing applications. Age and credit acquisition had a negative and significant correlation, while farming experience, landholding, and social participation showed a non-significant relationship.

CONCLUSION AND FUTURE THRUST

Digital marketing is fundamentally transforming agricultural marketing in India by fostering transparency, reducing the role of middlemen, and improving price discovery through platforms like e-NAM, e-Choupal, and Agmarknet. Mobile applications are further empowering farmers with real-time updates and e-commerce functionalities, enabling them to make informed decisions.

However, to fully realize the potential of digital agriculture, a concerted effort is needed to overcome existing challenges. This includes implementing robust awareness programs, developing user-friendly interfaces, and providing inclusive digital training. Strengthening infrastructure to address connectivity gaps and offering strong policy support will be crucial to empowering farmers and integrating them effectively into modern agri-market systems. By focusing on these areas, India can ensure that the digital revolution in agriculture leads to greater prosperity and a more equitable market for all its farmers.

FUTURE THRUST

- Expand regional coverage.
- Enhance digital literacy.
- Strengthen infrastructure.
- Promote platform interoperability.
- Focus on user-friendly design.
- Provide policy and institutional support.
- Encourage global market access.
- Leverage emerging technologies.

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