NEXT IAS

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CHAPTER 1- AGRICULTURE 4.0: TOWARDS AGRI-TECH REVOLUTION

Agriculture continues to be the backbone of India's economy, employing **42.3% of the workforce** and contributing **18.2% to GDP**.

- Yet, it suffers from **low productivity, high climate dependence, small landholdings, post-harvest losses, and volatility in farm incomes**.
- With **89.4% of farmers owning <2 ha of land**, India's yields remain **20–60% lower than global averages** (e.g., rice yield 3.85 t/ha vs. China's 6.57 t/ha).
- **Agriculture 4.0,** driven **by digital technologies (AI, IoT, blockchain, drones, big data, robotics),** offers a pathway to enhance productivity, ensure food security, and boost farmer incomes.

Idea of Digital Agriculture

Digital agriculture refers to the use of **connected tools, data, and digital platforms** to improve productivity, sustainability, and efficiency. It works on two paradigms:

- **SmartFarm Digitisation (On-farm technologies):**
  - IoT soil & crop sensors, drones, automated irrigation, smartphone-based farm management.
  - Benefits: precision farming, reduced input use, climate resilience, labour substitution.
- **SmartAgriSphere Digitisation (Ecosystem-level technologies):**
  - Remote sensing, weather forecasting, blockchain-enabled supply chains, digital marketplaces, credit & insurance platforms.
  - Benefits: transparency, better market linkages, risk management, and institutional strengthening.

Challenges in Indian Agriculture

- **Low productivity:** 20–60% lower yields than global peers.
- **Climate vulnerability:** 52% of farming rainfall-dependent; pest losses may rise 10–25% with each 1°C increase.
- **Resource stress:** 17% groundwater blocks overexploited.
- **Post-harvest losses:** 0.9–15.8% depending on crop.

- **Labour shortages:** 90% of farmers cite labour availability as a challenge.
- **Low adoption of technology:** Drone use remains far behind countries like China, Japan, S. Korea.
- **Digital divide:** Weak internet and affordability issues in rural areas.

Opportunities through Agriculture 4.0

- **Precision Farming:** IoT sensors reduce irrigation needs by up to **50%**; drones enable targeted spraying.
- **Climate Resilience:** Real-time pest/disease monitoring, weather-linked advisories.
- **Supply Chain Transparency:** Blockchain ensures farm-to-fork traceability, boosting exports.
- **Market Linkages:** Digital platforms reduce middlemen, ensure fair pricing.
- **Livestock & Fisheries Digitisation:** Animal health tracking, smart dairies, mapping fishing zones.
- **Agri Stack (Comprehensive Agriculture Management System – CAMS):** Aadhaar-linked farmer IDs, land records, crop data, credit-insurance linkages, scheme monitoring → ensures **evidence-based policy planning**.

Government Initiatives

- **Digital India programme:** broadband to 2.5 lakh villages.
- **PM-KISAN, PMFBY, Kisan Credit Cards, Soil Health Cards.**
- **National e-Governance Plan in Agriculture (NeGPA).**
- **Support to FPOs & Cooperatives:** 8,875 FPOs, 1.01 lakh PACS → UN's 2025 Year of Cooperatives gives new push.
- **ICAR institutes, Agricultural Universities, KVKs:** crucial for lab-to-land transfer.

Way Forward

- **Strengthen digital infrastructure:** high-speed internet, renewable energy-based power supply in rural areas.
- **Inclusive adoption:** subsidies & affordability for smallholders, special focus on women, tribal farmers, and landless workers.
- **Capacity Building:** digital literacy, farmer training, skilling of agri-labour.
- **Policy & Regulation:** clear norms on drones, AI, cybersecurity safeguards.
- **Scale-up through cooperatives & FPOs:** economies of scale for digital agriculture.
- **Public-Private Partnerships:** for affordable agri-tech innovations and customised solutions.

Conclusion

Agriculture 4.0 is not just about adopting digital tools—it is about **reshaping rural economies, enhancing resilience, and ensuring inclusive growth**. By aligning with national missions like **Digital India, Atmanirbhar Bharat, and Make in India**, India can position itself as a **global leader in Agri-Tech**. The true measure of success will be when every farmer, irrespective of land size, thrives in the digital age.

CHAPTER 2- CONSERVATION AGRICULTURE: PRACTICES AND PERSPECTIVES

Introduction

The **Green Revolution of the 1960s** transformed Indian agriculture from subsistence to intensive farming, ensuring food security.

- However, it also led to soil degradation, groundwater depletion, air pollution, and unsustainable resource use. To address these concerns, scientists promoted **Conservation Agriculture (CA)** — a sustainable, resource-efficient, and eco-friendly farming practice.

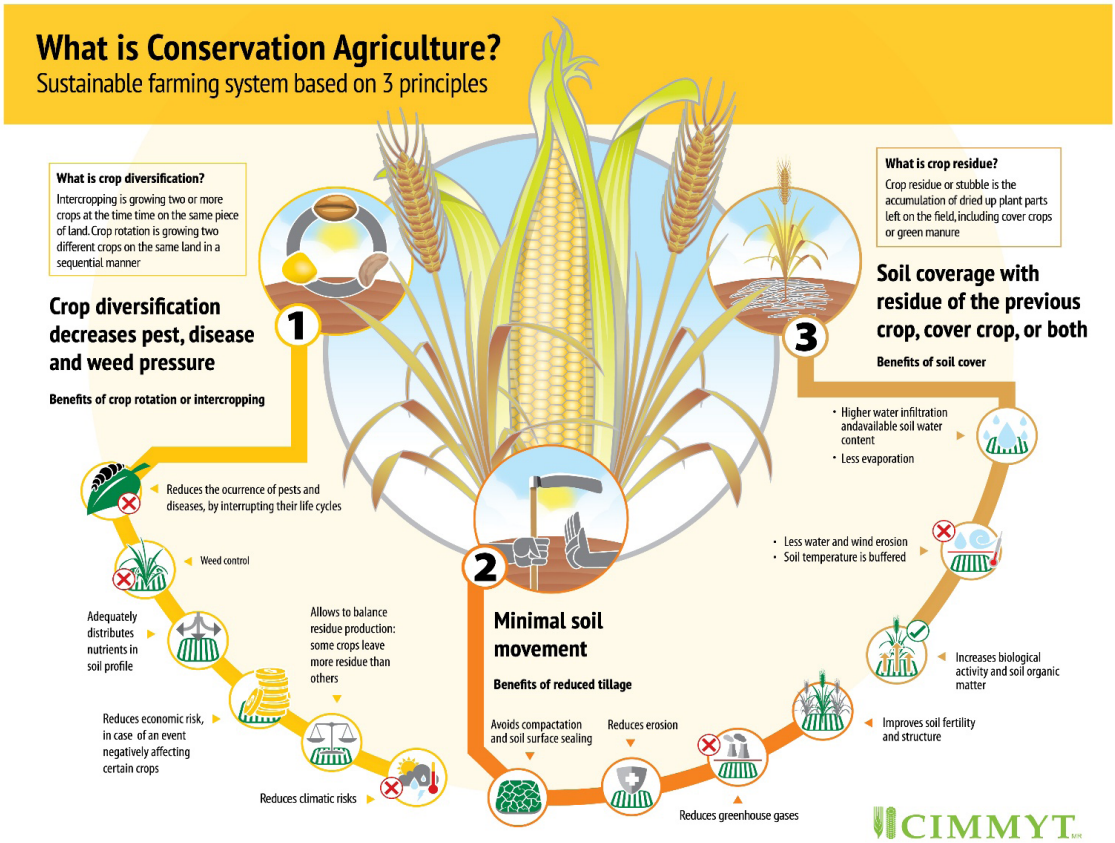
What is Conservation Agriculture (CA)?

According to FAO, CA is a system of managing agro-ecosystems that ensures:

- Food security,
- Profitability,
- Natural resource conservation.

It is based on three core principles:

- **Minimal soil disturbance** (Zero/Reduced tillage),
- **Permanent soil cover** (crop residues/mulching),
- **Crop diversification** (rotations, intercropping).



Significance of CA

- **Economic Benefits**
  - **Reduces cost of** cultivation by saving fuel, labour, and inputs.

- **Enhances farm income** through higher yields.
- Zero-tillage **saves 60 litres of fuel per hectare and** reduces costs by ₹2,000–3,000/ha.

- **Environmental Benefits**
  - **Reduces greenhouse gas emissions** and enhances carbon sequestration (up to 3,667 kg CO_2 per hectare/year).
  - **Prevents soil erosion**, conserves soil moisture, and improves fertility.
  - **Avoids stubble burning**, thus mitigating air pollution.

- **Social Benefits**
  - **Reduces drudgery**, particularly for women farmers.
  - Improves **resilience of small and marginal farmers** against climate variability.

Success Story – Zero Tillage in Bihar: In Rajapur village of Buxar, Bihar, farmers achieved **100% adoption of zero-tillage in wheat cultivation**, leading to remarkable outcomes.

- Yields rose from **3.5 tonnes per hectare in 2014 to 5.5 tonnes per hectare in 2023**, while soil health improved, labour costs declined, and timely sowing ensured better harvests.
- The practice also enhanced food security and reduced emissions, showcasing that **Conservation Agriculture (CA)** can be a transformative model for Indian farming.

Research, Support and Adoption in India

- **Institutional Support**:
  - ICAR, State Agricultural Universities, and international organisations (CIMMYT, IRRI, BISA, etc.) promoting CA.
  - National programs: NICRA, NATP, NAIP.

- **Government Schemes**:
  - Sub-Mission on Agricultural Mechanisation, support for Zero-Till Seed Drills, Happy Seeder, Laser Land Leveller.
  - Initiatives like **Namo Drone Didi Yojana** support women farmers through agri-drones.
  - Currently, **2.5–3 million hectares** are under CA, practiced by over **7 lakh farmers**, mostly in Indo-Gangetic plains.

Challenges in Adoption

- **Technical & Financial Constraints**
  - High cost and limited availability of zero-till machinery.
  - Fragmented landholdings restrict large-scale adoption.

- **Awareness Issues**
  - Lack of knowledge about long-term benefits among farmers.
  - Social reluctance due to dependence on conventional tillage.

- **Policy Gaps**
  - No dedicated national policy for CA.
  - Need for subsidies, mechanisation hubs, and assured crop residue management.

Way Forward

- **Strengthening Mechanisation** – Establish CA hubs at village level with affordable access to machinery.
- **Policy Interventions** – Dedicated schemes promoting CA, crop residue management, and carbon credit incentives.
- **Capacity Building** – Farmer training, field demonstrations, participatory research, and awareness campaigns.
- **Scaling Up Practices** – Expand CA beyond Indo-Gangetic plains to pulses, oilseeds, and coarse cereals in drylands.
- **Climate Resilience** – Integrate CA with climate-smart agriculture for long-term sustainability.

Conclusion

Conservation Agriculture offers a sustainable pathway for Indian agriculture by reconciling **productivity, profitability, and environmental conservation**. With proper policy support, mechanisation, and farmer awareness, CA can enhance farm incomes, ensure food security, reduce emissions, and help India meet its **SDG and climate commitments**.

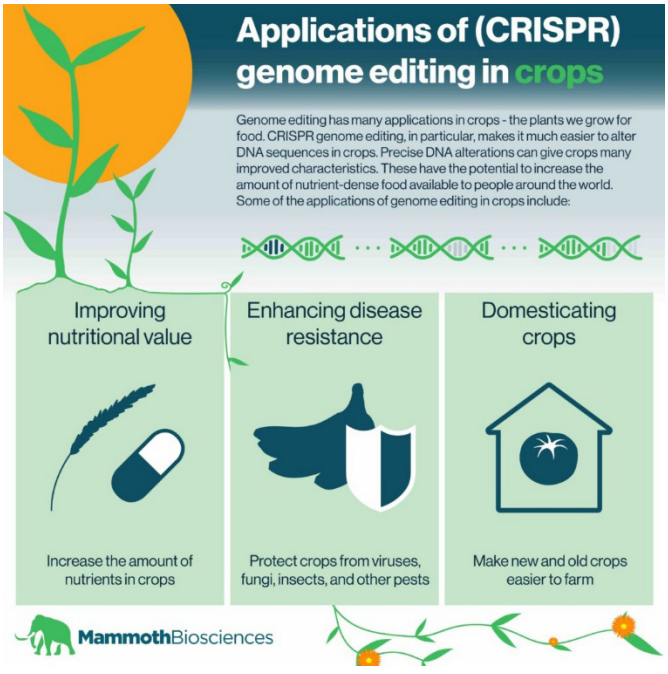
CHAPTER 3- GENE EDITING TECHNOLOGY

Gene editing is a **path-breaking biotechnology** that enables precise modification of DNA without introducing foreign genetic material. The most powerful tool, **CRISPR-Cas9**, discovered by **Jennifer Doudna & Emmanuelle Charpentier** (Nobel Prize 2020), revolutionized genetic science. In agriculture, it promises **higher productivity, nutritional security, climate resilience, and sustainability**.

Scientific Basis & Evolution

Gene editing uses **Site-Directed Nucleases (SDNs)** for targeted deletions, substitutions, or insertions. **CRISPR** originated from the **bacterial immune system** (Francis Mojica, 1990s). Recent innovations like the **all-in-one CRISPR toolbox** (University of Maryland) extend applications across **monocots (rice)** and **dicots (tomato)**.

Applications in Agriculture



- **Productivity & Yield**: Rice genes OsAPL and OsSXKk1 edited for higher yield and photosynthesis; Wheat asparagine synthetase knockout reduces **carcinogenic acrylamide**; Potato gbss gene modified for **amylose-free starch** with industrial value.
- **Nutritional Security**: **Golden Rice & Golden Maize** enriched with Vitamin A; Rice/Wheat OsNAS gene edits increase **iron & zinc**, reducing **anaemia & malnutrition**; Soybean with reduced phytic acid for mineral absorption; Japan's **High-GABA Tomato** for heart health.
- **Biotic & Abiotic Stress**: Maize ZmHDT103 and Wheat TaRPK1 for **drought tolerance**; Rice OSERF922 knockout for **blast resistance**; Banana DMR gene edit for **wilt resistance**; Citrus LOB promoter edit against **canker**. Pest control via CRISPR knockouts in **moths & armyworms**.
- **Climate Change Mitigation**: Methane-free cows (AI + CRISPR, conceptual); **drought, salinity, flood-tolerant crops**; enhanced **carbon sequestration** through improved photosynthesis.

Indian Initiatives

India is a **global pioneer** in gene-edited crops. In May 2025, ICAR released:

- **DRR Rice 100 (Kamla)**: 20% higher yield, matures 20 days earlier, saves water/fertilizer, lowers methane emissions (9 tonnes/ha).
- **Pusa DST Rice 1**: Suited to **saline/alkaline soils**, promises 19% yield increase, **7,500 MCM water savings**, 20% lower GHG emissions.

Other initiatives: Delhi University's **low-glucosinolate mustard**; SKUAST-Kashmir's **first Indian gene-edited sheep** (30% higher muscle mass via myostatin gene).

- Government support: **₹500 crore (Budget 2023–24)**; ICAR working on **24 field crops & 15 horticultural crops**; CSIR-NBRI developing edited tomato, cotton, chickpea, Brassica.
- **209 Indian agri-biotech startups**, supported by **BIRAC** and its Biotechnology Ignition Grant (₹50 lakh).

Regulatory Framework

Unlike **GM crops** (with foreign DNA), **gene-edited crops mimic natural mutations**. India's **2022 Guidelines for Safety Assessment of Genome Edited Plants** exempt **SDN 1 & 2 edits** from stringent GM rules under **Environment Protection Act**.

- Oversight: **Institutional Biosafety Committees (IBSCs)**; Approvals from **MoA&FW** and **FSSAI** required. Globally, ~30 countries treat them as **equivalent to conventionally bred crops**, aiding faster adoption.

Economic & Commercial Potential

- Global **Agri-Genomics Market**: **USD 4.32 bn (2024) → USD 10.32 bn (2035)**.
- India's **genomics market**: USD 2.2 bn (2024, including healthcare).
- **Seed industry**: USD 3.61 bn (2024) → USD 5.01 bn (2030).
- Global **seed market**: USD 88.82 bn (2024) → USD 99.94 bn (2030).
- Private players dominate India's seed sector (65% share). Companies like **Bayer, Mahyco, Syngenta, Benson Hill** investing heavily. Example: Bayer + **G+FLAS** (South Korea) developing **Vitamin D3-enriched tomato** to fight global deficiency (1 billion people affected).

Concerns & Risks

- **Scientific**: Off-target mutations, unintended traits.
- **Environmental**: Gene flow into wild relatives, biodiversity loss.
- **Ethical**: Germline editing, corporate monopolies.
- **Socio-economic**: Small farmer access, regulatory harmonization.

Way Forward

India must expand **ICAR & DBT research** into **pulses, oilseeds, millets**; ensure **equitable seed access** to smallholders; promote **PPP models**; strengthen **biosafety monitoring**; launch **awareness campaigns** to build trust; and harmonize global standards for **trade compatibility**.

Conclusion

Gene editing with CRISPR-Cas9 is a **revolution in plant genetics**, echoing **Norman Borlaug's vision** that only genetic advances can meet future food needs. India's pioneering work in **genome-edited rice, mustard, and livestock** offers hope for **higher yields, better nutrition, resource efficiency, and climate resilience**. Balancing **innovation with ethics, biosafety, and inclusivity** will enable gene editing to become a cornerstone of **sustainable agriculture and food security in the 21st century**.

CHAPTER 4- CARBON FARMING FOR CLIMATE-SMART AGRICULTURE

Agriculture, directly linked to multiple **Sustainable Development Goals (SDGs)**, faces compounded challenges from **climate change**—declining yields, soil erosion, and rising **GHG emissions** (20% globally, FAO 2020).

- Yet, it holds dual potential: both a **major emitter** and a **carbon sink**. **Carbon farming**, through sequestration practices, can convert farms into **net absorbers of CO_2**, ensuring **food security**, resilience, and farmer incomes via **carbon credits**.

Concept and Potential

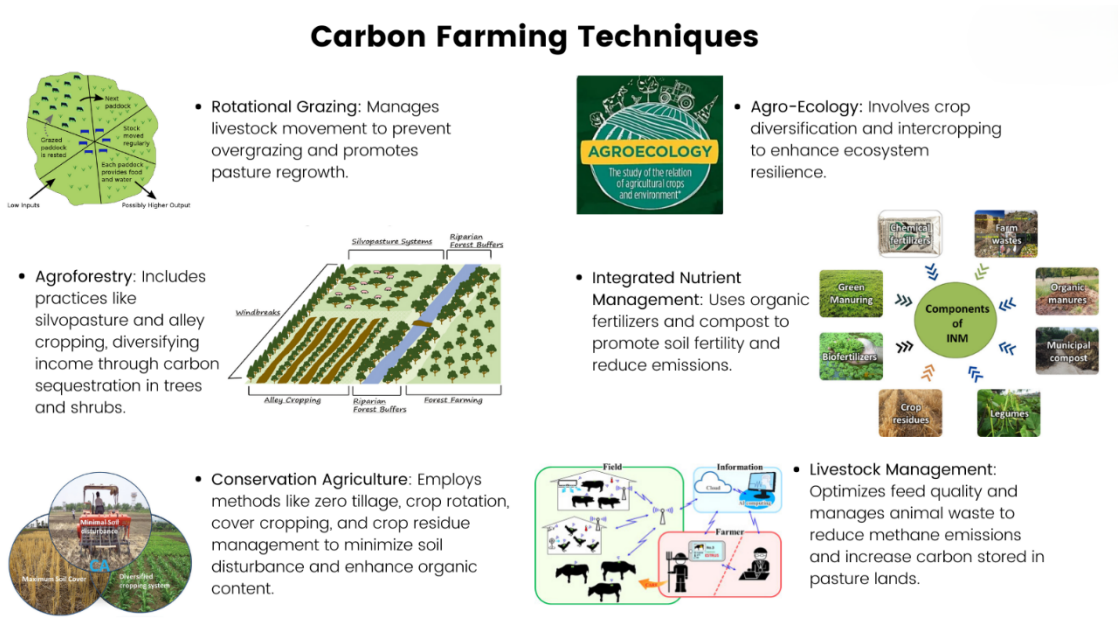
Carbon farming involves agricultural practices that enhance **soil organic carbon (SOC)** and **vegetative carbon storage** using natural processes like **photosynthesis** and **soil organic matter build-up**.

- In India, with **85% smallholder farmers** (GoI 2021), it remains underutilised. One **carbon credit = 1 tonne CO_2 removal**. India's **170 million hectares of arable land** has a potential worth **$63 billion**, with soils capable of storing **3–8 billion tonnes CO_2 annually for 20–30 years**, linking farmers to **voluntary carbon markets**.

Core Carbon Farming Practices

- **Forest Management & Agroforestry**: Afforestation, reforestation, agroforestry integrate trees into farms, enhancing **carbon sequestration**, **biodiversity**, and **income diversification**.
- **Grassland Conservation**: Protecting native vegetation avoids carbon losses.
- **Reduced Fertiliser Use**: **Precision farming, controlled-release fertilisers, fertigation** cut emissions, lower costs, and improve soil carbon retention.
- **Biochar**: Long-term **carbon sink**, improves soil fertility, water retention, and lowers fertiliser needs.
- **Reduced/No Tillage**: Prevents CO_2 release, conserves soil structure, enhances **soil organic matter (SOM)**.

- **Cover Cropping**: Prevents **erosion**, fixes nitrogen, retains moisture, increases SOC (e.g. **Dhaincha in rice–wheat systems**).
- **Crop Rotation & Companion Planting**: Enhances soil health, nutrient cycling, pest management.
- **4Rs Nutrient Management**: Right **time, rate, source, place** improves efficiency, lowers emissions.
- **Eliminating Bare Fallows**: Continuous cover with **nitrogen-fixing crops** prevents carbon losses.
- **Rotational Grazing & Silvopasture**: Combines livestock + forestry, boosting sequestration, soil health, and productivity.
- **Residue Management**: Retaining crop residues as mulch increases soil carbon and fertility.
- **Water Management**: Efficient irrigation reduces erosion and nutrient loss.
- **Digital Tools**: **Data-driven Decision Support Systems** ensure precision in fertiliser, irrigation, and pest control.



Carbon Markets and Incentives

The **Carbon Market** allows trade of **carbon credits** (1 credit = 1 tonne CO_2 reduced/removed, UNFCCC 2021). Emerging from the **Kyoto Protocol (1997)** and strengthened by the **Paris Agreement (2015, Article 6.4)**, it monetises emission reductions. India, with the **second-highest CDM projects globally**, amended the **Energy Conservation Act (2001) in 2022** to establish an **Indian Carbon Market**. Farmers adopting practices like **zero tillage, agroforestry, manure management** can earn credits, selling them to industries seeking offsets. This provides **new revenue streams** while incentivising **sustainable agriculture**.

Challenges in India

- **High costs** of CSA technologies (precision farming, improved irrigation).
- **Limited awareness and technical knowledge** among smallholders.
- **Weak infrastructure** for MRV (**Measuring, Reporting, Verification**) of carbon credits.
- **Cultural resistance** to shifting from traditional methods.
- **Voluntary carbon markets** lack regulation and transparency.

Way Forward

- **Policy Strengthening**: Launch a **National Carbon Farming Mission**, aligning with **Soil Health Card Scheme** and **National Mission on Sustainable Agriculture**.
- **R&D Investments**: Develop **low-cost carbon measurement tools**, crop-specific sequestration innovations under **NICRA**.
- **Capacity Building**: Use **KVKs** for farmer training, demonstrations, and awareness.
- **Market Mechanisms**: Develop **transparent carbon trading platforms**, support **Carbon Farmer Producer Organisations (CFPOs)** for credit aggregation.
- **Monitoring & Accountability**: District-level carbon targets, annual reporting aligned with **Net Zero 2070**.

Conclusion

Carbon farming is a **game-changer** that transforms agriculture from a **GHG emitter to a carbon sink**, ensuring **climate resilience, farmer incomes, and food security**. With robust policies, technological innovation, credible carbon markets, and farmer participation, India can lead a **farmer-centric, climate-smart agricultural revolution**. As a convergence of **sustainability and economics**, carbon farming will be pivotal in meeting India's **SDGs** and **Net Zero commitments**, while safeguarding livelihoods for future generations.

CHAPTER 5-PLOUGHS TO PRECISION: DIGITAL REVOLUTION IN AGRICULTURE

Agriculture has been the **backbone of Indian economy** for millennia, contributing ~18% of **GVA (2023–24)** and providing livelihoods to **46% population**.

- Sectoral GVA rose from **₹15.02 lakh crore (2011–12) to ₹48.78 lakh crore (2023–24)**, but its relative share in total GVA declined due to faster growth in industry & services.
- Modernisation via **digital technologies**—AI, IoT, drones, satellite imagery, blockchain, and mobile apps—marks a shift from **subsistence farming → precision farming**, enhancing **food security, resilience, and rural incomes**.

Transition: From Tradition to Technology

- Earlier: Reliance on **manual labour, wooden ploughs, monsoon dependency**.
- Now: **Precision Agriculture** using AI, drones, IoT, GPS, and **data-driven decision-making**.
- Benefits: Real-time crop & soil monitoring, weather forecasting, reduced input waste, increased productivity, resilience against climate risks.

Key Digital Interventions in Agriculture

(a) Precision Farming & IoT

- IoT devices enable **real-time monitoring** of soil, crop health, water, fertiliser use.
- Improves irrigation scheduling, pest control, fertiliser delivery.
- Reduces **waste, costs, environmental runoff**.

(b) Artificial Intelligence (AI)

- Analyses **satellite data, weather patterns, crop yields**.

- Enhances **soil health monitoring, pest detection, yield forecasting**.
- Example: Microsoft's AI-based **Farm Vibes (Maharashtra)** → 40% increase in yields, 50% less water use.

(c) Satellite & Remote Sensing

- Used for **large-scale monitoring** of soil moisture, pest outbreaks, and drought prediction.
- Govt initiatives: **FASAL, Agro-meteorology & ISRO collaborations** for accurate crop forecasting.

(d) Digital Marketplaces & e-Governance

- **e-NAM** (National Agriculture Market): 1.79 crore farmers, 2.67 lakh traders, 1,522 mandis integrated. Ensures **fair pricing, reduced middlemen dependence**.
- **SmartGaon, ONDC, e-Choupal**: democratise access to supply chains.
- Private platforms like **DeHaat, AgroStar, AgriBazaar** link farmers to inputs & buyers.

(e) Blockchain

- Ensures **traceability & transparency** from farm to fork.
- Builds **consumer confidence**, reduces post-harvest losses, enables farmers to access **premium markets**.

(f) Hardware Automation

- Tools: **Automated irrigation, drone sprayers, remote-operated transplanters, Nano Ganesh pumps**.
- Reduces manual labour, improves efficiency, esp. for **small/marginal farmers**.

Government Initiatives in Digital Agriculture

- **Digital Agriculture Mission (2024)**: Budget **₹2,817 crore** for 2025–26. Focus: AI, drones, IoT, blockchain, farmer registries, geo-tagged village maps, crop-sown registry.
- **AgriStack Project**: Unified **digital database of 11 crore farmers** (Aadhaar-linked). Enables access to **credit, insurance, subsidies, procurement**.
- **Kisan Suvidha App (2016)**: Provides **weather, crop prices, input dealers, plant protection advisories**. SMS-based **m-Kisan** service: reached **8.93 crore farmers**.
- **Common Service Centres (CSCs)**: 5.6 lakh centres (77% rural) provide soil testing, insurance, agri-advisories.
- **Sub-Mission on Agricultural Mechanization (SMAM)**: Supports **Custom Hiring Centres (CHCs)** & **Farm Machinery Banks (FMBs)**.
- **Women-led Agri-Tech**: Namo Drone Didi Scheme (2023) → ₹1,261 crore to train **15,000 women SHGs** in drone usage for fertiliser/pesticide spraying.
- **Soil Health Card Scheme (2015)**: Over **24.74 crore cards** issued; now GIS & QR code enabled.

Benefits to Farmers

- **Productivity**: Higher yields with less input.
- **Cost Efficiency**: Reduced fertiliser, pesticide, and water use.

- **Market Access**: Transparent prices, reduced middlemen.
- **Resilience**: Climate adaptation, timely advisories.
- **Inclusivity**: Women's empowerment, small farmer participation, rural digital inclusion.

Challenges Ahead

- **Digital divide**: Poor internet connectivity, low digital literacy in rural areas.
- **High cost**: Digital tools often unaffordable for smallholders.
- **Infrastructure gaps**: Limited rural ICT, unreliable power supply.
- **Adoption barriers**: Trust deficit, privacy concerns, resistance to new tech.

Way Forward

- Invest in **rural digital infrastructure** (internet, power, storage).
- **Localized training** in vernacular languages for farmers.
- Strengthen **public–private partnerships** with agri-startups & FPOs.
- Develop **affordable, farmer-centric technologies** (low-cost IoT devices, mobile apps).
- Enhance **digital inclusion** via women SHGs, CSCs, and cooperatives.

Conclusion

Indian agriculture is shifting from **age-old traditional practices to data-driven precision farming**. Technologies like **AI, IoT, drones, blockchain, and digital platforms** are making farming **more productive, sustainable, and profitable**. With flagship programmes such as **Digital Agriculture Mission, e-NAM, AgriStack, and Drone Didi**, India is laying the foundation for a **resilient, climate-smart agricultural ecosystem**. Sustained investment, inclusive policies, and farmer empowerment will ensure that **the benefits of digital agriculture reach every corner of rural India**, securing both **food security and rural livelihoods**.

UPSC Mains Practice Questions-(Around 250 words)	
Q1.	Discuss how the integration of Artificial Intelligence, Internet of Things, and Blockchain is transforming Indian agriculture from subsistence farming to precision farming. Highlight the opportunities and challenges in this transition.
Q2.	Carbon farming can provide India's smallholder farmers with additional revenue through carbon credits, but scaling adoption remains a challenge. Critically analyse.

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