TRANSFORMATION OF AGRICULTURE INTO SUSTAINABILITY- USE OF TECHNOLOGICAL ADVANCES

Abstract

The present paper appreciating the need for transforming agriculture into sustainable, delineates how developments in science and technology combine with AI, ML, IoT and data analytics lead to smart farming to counter the challenge of food security and climate change in the global context. The focus of transformation of agriculture in different countries and organizations is presented. The need for supporting infrastructure has been stressed for effective use of technological advances amongst the marginal farmers in a country.

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Introduction:

As the global population grows to approximately 9 billion by 2050, the world's farmers need to grow 50% more food to meet the needs of the growing world (FAO, 2009). But the arable land is shrinking due to urbanization and degradation. With catastrophic climate changes, 70% of world's fresh water supply is being used now in agriculture. Worsening soil issues due to climate change, shortage of labour force, pest damage add to the challenges faced by farmers. In fact, the world's food systems face enormous challenges of changing climate, a decline in biodiversity, limited natural resources, global crisis, and above all the growing population. This leads to an absolute necessity for agricultural transformation.

The Green Revolution in agriculture of the 1960s made impressive strides between 1961 and 2004. Cereal yields in East Asia improved by 2.8 percent a year or over 300 percent over the period. This was enabled by modern farming practices, including irrigation, use of fertilizers and pesticides, and the development of new and more productive crop varieties (World Development Report, 2008). Gradually, the wave of automation started spilling into the fields, the tractor was introduced, followed by new tillage and harvesting equipment, irrigation and air seeding technology, all leading to higher yields and improved quality of the food.

The digital agriculture began since the early nineties when GPS was first mounted on tractors. Sensors placed in fields allow farmers to obtain detailed maps of both the topography and resources in the area, as well as variables such as acidity and temperature of the soil. Moisture sensors in the ground are able to communicate information about the level of moisture present in the soil. Instead of prescribing a fertilizer map for a field, crop sensors direct application equipment how much to apply in real time. By using the correct sensors, drones can provide today's farmers with real-time information regarding their crops, soil deterioration, dry regions, fungal infections. Digitalization has also enabled farmers to use their phone camera to identify a pest or a disease. Of course, the credit for the biggest digital transformation, be it in agriculture or for any sector, goes to Coronavirus, the world after

Corona became digitized more than ever.

But in spite of all those advancements in digital agriculture, hunger and malnutrition are spreading faster today when nearly 350 million people are already experiencing the most extreme forms of hunger. Since the beginning of 21st century, global GHG emissions had followed an increasing trend, 25% increase from 1990 to 2024, posing climate change a big challenge. During earlier days, increasing crop production and reversing environmental damage were considered incompatible, but now the global agriculture scene is changing. Today it is how to produce more with less so that we can conserve our resources, how to reverse the trend of soil degradation, how to reduce carbon footprints and start storing carbon in soil and plants instead to counter the climate challenge. The goal is to achieve both productivity and sustainability and enhance farmers' welfare not only today but also for the future, encouraging still more development for sustained agriculture (as reflected in the Fig.-1).

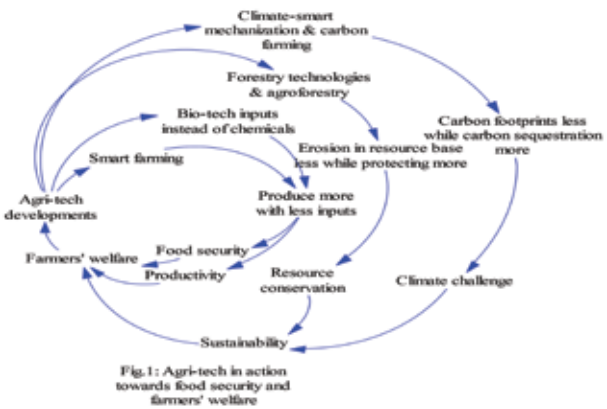

Fig.1: Agri-tech in action towards food security and farmers' welfare

Agricultural technology advancing:

With focus on sustainability, agroforestry proved itself a sustainable approach integrating trees with farming. Regenerative practices in sustainable agriculture focus on rebuilding soil health, increasing biodiversity, and improving water cycles, using techniques like no-till, cover cropping, crop rotations, integrating livestock, and agroforestry to sequester carbon, reduce chemical inputs, and create resilient farms that give back more to the land than they take. Choice of such strategies is reflected in the Table-1.

Table-1: Choice of farming strategies with positive impact on soil

No.	Farming practices	Impact on soil
1.	Moving towards no-till farming	Preserves soil structure and biology
2.	Use cover crops, mulching and leave crop residues to protect soil from erosion and retain moisture	Protects soil from erosion and retain moisture
3.	Diversify crops like crop rotation and intercropping	Breaks pest cycles and improve nutrient cycling
4.	Combine crops, agroforestry, integrate livestock	Creates resilient farm ecosystems
5.	Avoid use of chemicals and monoculture	Minimizes biodiversity loss
6.	Use biological inputs instead of synthetic fertilizers/pesticides	Enhances soil carbon, fertility and plant resilience
7.	Variable input rate application using drones	Balances between nutrient deficiency and toxicity
8.	Practice carbon sequestration through: i)Biologically through reforestation & afforestation ii) Technologically by pulling carbon dioxide from atmosphere and storing it in soil and plants	Enhances soil fertility and water holding capacity and to reduce GHG

With developments in agronomic sciences in all facets of plant genetics, plant physiology, Gene biotech innovations develop crops with climate resilient high yield (using minichromosome technology), pest/drought resistance, improved nutrition, higher yields and better sustainability with less water and energy to tackle climate change and food security. With AI and digital twin technology, we simulate different seed varieties how they respond to various soil and weather

conditions in the breeding platform to achieve desired performance targets as well as consumer demands (as presented in the Fig.2).

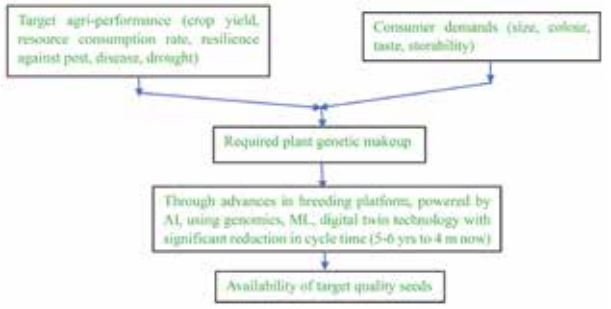

Fig.-2: Tech advances: Seed-Farming scenario

AI is the core technology in powering the digital transformation of agriculture through advances in application technology and data science which helps tackle simultaneously climate change and ensure global food security, balancing productivity with ecological responsibility. The agricultural sector is moving towards precision farming in irrigation, weeding, plant and environment monitoring to use of renewable energy and digital platforms as reflected in the Table-2. ”Data is the new soil, AI the nervous system and biotechnology the new structure” as said by Debjani Ghosh, NITI Aayog of India, 2025.

Table-2: Technology-driven smart farming leads to productivity and sustainability

No.	Tech-driven smart farming	Impact
1.	Use farm management platforms with digital mapping using satellite imagery with GPS technology, workflow automation, AI technologies like ML, computer vision, data analytics and IoT-enabled sensor networks to collect weather & rain pattern, soil and air-quality data	Real-time decision making for smart farming from planting to harvesting to boost yields, reduce input costs, and protect environmental health
2.	Precision sowing, planting of seedlings using machines and robots	Ensures accuracy in depth, spacing and positioning to enhance crop uniformity and reduce labour cost
3.	Precision irrigation using IoT-based soil-moisture sensors and pilot generative AI tool triggering automated irrigation (along with water-soluble nutrients for IoT-based precision fertigation systems) at right time for the right amount charged at the roots through the sprinklers/ drip system	Optimise resource consumption, plant growth and soil protection
4.	Precision weeding, locating weeds in particular using AI-powered robotics with computer vision camera, using tillers for uprooting weeds, and spray chemicals on weeds, pesticides for insect and disease control instead of blanket spray	To reduce the consumption and protect plant
5.	Automated remote monitoring of environment conditions and pest populations using drones and precision tools	To predict and prevent outbreaks before they harm crops
6.	Use renewable energy solutions for irrigation and food storage (particularly in regions with erratic power supply) instead of fossil-fuel systems	To reduce farm carbon footprints and provide reliable energy enhancing both productivity and sustainability
7.	IoT-based farming maintains optimal growing conditions	To achieve higher yields with less energy thereby enhancing efficiency and sustainability
8.	Use IoT and block chain to track agricultural goods from farm to fork	Streamlining logistics and improving traceability, strengthening consumer confidence supporting food safety, quality, and efficiency throughout the agricultural supply chain

9.	IoT sensors monitors machine performance along with alerts when operating parameters are out of range or malfunctions occur	Enabling preventive steps and reducing downtime
10.	Use of controlled environment like vertical farming, hydroponics or aeroponics	Minimizes external dependencies and maximizes controllability
11.	Use of automated sorting and grading machines, IoT-enabled ripening chambers and cold storage with ethylene control	Effective harvest management and storage
12.	Online agricultural market place solutions and digital backed credit for the upcoming season	Effective market linkage and funds availability

Agri-tech scenario in practice:

Around other countries:

Global tech-enabled sustainable agriculture shows high adoption rate in the North America and rapid growth in Latin America and Asia. Precision agriculture has been the primary tech-driver with a global market valued over $11 billion in 2024. North America leads with a 60% adoption rate in 2024. Europe maintains a 55% adoption rate, although recent trends indicate 7% drop. Latin America shows the fastest-growing region, reaching a 75% /adoption rate. The adoption rate of Asia-Pacific varies widely; while advanced nations like Japan and Singapore are key players, the region's overall tech adoption has been lower at roughly 10% due to the prevalence of small-scale farming (McKinsey & Company, 2024).

Indian scenario:

If we look at India, it has around 160 million hectares of arable land (second behind U.S.) and almost half of its population depends on agriculture for their livelihood. Though its agriculture contributes nearly 20% to its national GDP, the productivity per hectare (except for the irrigated wheat approaching world standards) is lower than leading nations like the China, U.S., and Europe. The small farm size of India restricts individual farmers to continue mostly with traditional farming practices. India uses around 85% chemical fertilizers (being the, world's second-largest user and third largest producer) to maximize crop yield. However, use of chemicals has its usual pitfalls of environmental damage.

To deal with such challenges, the government of India had made lot of efforts in the mean while and launched centrally sponsored schemes like the National Mission on Agricultural Extension and Technology (NMAET in Feb 2014) to deliver modern technology and improved agronomic practices available to farmers and the National Mission for Sustainable Agriculture (NMSA) under the eight missions for the National Action Plan on Climate Change (NAPCC in 2014-15) to improve soil health, water use efficiency (Per Drop More Crop) and integrated farming systems. With the Digital India Program (launched in July 2015) had already made India into a digitally empowered society with a mobile in the hands of each and every farmer at the length and breadth of the country, the honourable prime minister of India announced the bold vision of Viksit Bharat 2047 (Dec 2023) to transform the country into a fully developed and self-reliant nation. Agriculture being the key driver of Viksit Bharat with half of its population in agri-food system, the Digital Agricultural Mission 2.0 was launched by the government of India through its apex public policy think tank, NITI Aayog (National Institution for Transforming India) in Nov, 2025. Its objective is to transform agriculture from input-based to intelligence-driven using AI, IoT and data analytics focusing on three broad areas: development of agri-system and practices to take the advantages of the digital infrastructure; revamping the institutional innovation system towards interdisciplinary industry-based research and setting up centres of excellence and policy foresight units to converge public-private efforts to accelerate the transformation process for three-fold increase in agriculture sector, enabling the Indian economy for five-fold increase by 2047 as envisaged in the Viksit Bharat 2047.

Around various organizations:

AgroStar is a leading AgTech start-up in India with a portfolio of 200 plus high-quality farm inputs with innovative bio and organic alternatives, partially replacing chemical fertilizers reducing emissions, increasing yields, reducing cost of cultivation and impact on the environment.

Cropin, the world's first real-time, generative AI agri-intelligence platform, powered by largest crop knowledge grid spanning over a billion acres of land, 400 crops of 10,000 varieties across 103 countries since 2010 transforms the past, present and future of crops data into better decisions.

DJI Agriculture (Da-Jiang Innovations), drones used for spray pesticides with high precision on wheat fields in Punjab and paddy fields in AP, Matrice series drones with multispectral and thermal cameras and sensors for crop health analysis helping farmers to save time, reduce health hazard from chemicals, minimize cost and increase crop productivity.

E.L.Y. (Expert Local Yield/Intelligence) GenAI expert system developed by Bayer Crop Science in collaboration with Microsoft and EY (AI-based AgTech Solution of the Year 2025 breakthrough award winner) quickly and accurately answers questions related to agronomy, farm management, thus benefiting farmers all over the world

Intello Labs digitizes food quality using image matching, machine learning and data analytics to gauge the quality of crops and outputs detecting any change from prescribed specifications and offers complete automation in supply chain management, fair pricing and reducing food wastage

KrishiMitra, the AI copilot showcased at World Agri-Tech 2024 with image analytics feature supports farmers with IoT crop monitoring, suggests soil nutrition based on soil characteristics, real-time identification of pest along with its timely resolution, notification-based, crop-specific periodic advisory system.

Niqo Robotics, AI-powered BrijBot to assist small farmers with precision weeding, identify and selectively spray chemicals on weeds, pesticides for insect and disease control using AI, computer vision to distinguish between crops and unwanted plants, reducing chemical and water usage compared to traditional blanket spraying.

Plantix, an AI-powered mobile app, uses image recognition to identify pests, diseases, and nutrient deficiencies, provides customized treatment plans, offering both organic and chemical solutions for over 30 major crops and 780 plus plant damage, also real-time tracking and alerts for any nearby potential disease outbreaks and expert advice through global social network

SatSure's platform monitors through satellite imagery, machine learning, big data analytics and cloud infrastructure tracking crop growth and health across regions from germination to harvest for farmers (Sparta), fintech oriented crops' risk-return suite for lending institutions and years of crop data mapped across seasons and regions (Digital AgriStack).

Conclusions:

Development in sustainable agricultural technology is indeed a boon for large farms. They can assess the risk-return of tech adoption and go ahead depending on their needs. But for a country like India, where we are dealing mostly with marginal farmers with nominal land holding, they cannot think of deciding in favour of such tech-adoption. To catalyse technological renaissance in the country's agriculture, full-fledged supporting infrastructure needs to be put in place first and the supporting body needs to be proactive with effective delivery mechanism of tech-innovations, then only country's marginal farmers will be convinced to adopt the sustainable tech-aided practices. MA

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