TRANSFORMING AGRICULTURE WITH A. I.

A PROJECT WORK ON NEW TECHNOLOGY WHICH HELPS

TO IMPROVE THE AGRICULTURE & ENVIRONMENT.

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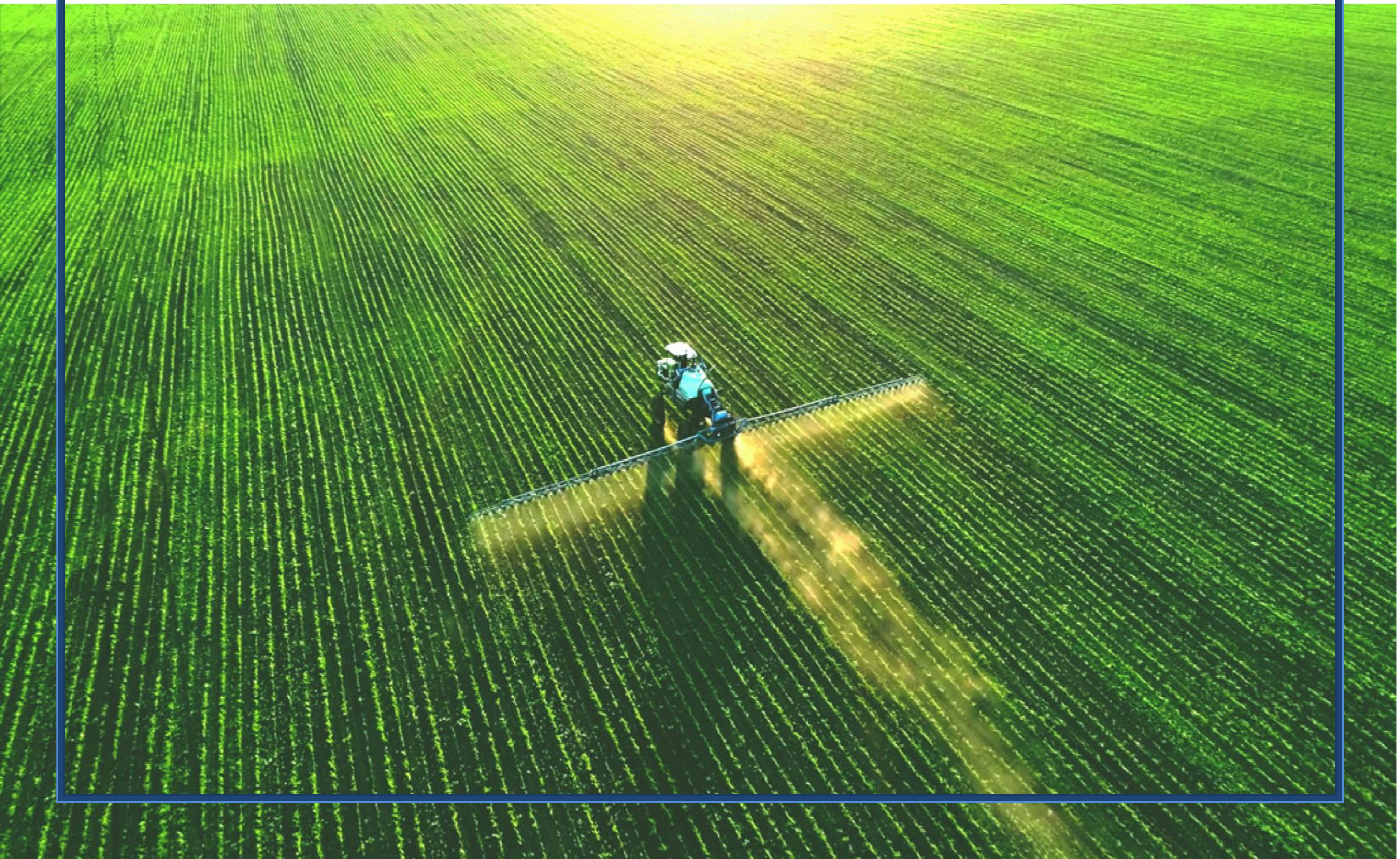

Abstract: *Agriculture is an important sector in India. It is indispensable for the sustenance and growth of the Indian economy. On average, about 70% of the households and 10% of the urban population are dependent on agriculture as their source of livelihood. Today, India is a major supplier of several agricultural commodities like tea, coffee, rice, spices, oil meals, fresh fruits, fresh vegetables, meat and its preparations and marine products to the international market. India is a large producer of several agricultural products.*

In terms of quantity of production, India is the top producer in the world in milk and second largest in wheat and rice. Agricultural production is prone to several risks which affect both producers and consumers. In order to enhance investment and achieve a sustained increase in production, coherent and integrated long-term strategies and policies are required to reduce risk aversion and build flexibility among Indian rural producers. There is a need to provide remunerative prices for farmers in order to increase the incomes of farmers. In this research paper the researcher's objective is to study the major agriculture crops production, export and import of agriculture crop wheat.

Definition of AI in Agriculture:

Artificial Intelligence (AI) in agriculture refers to the integration and application of advanced computational technologies, including machine learning, computer vision, robotics, and data analytics, to enhance various aspects of agricultural practices. The goal is to leverage intelligent systems to improve efficiency, productivity, and sustainability throughout the agricultural value chain. AI in agriculture involves the use of algorithms and models that enable machines to perform tasks traditionally carried out by humans, enabling smarter decision-making, precise resource management, and improved outcomes in farming practices.

Key Components of AI in Agriculture:

1. Machine Learning (ML):

- In agriculture, ML algorithms analyse vast datasets to identify patterns and make predictions.
- Supervised learning is used for tasks like crop classification and yield prediction.
- Unsupervised learning aids in anomaly detection, identifying deviations from normal patterns in crops or livestock.

2. Computer Vision:

- Computer vision enables machines to interpret and understand visual information from images or videos.
- In agriculture, it is used for crop monitoring, disease detection, and weed identification through image recognition.

3. Internet of Things (IoT):

- IoT devices, such as sensors and actuators, collect and transmit real-time data from the field.
- This data helps in monitoring soil conditions, weather patterns, and crop health, facilitating data-driven decision-making.

4. Robotics:

- Agricultural robots equipped with AI capabilities perform tasks like planting, harvesting, and sorting.
- These robots can navigate autonomously and adapt to dynamic environments, enhancing efficiency and reducing manual labour.

5. Data Analytics:

- Data analytics involves processing and interpreting large datasets to derive actionable insights.
- In agriculture, analytics helps in optimizing resource allocation, predicting market trends, and improving overall farm management.

Applications of AI in Agriculture:

1. Precision Agriculture:

- AI enables precise management of resources such as water, fertilizers, and pesticides based on real-time data, optimizing crop yields.

2. Crop Monitoring and Management:

- AI-driven systems monitor crop health, identify diseases, and recommend appropriate interventions, leading to early detection and prevention.

Figure 1.1: Crop Monitoring System

3. Smart Irrigation Systems:

- AI helps in optimizing irrigation schedules based on weather conditions, soil moisture levels, and crop requirements, reducing water wastage.

4. Supply Chain Optimization:

- AI algorithms predict market demands, assist in inventory management, and optimize logistics, ensuring efficient supply chain operations.
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5. Livestock Monitoring:

- AI is used to monitor the health and behaviour of livestock, enabling early disease detection and improving overall animal welfare.

Figure 1.2: *livestock monitoring system*

Benefits of AI in Agriculture:

1. Increased Productivity:

- AI enables farmers to make data-driven decisions, leading to optimized resource usage and higher crop yields.

2. Resource Efficiency:

- Precise management of resources such as water and fertilizers reduce waste and environmental impact.

3. Cost Savings:

- Automation and optimization of farming processes result in reduced labour costs and increased operational efficiency.

4. Sustainability:

- AI helps in adopting sustainable farming practices by minimizing environmental impact and promoting responsible resource management.

Importance of AI in Modern Agriculture:

1. Precision Farming:

- ***Optimized Resource Management:*** AI enables precise monitoring and management of resources such as water, fertilizers, and pesticides. This leads to efficient resource usage, minimizing waste and environmental impact.
- ***Variable Rate Technology (VRT):*** AI-driven systems analyse data from sensors to create variable rate maps, guiding equipment to apply inputs at optimal rates across different areas of a field.

2. Increased Productivity:

- ***Predictive Analytics:*** AI algorithms analyse historical and real-time data to predict crop yields, helping farmers make informed decisions and maximize productivity.
- ***Automation in Farming Tasks:*** Robotics and AI-driven machinery perform tasks such as seeding, weeding, and harvesting with precision, reducing manual labour and increasing overall output.

3. Crop Monitoring and Disease Detection:

- ***Early Detection:*** Computer vision and machine learning models analyse images from drones or sensors to identify early signs of crop diseases, allowing timely interventions and preventing the spread of infections.
- ***Weed Identification:*** AI can distinguish between crops and weeds, facilitating targeted weed control and reducing the need for herbicides.

4. Smart Irrigation:

- ***Water Conservation:*** AI algorithms analyse weather data, soil conditions, and crop requirements to optimize irrigation schedules. This reduces water usage, conserving a precious resource.

5. Supply Chain Optimization:

- ***Market Predictions:*** AI analyses market trends, demand patterns, and external factors to predict market conditions. Farmers can adjust their production, accordingly, minimizing post-harvest losses and optimizing profitability.
- ***Inventory Management:*** AI helps in efficient inventory management, reducing wastage and ensuring a steady supply of agricultural products.

6. Livestock Monitoring:

- ***Health Management:*** AI-based monitoring systems track the health and behaviour of livestock. Early detection of health issues allows for timely veterinary interventions, improving overall animal welfare and farm productivity.

7. Data-Driven Decision-Making:

- ***Actionable Insights:*** AI processes large volumes of data, providing farmers with actionable insights for better decision-making. This includes choosing optimal planting times, adjusting irrigation schedules, and predicting disease outbreaks.

8. Climate Resilience:

- ***Adaptation to Climate Variability:*** AI helps farmers adapt to changing climate conditions by providing real-time data on weather patterns and recommending suitable crop varieties and practices.
- ***Risk Mitigation:*** Predictive analytics can identify potential risks, enabling farmers to take preventive measures and reduce the impact of adverse weather events.

9. Sustainability:

- ***Environmental Impact Reduction:*** Precision farming and optimized resource management contribute to sustainable agricultural practices, minimizing the environmental footprint of farming activities.
- ***Biodiversity Conservation*:** AI can aid in designing agroecological landscapes that promote biodiversity and ecological balance.

10. Empowering Farmers:

- ***Accessibility to Technology:*** AI technologies empower even small-scale farmers with access to advanced tools and information, bridging the technological gap in agriculture.

- ***Training and Education***: Training programs on AI applications in agriculture can enhance farmers' skills and knowledge, enabling them to adopt innovative practices effectively.

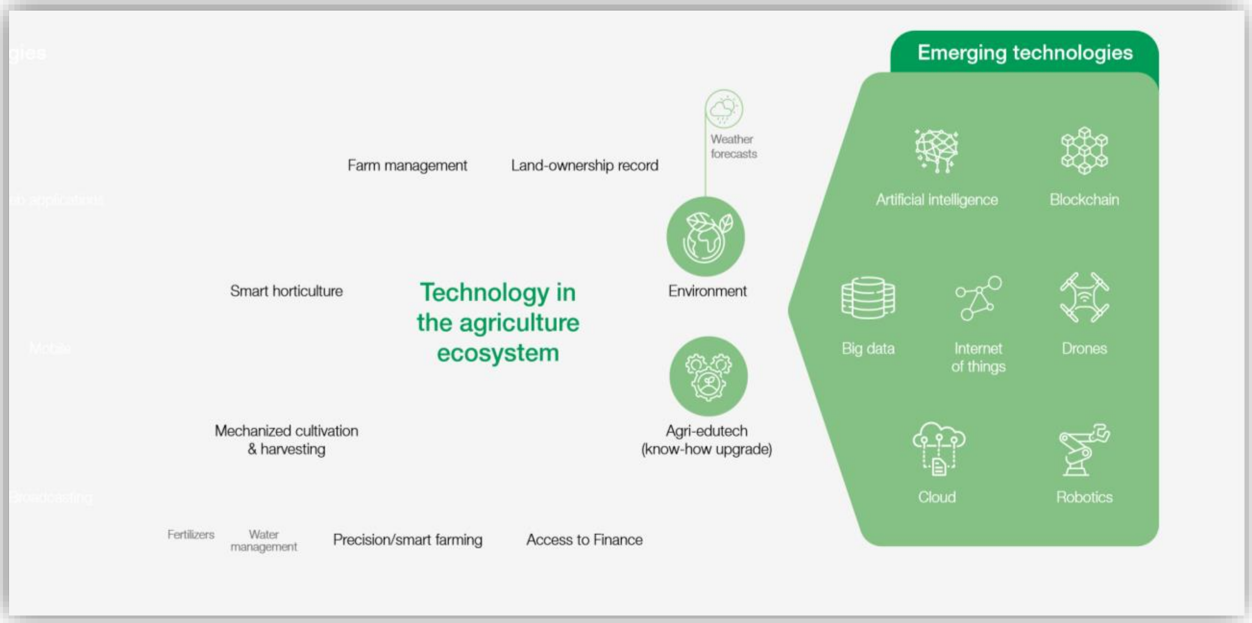

Figure 1.3: AI in Agricultural System

2. Historical Context…

HISTORY OF AGRICULTURE

- ***The history of agriculture is a fascinating journey that spans thousands of years and involves the evolution of human societies from nomadic hunter-gatherers to settled agricultural communities. Here is a detailed overview of the history of agriculture:***

1. Origins of Agriculture (10,000 BCE - 8,000 BCE):

- ***Transition from Hunter-Gatherer Lifestyle:*** Early humans began cultivating plants and domesticating animals as a shift from a nomadic, hunter-gatherer lifestyle to settled agricultural communities.
- ***The Fertile Crescent:*** Agriculture likely originated in the Fertile Crescent, a region in the Middle East, where wild cereals like wheat and barley were first cultivated.

2.

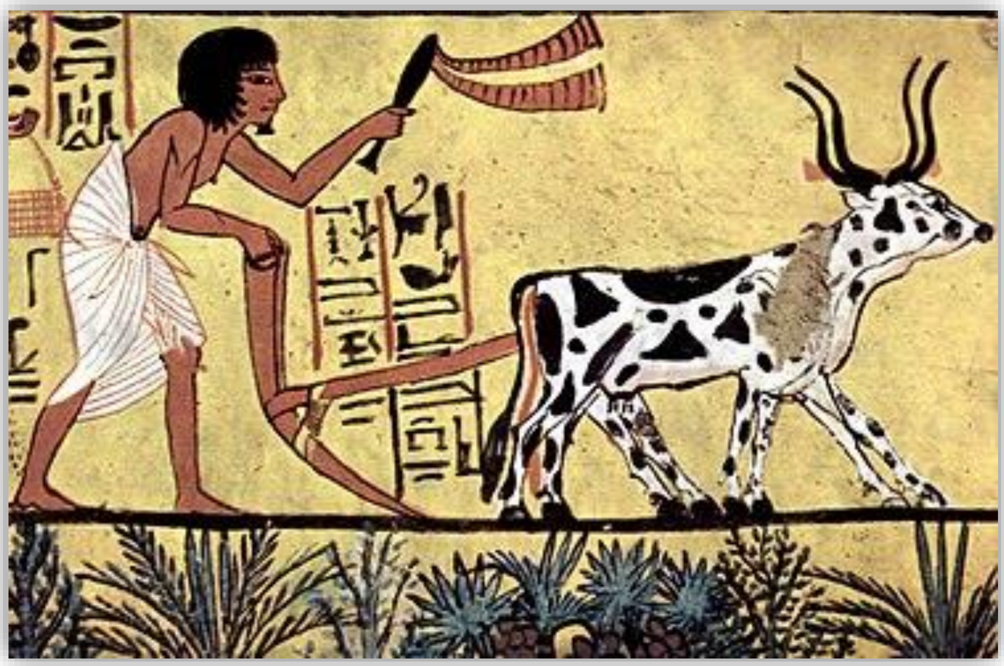

Figure 2.1: *Origin of Agriculture*

Neolithic Agricultural Revolution (8,000 BCE - 4,000 BCE):

- ***Domestication of Plants and Animals:*** Humans domesticated a variety of plants and animals, including wheat, barley, peas, lentils, goats, sheep, and cattle.
- ***Development of Agricultural Techniques:*** Early farming techniques, such as irrigation and the use of simple tools, emerged to enhance crop cultivation.

Figure 2.2: Neolithic Agriculture System

3.Spread of Agriculture (4,000 BCE - 2,000 BCE):

- ***Mesopotamia:*** Agriculture spread to Mesopotamia, where the Sumerians developed complex irrigation systems and the plow.
- ***Indus Valley Civilization:*** Agriculture thrived in the fertile plains of the Indus Valley, where advanced urban centers like Mohenjo-Daro and Harappa engaged in crop cultivation.

4. Ancient Agricultural Practices (2,000 BCE - 500 CE):

- ***Egyptian Agriculture:*** The Nile River played a crucial role in Egyptian agriculture, providing fertile soil through annual flooding. Egyptians cultivated crops like wheat, barley, and flax.
- ***Chinese Agriculture:*** Ancient China witnessed the cultivation of rice, millet, and other crops. Advanced techniques such as terrace farming were employed.

5. Classical Civilizations and Agricultural Innovation (500 CE - 1,500 CE):

- ***Greco-Roman Agriculture:*** The Greeks and Romans practiced agriculture extensively, with innovations like crop rotation and the use of manure.
- ***Byzantine Empire:*** Agricultural practices continued to evolve, and new crops such as citrus fruits were introduced.

6. Medieval Agriculture (500 CE - 1,500 CE):

- ***Manorial System:*** The manorial system emerged in medieval Europe, characterized by large agricultural estates where peasants worked the land for the landowners.
- ***Three-Field System:*** The adoption of the three-field system improved soil fertility and increased agricultural productivity.

7. Agricultural Revolution (18th Century):

- ***Enclosure Movement***: In Europe, the enclosure movement consolidated small, scattered landholdings into larger, enclosed farms, leading to more efficient land use.
- ***Crop Rotation and Selective Breeding:*** Scientific advancements in agriculture included innovations like crop rotation and selective breeding of livestock.

Figure 2.3: Agricultural Revolutions

8. 19th and 20th Century Agricultural Advances:

- ***Mechanization:*** The introduction of machinery such as the plow, tractor, and combine revolutionized farming, significantly increasing productivity.
- ***Green Revolution:*** The mid-20th century saw the Green Revolution, characterized by the development of high-yield crop varieties, synthetic fertilizers, and pesticides.

9. Contemporary Agriculture (21st Century):

- ***Precision Agriculture:*** Modern agriculture integrates technologies like GPS, sensors, and drones for precision farming, optimizing resource use.
- ***Organic Farming:*** There is a renewed focus on sustainable and organic farming practices to address environmental concerns and promote healthier food production.

Figure 2.4: *Crop Monitoring System & Contemporary Agriculture*

EVOLUTION OF TECHNICNOLOGY IN AGRICULTURE

- ***The evolution of technology in agriculture has been a transformative journey, shaping the way farming is practiced and revolutionizing the global food production system. Here's an overview of the key stages in the evolution of agricultural technology:***

1. Early Agricultural Tools (Prehistoric - 3000 BCE):

- ***Hand Tools:*** Early farmers used simple hand tools such as digging sticks, hoes, and sickles for planting and harvesting crops.

- ***Animal Traction:*** The domestication of animals like oxen allowed for the use of animal-drawn plows, enhancing the efficiency of soil cultivation.

Figure 2.5: *Early Agricultural Tools*

2. Ancient Agricultural Innovations (3000 BCE - 500 CE):

- ***Irrigation Systems:*** Civilizations like the Sumerians and Egyptians developed intricate irrigation systems to control water flow for crop cultivation.
- ***Plow Technology:*** The invention of the plow in various forms, such as the Ard and heavy plow, improved soil preparation for planting.

3. Medieval Agricultural Advancements (500 CE - 1500 CE):

- ***Windmills and Watermills:*** Windmills and watermills were used for tasks like grinding grains and pumping water, reducing human labor.
- ***Horse Collar:*** The adoption of the horse collar allowed for more efficient use of horses in agriculture.

4. Agricultural Revolution (18th Century):

- ***Seed Drill:*** Jethro Tull's seed drill, developed in the early 18th century, allowed for precise seeding, improving crop yields and planting efficiency.
- ***Enclosure Movement:*** The enclosure movement consolidated small landholdings, enabling larger-scale, more efficient farming.

5. Mechanization and the Industrial Revolution (Late 18th - 19th Century):

- ***Steam Power:*** The application of steam engines to agriculture powered machines such as threshers and tractors, transforming productivity.
- ***Reaper and Combine:*** Cyrus McCormick's reaper and later the combine revolutionized grain harvesting, significantly reducing labor requirements.

6. 20th Century Technological Advancements:

- ***Tractor Revolution:*** The widespread adoption of tractors in the early 20th century replaced animal power, enhancing the speed and scale of farming operations.
- ***Chemical Fertilizers and Pesticides:*** The development and use of synthetic fertilizers and pesticides during the mid-20th century contributed to the Green Revolution.

7. Green Revolution (1950s - 1960s):

- ***High-Yield Varieties:*** The Green Revolution introduced high-yield crop varieties, such as dwarf wheat and rice, with improved resistance to diseases and pests.
- ***Technological Inputs:*** Increased use of fertilizers, irrigation, and pesticides led to a dramatic increase in crop yields, addressing food shortages.

8. Digital and Precision Agriculture (Late 20th Century - Present):

- ***Computers and Sensors:*** The integration of computers and sensors allowed for data-driven decision-making, optimizing resource use.
- ***GPS Technology:*** Global Positioning System (GPS) technology enabled precision agriculture, guiding equipment for precise planting, harvesting, and irrigation.

9. Biotechnology and Genetically Modified Organisms (GMOs):

- ***Genetic Engineering:*** Advances in biotechnology led to the development of genetically modified crops with traits such as pest resistance and improved nutritional content.

10. 21st Century Agricultural Technologies:

- ***Drones and Satellite Imaging:*** Drones and satellites provide real-time data for crop monitoring, disease detection, and yield estimation.
- ***Robotics:*** Agricultural robots are used for tasks like planting, weeding, and harvesting, reducing labor requirements, and improving efficiency.
- ***Internet of Things (IoT):*** IoT devices collect and transmit data from the field, facilitating smart farming practices and real-time monitoring.

11. Sustainable Agriculture Technologies:

- ***Precision Irrigation:*** Technologies like drip irrigation and soil moisture sensors promote water conservation and sustainable water use.
- ***Organic Farming Technologies:*** Sustainable and organic farming practices are increasingly supported by technology, including natural pest control methods and organic fertilizers.

3. Current Agricultural Landscape…

OVERVIEW OF GLOBAL AGRICULTURE

1. Major Crops:

- The world's major crops include staples like wheat, rice, maize (corn), and soybeans, which are essential for global food security.
- Other important crops include fruits, vegetables, oilseeds, and cash crops like coffee and cocoa.

2. Livestock Farming:

- Livestock farming involves the breeding of animals for meat, dairy, wool, and other products.
- Major livestock species include cattle, poultry, pigs, sheep, and goats.

3.Technology and Modernization:

- Advances in technology, including precision farming, biotechnology, and mechanization, have transformed agricultural practices.
- Precision agriculture uses technologies like GPS, sensors, and data analytics to optimize crop yields, resource efficiency, and reduce environmental impact.

4. Global Agricultural Challenges:

- Agriculture faces challenges such as climate change, water scarcity, soil degradation, and the need for sustainable practices.
- Issues like food security, rural development, and equitable distribution of resources are also critical concerns.

5. Global Trade and Supply Chains:

- International trade in agricultural products is significant, with countries exporting and importing various commodities.
- Global supply chains connect producers to consumers, facilitating the movement of agricultural goods across borders.

6. Environmental Impact:

- Agriculture has environmental implications, including deforestation, greenhouse gas emissions, and the use of agrochemicals.
- Sustainable farming practices and initiatives aim to address environmental concerns and promote eco-friendly agriculture.

7. Role of Smallholder Farmers:

- Smallholder farmers, often in developing countries, play a crucial role in global agriculture.

- Efforts are being made to support and empower small-scale farmers to improve food security and reduce poverty.

8. Policy and Governance:

- National and international policies influence agricultural practices and trade.
- Organizations like the Food and Agriculture Organization (FAO) of the United Nations work on global initiatives to address agricultural challenges.

9. Future Trends:

- Emerging trends include the use of artificial intelligence, blockchain, and attach in agriculture.
- Sustainable and regenerative agriculture practices are gaining attention to address environmental concerns.

4. *Indian Agriculture & management…*

Indian agriculture, deeply rooted in the country's history and culture, has undergone significant transformations over the years. The management of Indian agriculture plays a crucial role in ensuring sustainable development, increasing productivity, and addressing the challenges faced by the farming community. Let's delve into the key aspects of Indian agriculture and the management strategies adopted to enhance its efficiency.

Historical Perspective:

1. Traditional Farming Practices:

- India has a rich agricultural heritage with traditional farming practices deeply ingrained in its cultural fabric.
- Small-scale and subsistence farming were predominant, with an emphasis on diverse crops.

2. Green Revolution:

- The 1960s and 1970s marked the Green Revolution, introducing high-yielding varieties of crops, modern irrigation techniques, and chemical fertilizers.

- This period significantly increased agricultural productivity but also led to environmental concerns and socio-economic disparities.

Agricultural Management Strategies:

1.Technology Integration:

- ***Precision Farming:*** Utilizing technology for precise monitoring and management of crops, optimizing inputs like water, fertilizers, and pesticides.
- ***Drones and Satellites:*** Monitoring crop health, identifying pest infestations, and assessing land conditions using aerial technology.

Water Management:

The water condition in India for agriculture is a critical aspect that significantly influences crop production, food security, and the livelihoods of millions of farmers. India faces various challenges related to water availability, distribution, and management, impacting agricultural practices across the country.

Water Efficiency & Availability

The situation of water availability going forward is perhaps more alarming. Figure 9 shows baseline water stress in India, defined as annual water withdrawals as a percentage of total annual available flow. Higher values indicate greater stress. As it can be seen, large parts of India are threatened with medium baseline ground water stress or above. NITI Aayog's Composite Water Management Index (CWMI) notes that approximately 820 million Indians have a percapita availability of water of less than 1000 m^3, the official threshold for water scarcity as per the Falkenmark Index. With growing demand, water availability is likely to go down further. The CWMI further states that demand will exceed supply by a factor of 2 by 2030.

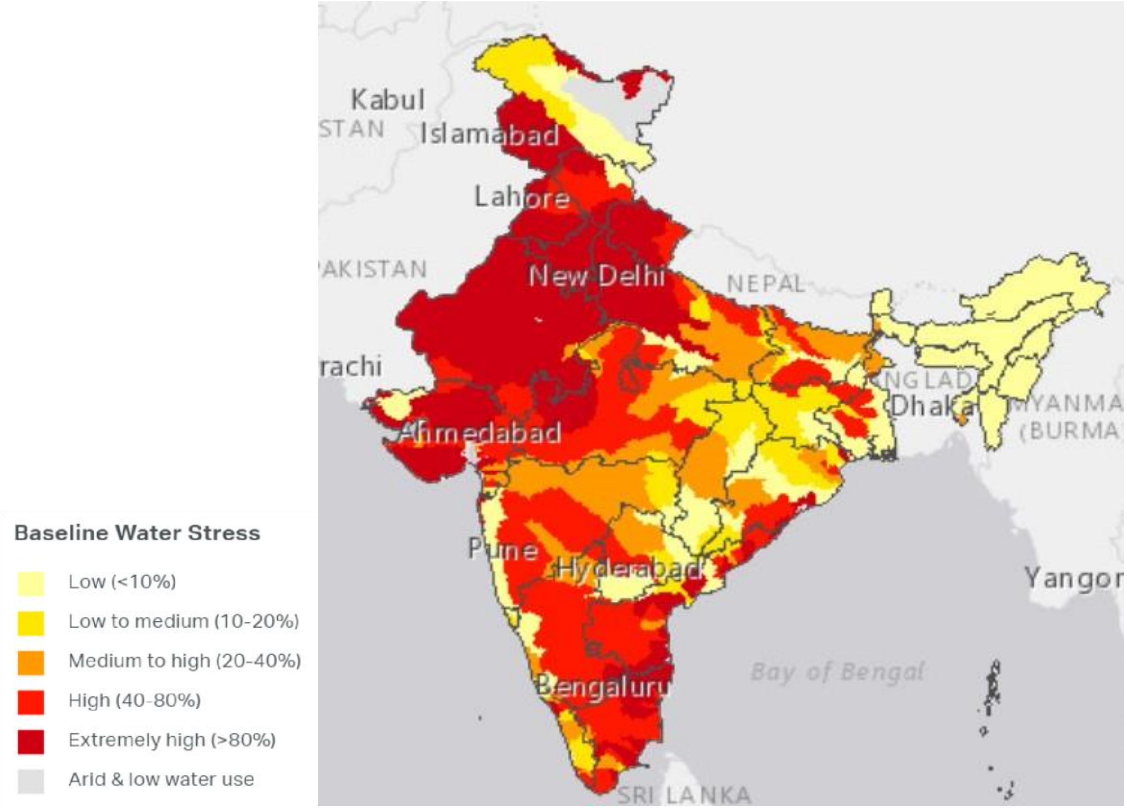

Figure 4.1: *Baseline Ground Water Stress in India, 2010*

Source: *India Water Tool.*

A large fraction of India's water use is in agriculture. As the table 9 shows, nearly 90% of India's groundwater extraction is in the agriculture sector. States such as Punjab & Haryana, where the area under irrigation is greater than 90%, extract the most water, and are at alarming levels of annual groundwater extraction. Overall, India extracts 61.1% of its annual extractable groundwater resources. With this stage of groundwater extraction and the need to provide adequate water for all uses, domestic, industrial and agriculture, efficiency in water use, particularly in agriculture is critical, going ahead.

	State	Area Under Irrigation (%)	Agriculture Share in Annual Water Extraction (%)	Stage of Groundwater Extraction (%)
1	Andhra Pradesh	49.8	86.5	33.3
2	Bihar	74.2	79.3	51.1
3	Chhattisgarh	35.7	84.7	46.3
4	Goa	22.6	25.0	23.5
5	Gujarat	51.0	95.1	53.4

6	**Haryana**	**91.2**	**90.2**	**134.6**
7	Jharkhand	13.7	56.7	29.1
8	Karnataka	35.0	90.3	64.9
9	Kerala	20.0	43.8	51.7
10	Madhya Pradesh	48.6	91.4	56.8
11	Maharashtra	23.6	91.9	55.0
12	Odisha	29.0	80.2	43.7
13	**Punjab**	**98.5**	**96.9**	**164.4**
14	**Rajasthan**	**43.5**	**86.4**	**150.2**
15	Tamil Nadu	56.1	92.2	82.9
16	Telangana	54.2	89.0	53.3
17	Uttar Pradesh	80.7	89.7	68.8
18	Uttarakhand	52.4	72.4	46.8
19	West Bengal*	65.5	91.6	44.6
	India^	52.0	88.8	61.6

Notes: **The Ground Water resources assessment as of 2013 has been considered for the state of West Bengal. ^ All India figures include North Eastern & Himalayan States & Union Territories.

Table 1: Share of Agriculture in Annual Groundwater Extraction & Stage of Groundwater Extraction: 2020

Source: *Central Ground Water Resources Board*

Irrigation, however, remains inefficient and unsustainable in India. Flood irrigation still forms part of the standard practices, with lower water use efficiency, when compared to micro-irrigation. Compared to other nations, India's water efficiency stands much lower. India in comparison to USA & China, with the exception of sugarcane, there is a large gap in India's virtual water use in rice, wheat, soyabean and cottonseed. With food production only needing to expand, improving water use efficiency is imperative.

It is also pertinent to note that public procurement is concentrated in cereals and procured mostly from states such as Punjab & Haryana, where water stress is at its greatest. Whilst a review of public procurement policies is beyond the scope of this paper, it must be pointed out that one of the greatest incentives for farmers in Punjab, Haryana, and Western Uttar Pradesh, amongst others is public procurement of cereals at minimum support prices (MSP). Many states also make provision for free or subsidized power to farmers, enabling them to use borewells to extract groundwater for irrigation. Therefore, any solution must be looked at across the water energy-agriculture nexus.

Crop	India	US	China
Rice	4,254	1,903	1,972
Wheat	1,654	849	690
Soyabean	4,124	1,869	2,617
Sugarcane	159	103	117
Cottonseed	8,264	2,535	1,419

Table 2: Virtual Water Use for Crops

With water-use efficiency in mind, the Government of India started promoting micro-irrigation. There have been some improvements as a result of this scheme. As of 2014-15, 8.0% of India's gross irrigated area (GIA) was covered with micro-irrigation. By 2018-19, this number increased to 11.1%, a 3.6 million hectares increase. As always, there exists substantial variance at the state level. Whilst some states, such as Sikkim & Andhra Pradesh are much higher than the national average, other large states lag behind. Uttar Pradesh, with 80.7% of its area under irrigation, has micro irrigation in 0.7% of its irrigated area. A similar story emerges in Punjab as well, where 0.6% of the area is under micro irrigation. The figure 10 illustrates the current substantial variance across states in the adoption of micro irrigation practices. In particular, states where water stress is acute, micro irrigation adoption lags behind.

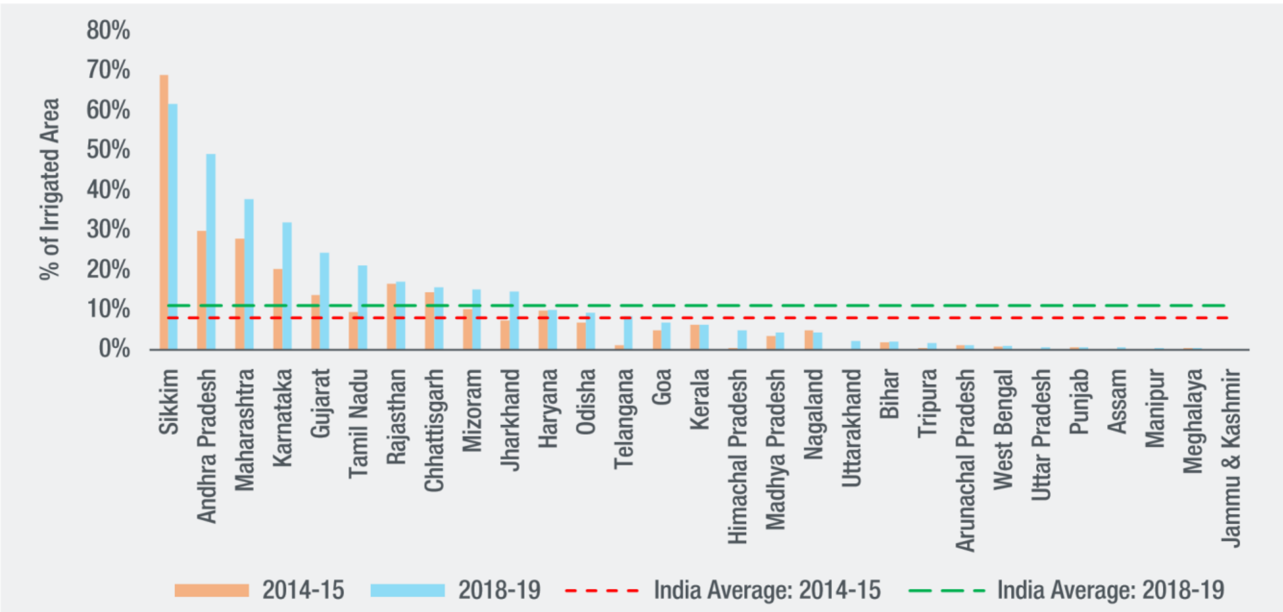

***Figure 4.2:** Share of Micro Irrigation in Gross Irrigated Area: 2014-15 and 2018-19*

***Source:** Ministry of Agriculture & Farmers Welfare*

Micro irrigation systems require substantial investments. As mentioned earlier, small, and marginal farmers are particularly constrained when it comes to investing in their farms. This constraint arises from both the demand side and the supply side. Some farmers may be constrained by a lack of long-term institutional finance. The cost of capital expenditure, vis-à-vis the expected returns, tend to make little economic sense, especially as the benefits of economies of scale do not accrue to small and marginal farmers.

India is facing two interrelated challenges. The first is raising land productivity to continue meeting the demands of a growing population. The second challenge is raising productivity whilst ensuring sustainable and resilient farms. Both challenges are interrelated but at times, seem at odds with each other. Increasing the intensification of industrial agriculture, which has been an ongoing process, and resulted in increased land productivity, has resulted in environmental damage. However, without increasing productivity, India may face food shortages in the future. Therefore, the challenge in front of India and indeed, the rest of the developing world is to increase land and farm labour productivity, whilst maintaining sustainability and building resilience to climate change.

Key Points Regarding Water Condition for Agriculture in India:

1.Uneven Distribution:

- ***Rivers and Rainfall:*** India has several major rivers, but their distribution is uneven. The northern plains receive more river water, while peninsular regions rely heavily on rainfall.
- ***Monsoon Dependency:*** Agriculture in many parts of India is highly dependent on the monsoon, making it vulnerable to variations in rainfall patterns.

2. Water Scarcity:

- ***Depleting Groundwater:*** Excessive extraction of groundwater, often beyond recharge rates, has led to declining water tables in many regions.
- ***Over-exploitation:*** Agricultural practices, including the use of inefficient irrigation methods, contribute to over-exploitation of water resources.

3.Irrigation Practices:

- ***Canal Irrigation:*** Traditional canal irrigation systems are present, but they may suffer from inefficiencies, waterlogging, and inadequate maintenance.
- ***Tube Wells and Wells:*** Groundwater extraction through tube wells and wells is common, but over-extraction can lead to aquifer depletion.

4.Water Quality:

- ***Contamination:*** Poor agricultural practices, industrial discharge, and inadequate sanitation contribute to water pollution, affecting both surface and groundwater quality.
- ***Salinity Intrusion:*** Coastal areas face challenges from salinity intrusion, affecting soil fertility and crop productivity.

5.Government Initiatives:

- ***Pradhan Mantri Krishi Sinchayee Yojana (PMKSY):*** Aims to improve water use efficiency through the development of water storage and distribution infrastructure.
- ***Micro-Irrigation Schemes:*** Encouraging the adoption of drip and sprinkler irrigation to enhance water use efficiency.

6.Water Management Challenges:

- ***Inter-State Water Disputes:*** Conflicts over sharing river water among different states pose challenges to effective water management.
- ***Climate Change Impact***: Changing precipitation patterns and increasing temperatures due to climate change further stress water resources.

7.Efforts Towards Sustainable Agriculture:

- ***Rainwater Harvesting:*** Promoting rainwater harvesting techniques to capture and store rainwater for agricultural use.

- ***Watershed Management:*** Implementing watershed management practices to conserve water and prevent soil erosion.

8.Crop Selection and Rotation:

- ***Crop Diversification:*** Encouraging farmers to diversify crops based on water availability and suitability.
- ***Adopting Drought-Resistant Varieties:*** Promoting the use of drought-resistant crop varieties to mitigate the impact of water scarcity.

Future Strategies:

1.Water Use Efficiency:

- ***Modern Irrigation Techniques:*** Promoting the use of efficient irrigation methods like drip and sprinkler systems.
- ***Smart Water Management:*** Implementing smart technologies for real-time monitoring and management of water resources.

2.Policy Reforms:

- ***Integrated Water Resource Management:*** Formulating and implementing policies that focus on holistic water resource management.
- ***Community Participation:*** Involving local communities in water management decisions to ensure sustainability.

3.Research and Innovation:

- ***Drought-Resistant Crops:*** Continued research to develop and promote crops that are resilient to water scarcity.
- ***Water-Saving Technologies:*** Investing in technologies that help farmers use water more efficiently.

4.Awareness and Education:

- ***Farmers' Education:*** Conducting awareness programs and providing education to farmers about sustainable water practices.
- ***Promoting Water Conservation:*** Encouraging a culture of water conservation and responsible usage among farmers.

Addressing the water condition for agriculture in India requires a multi-faceted approach, involving technological advancements, policy reforms, community engagement, and sustainable farming practices. The goal is to ensure water security for agriculture while preserving water resources for future generations.

Soil Management:

The soil conditions in India vary widely due to the diverse geographical and climatic features across the country. India is home to several types of soils, each with its unique characteristics. Understanding the soil conditions is crucial for successful agriculture. Here are some key aspects of the soil conditions for agriculture in India:

Degrading soil health is another factor that will affect productivity growing forward. According to the National Academy of Agriculture Sciences (NAAS, 2018), degradation of soil can occur due to four reasons: (i) salinization/alkalinization; (ii) acidification; (iii) soil toxification through chemicals and (iv) depletion of nutrients and organic matter. Soil organic carbon (SOC) has been cited as an important indicator of soil health, due to its contributions to food production and adaptation to climate change (FAO, 2017). Data from the Soil Health Card (SHC) scheme launched by the Government of India in 2015 indicates prevalence of low SOC content across India.

Figures 4.3 & 4.4 plot the status of SOC in the samples tested under the SHC scheme. The samples have been divided into 5 categories to measure the level of SOC. The categories are very low, low, medium, high and very high. The categories have then been colour-coded and plotted, state-wise. Again, there is substantial variation across states. Figure 4.3 plots the status in cycle 1 of the scheme (2015-16 to 2016-17) and figure 4.4 plots the status in cycle 2 of the scheme (201718 and 2018-19). As it can be seen, in some states, a significant portion of samples tested either very-low or low. This is especially evident in the case of Punjab and Haryana. However, between the two cycles, both states have shown some improvements. Rajasthan & Uttar Pradesh are other major states with low SOC content.

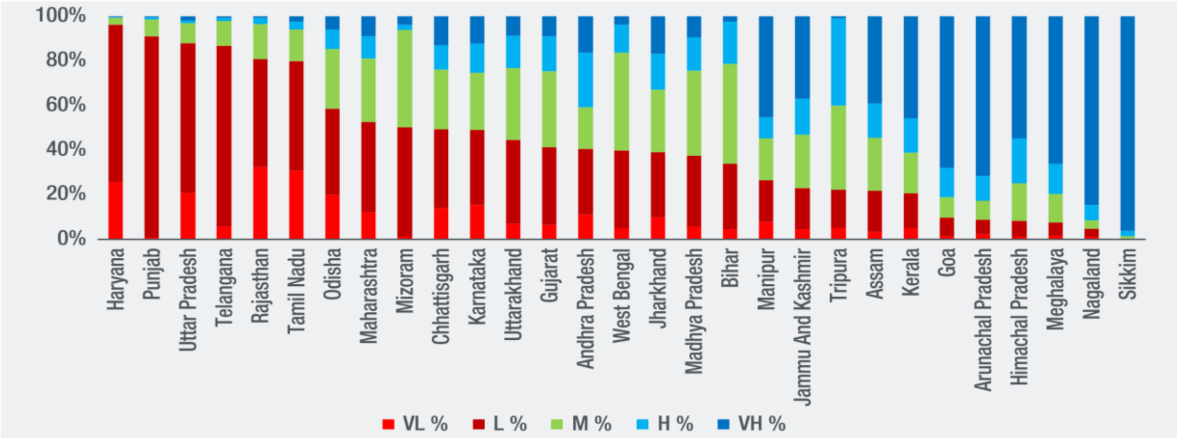

Figure 4.3: *Soil Organic Carbon Status in Cycle I of SHC Scheme: 2015-17*

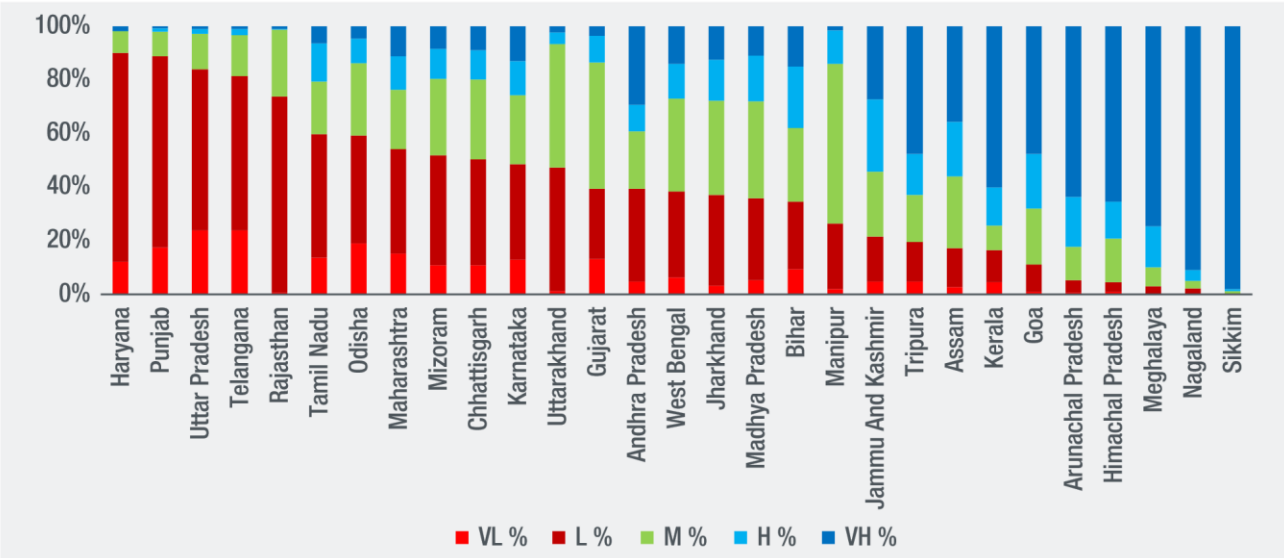

Figure 4.4: *Soil Organic Carbon Status in Cycle II of SHC Scheme: 2017-19*

Source: *Soil Health Card Portal, Ministry of Agriculture & Farmers Welfare,*

The link between imbalanced fertilizer use and soil degradation has been examined by the NAAS (2018). They note that skewed NPK ratios have led to degradation of soil health. Chand and Pavithra (2015) estimated the state-wise requirement of fertilizers. Table 3 notes the prescribed use of fertilizers to increase productivity, against the actual usage. Andhra Pradesh, Bihar, Haryana, Jharkhand & Punjab are applying fertilizers above the prescribed norms. The rest of the states are utilizing less fertilizer than prescribed, as per the results of Chand and Pavithra (2015).

The conventional knowledge has been that at a national level, a ratio of 4:2:1 was ideal. However, as noted by Chand and Pavithra (2015), this norm needs to be revisited, especially as a national level norm cannot reflect the heterogeneity across and within states. Table 4 compares the normative ratios against the actual ratios. The imbalance in fertilizer use towards N is evident across all states. On the impact of imbalanced use of fertilizers on soil health, the authors note that where the actual use of fertilizer is below the prescribed use, the impact on soil health of NPK balance will be negligible. It is pertinent to note that the NPK imbalance is the greatest in States with the highest area under irrigation.

In interpreting tables 6 & 7, it must be kept in mind that the norms derived by Chand & Pavithra (2015) were based on the cropping patterns prevalent during 2011-12. Since the cropping patterns may have changed since then, the prescribed norms would have altered as well. It is for this reason the prescribed norms as per the paper are presented against the actual usage and ratios for 2011-12 and 2019-20. Recalculating the prescribed norms of fertilizer usage based on the package of practices published by State Agriculture Universities (SAUs) and the Indian Council of Agriculture Research (ICAR) is beyond the scope of this paper, as such an exercise is a paper in its own right. This remains a future avenue of research, where the normative fertilizer usage is calculated at regular intervals, to aid policymaking.

Yet, a preliminary analysis was undertaken to understand if there has been any major shift in cropping patterns, especially in the large producing states.

Rice	% of GCA	
	2011-12	2019-20
Punjab	35.7%	37.2%
Haryana	19.1%	22.0%
Uttar Pradesh	22.9%	21.4%
West Bengal	58.1%	54.8%
Andhra Pradesh	29.8%	31.4%
Odisha	80.6%	85.9%

Wheat	% of GCA	
	2011-12	2019-20
Uttar Pradesh	37.5%	35.4%
Madhya Pradesh	21.7%	25.1%
Punjab	44.7%	44.7%
Haryana	38.8%	38.3%
Rajasthan	12.0%	12.3%
Bihar	28.0%	30.4%

Table 3: % of Area under Rice & Wheat: 2011-12 and 2019-20

Gram	% of GCA	
	2011-12	2019-20
Rajasthan	5.8%	9.7%
Maharashtra	4.8%	12.1%
Madhya Pradesh	13.5%	7.4%
Karnataka	6.6%	7.7%
Uttar Pradesh	2.2%	2.3%

Tur (Arahar)	% of GCA	
	2011-12	2019-20
Karnataka	6.4%	11.4%
Maharashtra	5.6%	6.3%
Uttar Pradesh	1.2%	1.1%
Gujarat	1.8%	1.8%
Jharkhand	7.7%	12.6%

Table 4: % of Area under Pulses (Gram & Tur) : 2011-12 and 2019-20

Groundnut	% of GCA	
	2011-12	2019-20
Gujarat	12.9%	14.8%
Rajasthan	1.7%	2.9%
Andhra Pradesh	9.5%	9.0%

Soyabean	% of GCA	
	2011-12	2019-20
Madhya Pradesh	25.2%	23.7%
Maharashtra	13.6%	21.1%
Rajasthan	3.7%	4.4%

Karnataka	5.6%	4.2%		Karnataka	1.6%	2.4%
Tamil Nadu	6.6%	6.2%		Gujarat	0.0%	0.9%

Table 5: % of Area under Oilseeds (Groundnut & Soyabean) : 2011-12 and 2019-20

Source: *Agriculture Statistics at a Glance, Ministry of Agriculture (various issues) & authors' calculations*

Tables 3-5 show that there have been some changes in cropping patterns, especially in pulses and oilseeds. Yet, in the case of rice and wheat, there have been no major changes in the areas they cover in the top producing states.

This implies that the normative fertilizer usage calculated by Chand & Pavithra (2015) may not necessarily hold true in 2019-20.

		Normative Use (2011-12)				Actual Use (2011-12)				Actual Use (2019-20)			
	State	N	P	K	Total	N	P	K	Total	N	P	K	Total
1	Andhra Pradesh*	1,138	679	474	2,291	1,977	1,043	322	3,342	980	490	212	1,683
2	Bihar	688	368	245	1,301	968	297	115	1,380	1.235	423	162	1,821
3	Chhattisgarh	498	298	208	1,005	356	177	62	596	450	226	62	737
4	Goa	114	82	73	270	3	3	2	8	2	1	1	4
5	Gujarat	1,247	450	456	2,153	1,183	417	133	1,733	1,296	382	114	1,792
6	Haryana	807	339	202	1,348	1,021	370	38	1,428	1,070	303	38	1,411
7	Himachal Pradesh	82	43	33	158	33	10	9	51	38	10	10	59
8	Jammu & Kashmir	95	57	29	181	66	29	5	100	51	17	11	79
9	Jharkhand	84	51	42	177	118	42	11	171	132	45	5	182
10	Karnataka	1,043	655	651	2,349	1,216	787	333	2,336	1,018	560	283	1,861
11	Kerala	227	164	349	740	136	66	100	301	79	34	62	175
12	Madhya Pradesh	1,080	1,181	449	2,710	1,062	751	80	1,892	1,673	894	116	2,683
13	Maharashtra	1,745	1,176	654	3,575	1,610	1,012	400	3,022	1,561	898	482	2,941
14	Orissa	313	177	176	666	323	136	56	515	348	151	75	574
15	Punjab	951	375	235	1,561	1,417	449	53	1,918	1,500	363	43	1,906
16	Rajasthan	1,335	742	130	2,206	914	416	26	1,356	1,217	479	21	1,718
17	Tamil Nadu	673	270	298	1,241	685	316	264	1,265	582	234	171	987
18	Telangana	-	-	-	-	-	-	-	-	987	370	122	1,479
19	Uttar Pradesh	3,210	1,436	1,085	5,731	3,067	1,024	166	4,258	3,740	1,227	206	5,173
20	Uttarakhand	114	82	73	270	124	32	10	166	124	31	9	163
21	West Bengal	162	75	51	288	832	477	309	1,617	790	461	349	1,599

Source: *Chand & Pavithra (2015) & Ministry of Agriculture. Totals may not add up due to rounding.*

*Undivided Andhra Pradesh.

Note: *Figures in thousand tonnes*

Table 6: State-Wise Normative and Actual Use of Fertilizers (Thousand Tons)

		Normative Ratios (2011-12)			Actual Ratios (2011-12)			Actual Ratios (2019-20)		
	State	N	P	K	N	P	K	N	P	K
1	Andhra Pradesh	2.4	1.4	1.0	6.1	3.2	1.0	4.6	2.3	1.0
2	Bihar	2.8	1.5	1.0	8.4	2.6	1.0	0.0	2.6	1.0
3	**Chhattisgarh**	**2.4**	**1.4**	**1.0**	**5.7**	**2.9**	**1.0**	**7.3**	**3.6**	**1.0**
4	Goa	1.6	1.1	1.0	1.5	1.5	1.0	2.0	1.0	1.0
5	**Gujarat**	**2.7**	**1.0**	**1.0**	**8.9**	**3.1**	**1.0**	**11.4**	**3.4**	**1.0**
6	**Haryana**	**4.0**	**1.7**	**1.0**	**26.9**	**9.7**	**1.0**	**28.2**	**8.0**	**1.0**
7	Himachal Pradesh	2.5	1.3	1.0	3.7	1.1	1.0	3.8	1.0	1.0
8	Jammu & Kashmir	3.3	2.0	1.0	13.2	5.8	1.0	4.6	1.5	1.0
9	**Jharkhand**	**2.0**	**1.2**	**1.0**	**10.7**	**3.8**	**1.0**	**26.4**	**9.0**	**1.0**
10	Karnataka	1.6	1.0	1.0	3.7	2.4	1.0	3.6	2.0	1.0
11	Kerala	0.7	0.5	1.0	1.4	0.7	1.0	1.3	0.5	1.0
12	**Madhya Pradesh**	**2.4**	**2.6**	**1.0**	**13.3**	**9.4**	**1.0**	**14.4**	**7.7**	**1.0**
13	Maharashtra	2.7	1.8	1.0	4.0	2.5	1.0	3.2	1.9	1.0
14	Odisha	1.8	1.0	1.0	5.8	2.4	1.0	4.6	2.0	1.0
15	**Punjab**	**4.0**	**1.6**	**1.0**	**26.7**	**8.5**	**1.0**	**34.9**	**8.4**	**1.0**
16	**Rajasthan**	**10.3**	**5.7**	**1.0**	**35.2**	**16.0**	**1.0**	**58.0**	**22.8**	**1.0**
17	Tamil Nadu	2.3	0.9	1.0	2.6	1.2	1.0	3.4	1.4	1.0
18	Telangana	-	-	-	-	-	-	8.1	3.0	1.0
19	**Uttar Pradesh**	**3.0**	**1.3**	**1.0**	**18.5**	**6.2**	**1.0**	**18.2**	**6.0**	**1.0**
20	**Uttarakhand**	**1.6**	**1.1**	**1.0**	**12.4**	**3.2**	**1.0**	**13.8**	**3.4**	**1.0**
21	West Bengal	3.2	1.5	1.0	2.7	1.5	1.0	2.3	1.3	1.0

Source: *Chand & Pavithra (2015) for normative use. Ministry of Agriculture for actual use in 2011-12 and 2019-20. Actual ratios for 2011-12 differ from Chand & Pavithra (2015), as updated data on fertilizer consumption was available.* ***Note:*** *Figures refer to the ratios of fertilizer use.*

Table 7: Actual vs Normative Fertilizer Use Balance in India: 2019-20

Table 7 makes clear the lop-sided use of fertilizers, skewed in favor of nitrogen. The imbalance is severe in Punjab, where against a prescribed ratio of 4.05:1.60:1.00, the actual ratio is 35:8:1 in 2019-20. A similar story emerges in Haryana, Uttar Pradesh and Rajasthan. Even in 2011-12, the imbalance was quite evident in these states. Between 2011-12 and 2019-20, the imbalance seems to have been exacerbated. Clearly, there seems to be an impact of this imbalance on soil health. In fact, NAAS (2018) notes that between 1970 and 2008, the amount of fertilizer nutrients required to maintain the same yield increased by 5 times, a clear indicator of poor soil health. This in turn is leading to fertilizer use efficiency declining as well, and in particular nitrogen use efficiency (NUE). The NAAS report notes that without regular application of organic manures and recycling of crop residues, soil health cannot be maintained.

Major Soil Types:

1.Alluvial Soil:

Distribution: Found in the plains of the Ganges and its tributaries, as well as in coastal areas.

Characteristics: Fertile and rich in minerals; ideal for the cultivation of rice, wheat, sugarcane, and other crops.

2. Black Soil (Regur):

Distribution: Deccan Plateau, parts of Gujarat, Maharashtra, and Madhya Pradesh.

Characteristics: Rich in iron, lime, and aluminum; suitable for cotton, cereals, oilseeds, and pulses.

3. Red and Yellow Soil:

Distribution: Found in areas with low rainfall, such as parts of Tamil Nadu, Karnataka, and Andhra Pradesh.

Characteristics: Deficient in nutrients, acidic in nature; suitable for millets, pulses, and oilseeds.

4. Laterite Soil:

Distribution: Western Ghats, Eastern Ghats, and parts of Odisha and Karnataka.

Characteristics: Poor fertility, leaching of minerals; suitable for tea, coffee, rubber, and cashew.

5. Arid and Desert Soil:

Distribution: Western Rajasthan, parts of Gujarat, Haryana, and Punjab.

Characteristics: Sandy and saline; suitable for drought-resistant crops like millets and pulses.

6. Mountain or Forest Soil:

Distribution: Himalayan region.

Characteristics: Varies based on altitude; suitable for orchards, temperate crops, and horticulture.

Soil Health and Challenges:

1. Soil Fertility:

- Continuous cultivation and imbalanced use of fertilizers can lead to soil fertility depletion.
- Organic farming practices and crop rotation are employed to maintain soil fertility.

2. Soil Erosion:

- Improper land management, deforestation, and excessive irrigation contribute to soil erosion.
- Contour plowing, agroforestry, and check dams are implemented to combat soil erosion.

3. Salinity and Alkalinity:

- Some coastal areas and regions with poor drainage can experience soil salinity.
- Reclamation measures include proper drainage systems and the use of gypsum.

4. Waterlogging:

- Poor drainage in some areas can lead to waterlogging, affecting crop growth.
- Installation of drainage systems and suitable crop selection are essential to mitigate waterlogging.

Soil Management Strategies:

1. Soil Testing:

- Regular soil testing helps determine nutrient levels and guides fertilizer application.

2. Crop Rotation:

- Alternating crops helps prevent soil nutrient depletion and reduces the risk of pests and diseases.

3. Organic Farming:

- Encouraging organic farming practices enhances soil health and sustainability.

4. Agroforestry:

- Planting trees alongside crops helps prevent soil erosion, improves fertility, and provides additional income.

5. Conservation Agriculture:

- Implementing minimal tillage practices reduces soil disturbance and improves water retention.

6. Irrigation Management:

- Efficient irrigation systems, such as drip and sprinkler irrigation, prevent waterlogging and salinity.

Understanding and addressing the diverse soil conditions in India is crucial for sustainable agriculture. Farmers, researchers, and policymakers work collaboratively to implement best practices, improve soil health, and ensure long-term productivity in the country's agricultural sector.

Climate Conditions:

India exhibits diverse climatic conditions due to its vast geographical expanse. The varied climate across different regions influences the types of crops that can be grown, the cropping patterns, and the agricultural practices. Here is an overview of the climate conditions in India and their impact on agriculture:

1. Tropical Climate:

Regions: Coastal areas, southern and northeastern parts of India.

Crops: Rice, coconut, spices (pepper, cardamom), bananas, and tropical fruits.

Challenges: High temperatures and heavy rainfall can lead to waterlogging and diseases.

2. Subtropical Climate:

Regions: Northern plains, Himalayan foothills.

Crops: Wheat, barley, mustard, fruits like apples and cherries.

Challenges: Cold winters limit the cultivation of tropical crops; frost can damage crops in some areas.

3. Arid and Semi-Arid Climate:

Regions: Rajasthan, parts of Gujarat, Haryana, Punjab.

Crops: Millets, oilseeds, pulses, cotton.

Challenges: Water scarcity, high temperatures, and sandy soils impact crop choices and yields.

4. Mountainous Climate:

Regions: Himalayan regions (Jammu & Kashmir, Himachal Pradesh, Uttarakhand).

Crops: Apples, cherries, walnuts, temperate fruits.

Challenges: Steep slopes limit cultivation; cold temperatures affect crop varieties.

5. Coastal Climate:

Regions: Western and eastern coasts.

Crops: Rice, coconut, cashew, spices.

Challenges: Cyclones and saltwater intrusion can impact crops; high humidity favors certain diseases.

6. Monsoon Climate:

Regions: Most of India experiences the monsoon.

Crops: Rice, sugarcane, jute, pulses.

Challenges: Heavy rainfall during the monsoon can lead to flooding and waterlogging; erratic monsoons affect crop planning.

7. Hilly and Forested Climate:

Regions: Western Ghats, Eastern Ghats, central India.

Crops: Tea, coffee, spices, fruits.

Challenges: Sloped terrains require terrace farming; dense forests limit agricultural expansion.

8. Desert Climate:

Region: Thar Desert (Rajasthan).

Crops: Pearl millet, wheat, pulses.

Challenges: Extreme temperatures, low rainfall, and sandy soils pose challenges to agriculture.

Impact on Agriculture:

1. Crop Planning:

- Farmers need to align their crop choices with the specific climate of their region.

2. Water Management:

- Efficient irrigation systems are crucial, especially in arid and semi-arid regions.

3. Crop Rotation:

- Adaptation of crop rotation strategies based on seasonal variations and soil health.

4. Climatic Events:

- Farmers must be prepared for climatic events such as cyclones, droughts, and floods.

5. Technology Adoption:

- Use of climate-resilient crop varieties and advanced technologies to mitigate climate-related risks.

6. Government Interventions:

- Policies and schemes that address the challenges posed by specific climatic conditions.

Understanding and adapting to the diverse climatic conditions in India are essential for sustainable and resilient agriculture. It requires a combination of traditional knowledge, modern technology, and supportive policies to ensure the well-being of farmers and the food security of the nation.

Government Policies:

As of my last knowledge update in January 2022, several government plans and schemes have been implemented in India to address various challenges and promote sustainable development in the agricultural sector. It's important to note that policies and programs may evolve over time, so it's advisable to check for the latest updates. Here are some key government initiatives related to Indian agriculture:

1. FROM FOOD TO FOOD SYSTEMS

India has focused on improving access to cereals and achieved significant results. In the quest to double farmers income, diversification of farm incomes has been cited as an important strategy. With intercropping and multi-cropping at its core, natural farming could scientifically contribute to the solution. There are also calls to diversify the diets provided by the National Food Security Act and the Mid-Day Meal Scheme (TCI, 2020). India's experience is testament to the fact that public procurement can incentivise production of certain crops. Public procurement in the initial years can provide as an incentive towards diversification of farm produce. Preference to procurement from Natural Farming practising farmer organisations can be an incentive to popularise natural farming.

2. OVERHAUL OF INCENTIVES AND SUBSIDIES

As per the Union Budget 2020-21, Rs. 79,998 crores were spent on fertiliser subsidies by the Union Government in 2019-20. In comparison, the entire budget for the Department of Agriculture Research & Education (DARE) stood at approximately Rs. 7,500 crores in 2019-20. Similarly, the total transfers to States for agriculture extension services stood at Rs. 940 crores. Many state governments also provide power subsidies to farmers, making the input subsidy bill even bigger in reality. The transfer to states as part of the *Paramparagat Krishi Vikas Yojana (PKVY)*, was Rs. 300 crores in 2019-20. Therefore, funding for Natural Farming will have to be scaled up substantially. To give a larger push to agroecology, PKVY can be reoriented as a Central Sector Scheme, with funding scaling up as the area under Natural Farming increases. Promoting natural farming will reduce the reliance on inputs and hence the large subsidy bill for fertilisers, electricity, water and credit. This cost saving can then be translated to higher allocations under PKVY.

3. NEW MONITORING AND EVALUATION FRAMEWORK

A set of indicators, with clearly defined inputs, outputs and expected outcomes needs to be developed (Frison, 2016) to measure the performance of states. Funding allocation to the scaled up PKVY can be linked to the performance of states on this set of indicators. Third party validation of data should also be promoted, in partnership with either the private sector or the civil society. This will ensure robustness and transparency of data on the portal. These indicators are in turn bound to be in synergy with the sustainable development goals as well. Development of the initial framework could perhaps be undertaken by the Development Monitoring and Evaluation Office (DMEO), NITI Aayog. The framework can then be finalised in consultation with the relevant ministries and state governments.

4. DOCUMENTATION OF NATURAL FARMING PRACTICES IN INDIA

As mentioned earlier, agroecological approaches are highly context specific. Therefore, there is no one system of Natural Farming that can be propagated all across India. The need of the hour is to document and widely disseminate these practices, based on local conditions. At the same time, there is a need to develop some overarching principles, as the FAO HLPE Report has. Identification of these principles will also aid in the certification process, which is critical in commanding higher prices in terminal markets. Standards also need to de developed to grade and assay produce from natural farming.

5. FARMER HANDHOLDING

Since Natural Farming is a knowledge-intensive system, co-training and co-educating farmers on the benefits of agroecological approaches remains the key challenge. The success of Andhra Pradesh in popularising Natural Farming was in part due to long-term handholding of farmers. Government support and advocacy was critical as well. Therefore, increasing extension budgets, and reorienting extension services to promote Natural Farming is the need of the hour. The central government can take the lead in this aspect, through making PKVY a Central Sector Scheme to develop extension systems to popularise Natural Farming a cornerstone of the efforts. The role of farmer producer organisations (FPOs), self-help groups (SHGs) will be critical in these efforts as well.

6. PARTNERSHIPS WITH THE CIVIL SOCIETY AND PRIVATE SECTOR

Partnering with the Civil Society would help in reaching farmers for training and capacity building. These partnerships could also result in enabling a robust monitoring and evaluation framework as well. The private sector can have a role to play here as well. Whilst India lags behind in food processing, a large part of industrial agriculture products feed the food processing industry. The requirements of such industries are therefore based on the prevalent system of production. Partnering with the private sector, to develop processable varieties that can be used as inputs in the food processing industry, keeping in mind the principles of natural farming is another area to explore. Processed products based on organic inputs sell at substantial premiums.

7. COLLECTIVISATION OF FARMERS

Another way to reach a large group of farmers can be through collectivising them into producer organisations or cooperatives. The Government of India is already pushing for the creation of farmer collectives at a large scale. This push can be effectively leveraged to popularise Natural Farming. The Andhra Pradesh model showed that women organised through self-help groups (SHGs) enabled collective action and peer learning. These farmer collectives can then be connected to terminal markets, or partners in the food processing industry, as described above. This will boost their bargaining power

8. TRANSFER PAYMENTS FOR ECOLOGICAL SERVICES RENDERED

As stated by Dorin et al. (2013, 2021), for agroecology to be popularised, farmers need to be compensated not just for their produce, but also the ecological services they render. India already has a mechanism to directly deliver cash to farmers’ bank accounts. This system can be leveraged to transfer benefits directly to farmers for the ecological services they render. At present, there exists no such system where direct payments are being made to farmers for the ecological services they render.

While there have been some experiments, they usually exist in a single domain, eg. water management or are limited in scale. For instance, in the PES schemes reviewed by Drucker & Ramirez (2020), payments were made for biodiversity conservation, and limited to a single crop. Similarly, Von Thaden et al. (2021), explore the effectiveness on payments for hydrological services in Velacruz, Mexico. Jayachandran et. al (2017) explore the effectiveness of PES to conserve forests on private land in Uganda. While they find the payments reduced deforestation and degradation, such payments have not yet been demonstrated at scale. In the Indian context, a case has been made by Devi et al. (2021). Venkatachalam & Balooni (2018) also make a case for PES for participatory water management in Tamil Nadu.

In terms of measuring and valuing ecosystem services, the United Nations Statistical Commission (UNSC) in March 2021 adopted the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA) framework. In India, preliminary work on environmental accounting has been initiated by the Ministry of Statistics & Programme Implementation (MoSPI), under the Natural Capital Accounting & Valuation of Ecosystem Services (NCAVES) project. The first report was published in January 2021.

Based on the literature and the data available, moving towards PES in agriculture in India still remains some time away. However, it may be prudent to explore the contours of such a system, such as acceptable indicators, data required, payment level (farmer, by farm etc.). For instance, if payments are made by practice (eg. natural farming), then mechanisms of valuing these services still need to be evolved. Since the work still at a nascent stage, both in terms of global practices and data available, ideating on such a system will be an exercise that involves economists, statisticians, ecologists, policymakers, and other stakeholders.

9. INVESTMENTS IN THE COLD CHAIN

Regardless of the way it is produced, post-harvest management is critical as well. Annual wastage in excess of Rs. 90,000 crores have been estimated as a result of inefficient postharvest management. Development of infrastructure at the farmgate, pre-processing facilities which are then linked to packhouses and cold storages, is critical in linking farmers to terminal markets, be they retail or exports. Despite claims that agroecological systems exhibit shorter value chains and produce is distributed locally, there still exists a requirement of an end-toend cold chain to connect farmers to terminal markets. The Government of India has recently launched a Rs. 1 lakh crore Agriculture Infrastructure Fund, for development of infrastructure close to the farmgate, which can be leveraged by producer organizations.

10. LEVERAGING FRONTIER TECHNOLOGIES

The rising demand for organic products and the premiums paid for them are cited as a major reason for a shift towards organic or Natural Farming. However, without traceability and certification, this market cannot be served by most of India’s farmers. A nationwide blockchain for quality certification and traceability may help solve this problem if such a blockchain does not consume too much fossil energy. This is another avenue for partnerships with the civil society and private sector. The Participatory Guarantee Scheme (PGS) for certification could be leveraged here. This is just one example of the potential frontier technologies carry. Further research and collaborations are needed to examine the use of such technologies in the popularisation of Natural Farming in India.

5. AI Technologies in Indian Agriculture for Future…

Innovations in agriculture are vast and diverse, reflecting the urgent need to address challenges such as climate change, population growth, and sustainability. Here are some key areas where innovations are expected to continue making significant impacts:

1. Precision Agriculture: Advances in GPS, IoT (Internet of Things), and AI technologies allow for more precise farming. This includes using drones and satellites for real-time monitoring of crop health, soil conditions, and weather. The data collected can optimize resources like water, fertilizers, and pesticides, reducing waste and environmental impact.

2. Biotechnology: Genetic modification and CRISPR gene editing are set to further revolutionize crop production by enhancing disease resistance, drought tolerance, and nutrient efficiency. These technologies can also be used to improve the nutritional content of crops, potentially combating malnutrition.

3. Vertical and Urban Farming: As urban populations grow, vertical and indoor farming technologies are expanding. These systems use significantly less land and water than traditional agriculture and can reduce the carbon footprint associated with transporting food items into cities. Innovations in LED lighting, hydroponics, and aquaponics are integral to these systems.

4. Robotics and Automation: Robotics are increasingly being used to automate tasks like harvesting, planting, and weeding. These innovations can help address labor shortages and increase efficiency, especially during peak seasons or in harsh working conditions.

5. Climate Smart Agriculture: Developing farming practices and technologies that can withstand and mitigate the effects of climate change is critical. This includes breeding crops that can tolerate extreme weather and implementing farming techniques that reduce greenhouse gas emissions or capture carbon.

6. Agroecology and Organic Innovations: Techniques that enhance biodiversity and natural resource cycles are gaining attention. This includes permaculture, regenerative agriculture, and organic farming, which focus on reducing chemical inputs, improving soil health, and increasing farm resilience.

7. Supply Chain Innovations: Blockchain and other traceability technologies can improve the transparency and efficiency of agricultural supply chains. These innovations help ensure food safety, reduce waste, and enhance the traceability of food from farm to table.

8. Alternative Proteins and Novel Foods: Innovation in plant-based proteins, cultured meats, and edible insects is responding to growing dietary trends and sustainability concerns. These technologies have the potential to reduce reliance on traditional livestock farming, which is resource-intensive and has a significant environmental footprint.

9. Water Management Technologies: Innovations in water-efficient irrigation technologies and moisture monitoring systems help farmers use water more efficiently. This is increasingly important in regions facing water scarcity.

10. Renewable Energy Integration: Using renewable energy sources like solar, wind, and biogas for farming operations can reduce dependence on fossil fuels and lower the carbon footprint of agricultural practices.

As these areas evolve, the interaction between technology, sustainability, and agriculture promises not only to enhance production capabilities but also to foster an environmentally responsible approach that could fundamentally reshape global food systems.

6. Conclusion

This paper has shown that the path of structural transformation India has taken is unsustainable. Land constraints are hampering India's agriculture labour productivity growth rates, leading to widening income gaps and greater inequality. Intensification of inputs has seen yields in India grow manifold over the past decades, allowing India to achieve cereal security and maintain sufficient buffer stocks for time of need. However, the intensification of inputs has led to severe environmental challenges. This creates a trade-off between the goals of increasing productivity and enhancing sustainability and resilience. In order to ensure the long-term health of India's agriculture sector and indeed, the economy, a new paradigm for agriculture in India has been mooted in this paper.

This new paradigm would embrace the principles of agroecology. While there is no definitive set of practices, there exist three characteristics which can be identified as agroecological: (i) reliance on ecological processes rather than purchased inputs; (ii) equitable, environmentally friendly, locally adapted and controlled and (iii) they adopt a systems approach. This agroecological approach can be seen in many parts of India. Natural farming in India is being promoted as the *Bharatiya Prakritik Krishi Paddhati* (BPKP) Program. This program seeks to promote agroecology based diversified farming system which integrates crops, trees and livestock with functional biodiversity and reducing a reliance on externally purchased inputs. The system is largely based on on-farm biomass recycling, stressing biomass mulching, use of on-farm cow dung-urine formulation and soil aeration. Clearly, this is in line with the characteristics of agroecological approaches discussed earlier. The need of the hour is to scale up such initiatives across India.

Agroecology carries with it the potential to convert this apparent trade-off in policy goals to mutually compatible goals. For this policy action will be critical. Extension services will need to be revamped, subsidies and incentives will need to be overhauled. A new monitoring and evaluation mechanism will be needed to track outcomes, defined in terms of both sustainability and productivity. Natural farming practices across India will need to be documented, verified and spread to the farm level using revamped extension services. Partnerships with both the civil society and private sector will be critical in spreading Natural Farming across India. In order to make natural farming more remunerative for small and marginal farmers, transfer payments for ecological services provided by farmers can be considered. However, certification will be critical in this endeavor. This relates to the goal of documentation and verification of practices as natural, as a set of practices must be identified prior to labelling a farm as natural. Public procurement may have an important role to play in demand generation, especially in the initial years.

At the same time, some existing policy thrusts must continue. Collectivization of farmers through producer organizations is one thrust. Financial inclusion another. Investments across the cold-chain remain critical in connecting farmers to terminal markets, be they natural farmers or 'modern' ones. More research is needed in distilling actionable policy recommendations for a complete paradigm shift as mooted by this paper. The policy implications derived in this paper can serve as a starting point for policy deliberations.

This paper has established that not only is India's structural transformation incomplete, but it is on an unsustainable path. A paradigm shift is needed in India shifting towards agroecological principles. This would require a move away from the input intensification based agriculture in India today. It would also need a recognition that farm sizes in India are unlikely to get bigger, unless there is strong political will towards land consolidation. Rather than seeing our small landholdings as a weakness, policymakers must seek to leverage this into an opportunity, especially as small farms have been shown to be more productive and receptive to change. However, this shift must ensure protection of farmers' incomes, along with long-term handholding, to ensure the long-term health of India's agriculture sector as well as the economy

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