



Sustainable Agriculture: A Catalyst for Inclusive and Resilient Development

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Review Article

ABSTRACT

Article History:

Received: 24 January 2025

Accepted: 27 March 2025

Published online: 01 June 2025

Keywords:

Agriculture
Green Revolution
Animal Husbandry
Farmer's Welfare
Sustainability

Indian agriculture has played a crucial role in transforming the sector, empowering farmers, ensuring food security of the nation. The sector employs 46 percent of the work force and contributes about 18% of GDP, laying foundation for modern agriculture practices. This includes introduction of high yielding crop varieties and modern inputs which have significantly increased the agricultural productivity. Subsequent focuses on white revolution, blue revolution, dairy and fisheries sector also paid attention to sustainability and productivity. Integrated farming practices have been adopted, leading to improved crop yields, enhanced soil health, biodiversity, reduced chemical use and improved water management. The Government of India has taken initiatives to benefit farmers by implementing schemes that enhance crop yield and ecosystem services. Emphasis is placed on boosting agricultural infrastructure, ensure farmers income against the crop losses and to meet food security issues addressing challenges in agriculture. The farmers are diversifying their cropping patterns according to their soil conditions and adopting new techniques with available irrigation resources suited to their agro-climatic zones. By addressing these key factors, sustainable agriculture demonstrates its potential to contribute to economically viable food production system and improve rural livelihoods.

To Cite :

Ninawe A., 2025. Sustainable Agriculture: A Catalyst for Inclusive and Resilient Development. Agriculture, Food, Environment and Animal Sciences, 6(1): 158-181.

INTRODUCTION

Agriculture is practiced in different environmental conditions in the world that includes tropical, temperate, Arctic and sub-Arctic regions, deserts and under mountain ranges. Primitive subsistence agriculture is still practiced in countries such as those in Africa, South America, and many parts of Asia, where simple tools and traditional cultivation techniques are used on small land holdings, resulting in low productivity. In agriculture the shifting cultivation exist as Slash and burns agriculture, Jhumming, Milpa, Kaingin in various regions of the world including Southeast Asia, Africa and India. The shifting cultivation in India is practiced in North eastern states, particularly in Assam, Meghalaya and Nagaland. In this practice fire clears the whole vegetation, and generated ashes improves soil fertility. After practicing cultivation at one place, farmers shift to newer locations due to loss of fertility in 3 to 5 years. The cultivation was mostly performed on small soil areas using primitive and archaic tools. The origins and spread of agriculture were influenced by various ecological conditions like soil, seed, availability, and spatial demography and available water resources for productive agriculture (Atkins et al., 1998). In India, Jhum cultivation follows a similar pattern in the northeastern states. In tea estates, it was introduced by the British colonials in India and Sri Lanka. Banana and sugarcane plantations were introduced in the West Indies, while rubber plantations were established in Malaysia. The Dutch monopolized sugarcane plantations in Indonesia. In Java, during the 17th and 18th centuries, widespread cultivation of sugarcane was introduced as a major export crop, with control over promotion, processing, and trade. Coffee and cocoa plantations were set up by French and British colonial powers in various parts of Africa and Asia, exploited natural resources for its growing demand in Europe. In Asia the main occupation of North Eastern states is shifting cultivation, also known as Jhumming agriculture. The main occupation of the people is highly practiced in highlands and in lowlands and in valleys regions with rice cultivation (Panda et al., 2017). The crops other than paddy were introduced in various parts of the country gave good returns (Sati and Rinawma, 2014). The researchers have shown negative impact of shifting cultivation on the forest land and landscape leading to production losses on cultivation. In plain regions, crops such as sugarcane dominate in Uttar Pradesh, western Maharashtra, and southern parts of India. Other crops, such as coffee, tea, cocoa, rubber, pineapples, oil palm, and cotton, are in high demand due to the vast export markets. The diversification in agriculture is encouraging the adoption of farming practices, shifting from mono-cropping to poly-culture contributing to more sustainable and resilient food production system.

Mixed Farming

In many African countries, farmers practice mixed cropping to promote soil fertility and reduce pests and diseases. In Kenya, farmers grow maize, beans, and potatoes

together. In Southeast Asia, mixed cropping is a common practice, particularly in Indonesia and the Philippines. Farmers grow multiple crops together, such as rice, maize, and soybeans. The major crops grown in mixed farming are corn, fodder, barley, oats, and root crops. Mixed cropping patterns is also common in India, particularly in the states of Maharashtra, Madhya Pradesh, and Uttar Pradesh. Farmers grow multiple crops together, such as wheat, gram, and mustard. Cultivation of mixed and rotational cropping can help mitigate climate change by sequestering carbon, reducing greenhouse gas emissions, and promoting soil health. It is taken as cultivation of crops alongside with rearing of animals for meat, eggs or milk defines mixed farming. Farmers in India are diverting into commercial farming making major investments using advanced technologies. The agriculture is practiced with animal husbandry by paying attention and addressing health care issues, cattle breeding, and the veterinary services. Intensive focus on feeding the dairy animals given for better milk yield and realize high income from farming in integrated mode in the studies undertaken near the industrial units and urban centers (Kumar et al., 2024). The cereal crops wheat and rye are grown with cattle, sheep, pigs, fish and poultry by adopting farming practices. The integration of animal husbandry and crop system helping animals for fodder and waste generated by the animals is used as a manure for crops.

Methods Adopted

Extensive reviews have been conducted to understand farming systems both in India and globally, spanning from prehistoric times to contemporary agricultural practices. The study covers the various cultures and cropping patterns adopted to suit diverse soil conditions. Additionally, strategies are proposed for optimizing farming patterns within the current irrigation systems, along with recommendations for integrated agricultural and allied activities. The sustainability of food-grain production and productivity issues studied to address various challenges in farming system. The schemes and programs pertaining to agriculture and allied sectors beneficial to farming community projected with an emphasis with introduction of new crops, introduction of technological innovations, farm management and crop diversity suitable in agro-climatic zones for enhancing the productivity and sustainability. Information gathered on data classification and grouping ecological aspects, natural resource management, organic fertilizers and biodiversity collected. Qualitative descriptive methods explained to discuss the issues and relationships and compared findings to understand the comprehensive and holistic approach in sustainable agriculture practices. Literature Selection relevant to research topic, data reliability, and topic related journals, books, research reports were referred.

Genesis of Agriculture Development

Indian agriculture has been known since the pre-independence era, dating back to the Indus Valley Civilization (3300-1300 BCE), where crops like wheat, barley, and cotton were cultivated. During the Vedic Period (1500-500 BCE), agriculture became a major occupation, with the use of iron tools and the introduction of new crops such as rice and sugarcane. In the medieval period, crops like maize and tobacco were introduced. The British introduced new agricultural practices, crops, and technologies in India primarily for their own benefit. After post-independence Indian government launched a series of Five-Year Plans to develop agriculture, with a focus on increasing food production and reducing poverty. The government launched community development programs to promote agricultural development, rural education, and health and introduced High-Yielding Varieties (HYV) of wheat, rice, and other crops, leading to increased food production. With liberation and globalization, the Indian government introduced economic reforms in agricultural sector to oversee the challenges in agriculture development. The commission was set up to study the problems related to agriculture, but no visible changes observed in the lives of farmers. India is considered as the second-largest in area for the arable land and is globally known for its high agriculture potential. It contributes about 18% GDP to the total GDP of the country and is a leading producer of numerous agricultural products, including world's top producer of milk, food grains, pulses and fish. Although India achieved self-sufficiency in grain production, the country is still grappling with widespread hunger and malnutrition, overcoming with critical issues like anemia and childhood wasting. The gender disparity is greatly addressing with the participation of women farmers, constitute 42% of the agricultural labor force by giving land ownership, access to credit, inputs system and involvement in the decision-making process. The small land holding farmers, who make up the majority, faces water shortages, climate change issues and fragmentation of land holdings hindering their ability to sustain their families with poor yields. The genesis of agriculture development thus shaped by a combination of factors, including technological innovations, government policies, and competition with the global trends in agriculture development and business entrepreneurship.

Malnourishment Issues

Malnutrition is a global issue today the world is facing. The inadequate nutritional supplements, mainly vitamins or minerals resulting in several diet-related non-communicable diseases. This gives attention for rich nutritional requirement in our daily diet. Global Hunger Index report, (2023), indicated that around 74% of India's

population could not afford to have healthy diet, and 39% fell short of nutrient adequate one. In agriculture food grain production India is progressing well. There is plenty of food in the world, but millions of poor still suffer from hunger and food insecurity (Eknath Shankarrao Mundhe, 2019). A record production of 332.298 million tones food grain production reported in 2023-24 which was 2.611 million tons higher than the previous year. This was due to a bumper harvest of rice and wheat, despite drought-like conditions and erratic rainfall (DOA & FW, 2024). India also produces fruits, vegetables, spices and pulses, significantly contributing to global food security by stable supply of safe and high-quality commodities to the world. In agriculture, every effort is made in doubling the farmer's income with technological innovations for social transformation. The farmers are producing organically grown crops to help the society by promoting agriculture crops and nutritional security for sustainable food grain production from their ecosystem (Chand et al., 2022). By addressing these challenges and to uplift the agriculture community, the Government of India has initiated several agricultural schemes to improve farm productivity, increase farmers' income, enhance agricultural infrastructure, and promote sustainable agricultural practices. These schemes cover diverse areas such as financial support, crop insurance, and access to irrigation, soil health, market linkages, and technology dissemination.

Agro-climatic Zones of India

The Government of India's Planning Commission division has divided India into 15 different zones giving emphasis on utilization of long-term resource efficiency and sustainability in agriculture based on the soil's topography (Planning Commission of India, 1989, Table 1 and Figure 1). Further an autonomous body, The Indian Council of agricultural Research (ICAR) has redefined the resources and differentiated these resources on crops based patterns considering soil health, topography, rainfall, and temperature. The identified zones are used for scientific research and agricultural development in India. (Pradhan, 2014, Mandal and Gagoie et al., 2022). Some of the cropping patterns in India in Indo-Gangetic Plains are suited for rice-wheat pattern cultivation due to the favorable climate, fertile soil, and availability of irrigation facility. The Deccan and Central Highlands region is dominated with mixed cropping pattern of cereals, pulses, and oilseeds adopted commonly in the dry land regions with low rainfall. In the Eastern Coast, rice is cultivated with mixed farming due to the humid climate, high temperatures, and presence of lakes and rivers. In the Western Coast, mostly the coconut-paddy-banana dominates due to high temperatures and rainfall. In Southern region, the rice- ragi-maize pattern is common due to the mixed soils and undulating topography. The Himalayan region is widespread with wheat-

maize cropping pattern is in the upper Himalayan valleys due to its short growing seasons.

Table 1. Different agro-climatic regions/zones are given below (Khanna, 1989)

Zone No.	Agro-climatic regions/zones	States represented	New Region
1	Western Himalayan region	Uttarakhand, Himachal Pradesh, Jammu and Kashmir	A
2	Eastern Himalayan region	Assam, Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Mizoram, Sikkim, Tripura and West Bengal	B
3	Lower Gangetic plain region	West Bengal	C
4	Middle Gangetic plain region	Bihar, Uttar Pradesh	
5	Upper Gangetic plain region	Uttar Pradesh	
6	Trans Gangetic plain region	Delhi, Haryana, Punjab, Chandigarh, Rajasthan	D
7	Eastern plateau and hills region	Orissa, west Bengal, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra	
8	Central plateau and hills region	Madhya Pradesh, Uttar Pradesh, Rajasthan,	
9	Western plateau and hills region	Madhya Pradesh, Maharashtra	E
10	Southern plateau and hills region	Karnataka, Tamil Nadu, Andhra Pradesh, Telangana	
11	East coast plains and hills region	Pondicherry, Tamil Nadu, Orissa, Andhra Pradesh	F
12	West coast plains and hills region	Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu	G
13	Gujarat plains and hills region	Gujarat, Rajasthan, Dadra & Nagar Haveli, Daman & Diu	H
14	Western dry region	Rajasthan	I
15	Island region	Andaman & Nicobar, Lakshadweep	Not used

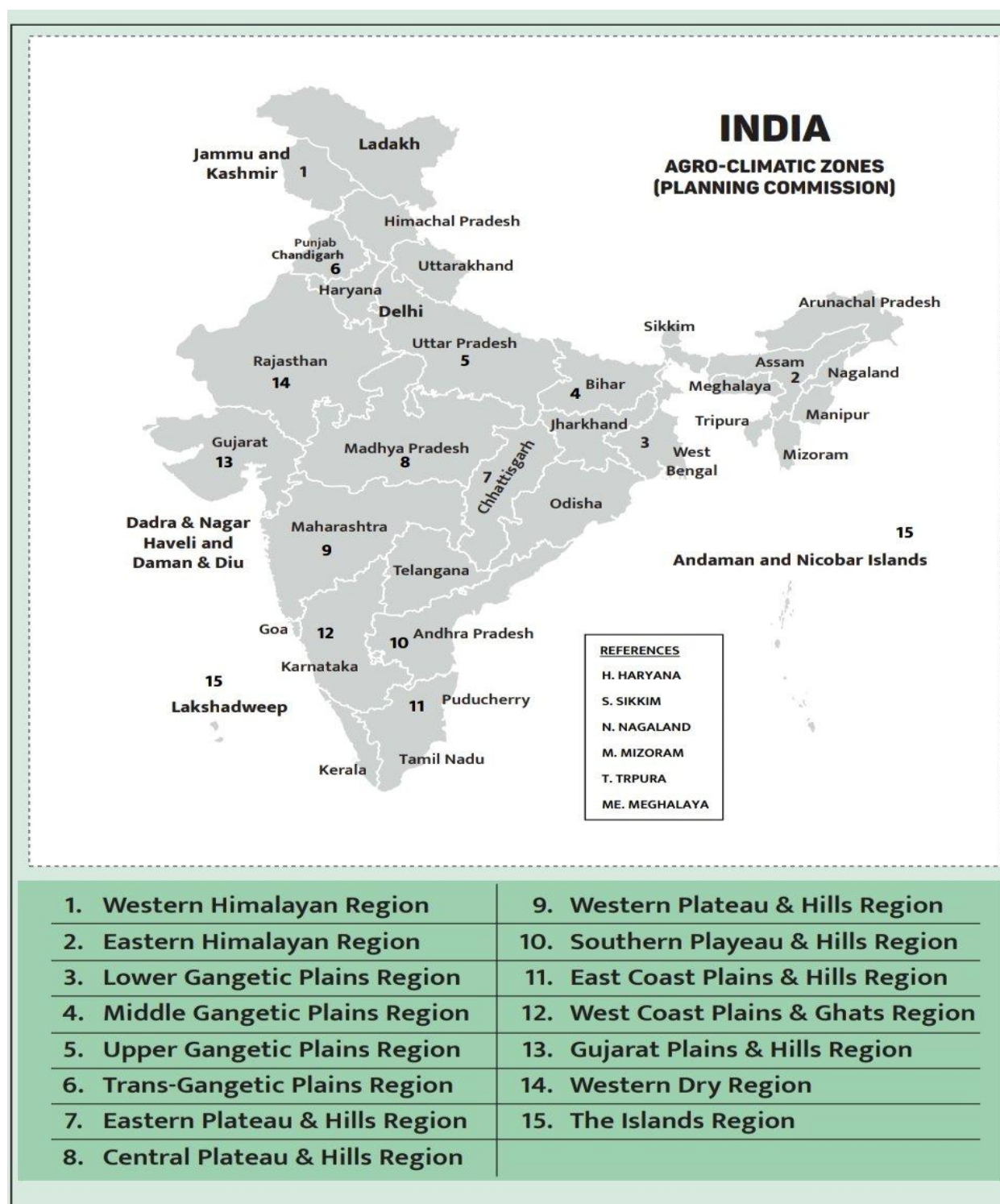


Figure 1. Agro-climatic zones in Indian States (Khanna, 1989)

India's climate varies from tropical to temperate, with four distinct seasons: winter, summer, monsoon, and post-monsoon. The influx of warm and humid climate during southwest monsoon supports more than 80% of the total annual rainfall during the season, particularly in the states of Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh. The region receives significant rainfall during the monsoon season, and

typically lasts from June to September. Several factors contribute to the warm and humid climate in southern India as it is located near the Equator receives direct sunlight throughout the year, leading to high temperatures. The Indian Ocean also create moderating effect on the climate of southern India, keeping temperatures relatively high and humid. The warm and humid climate, supported rich biodiversity in southern India, with several national parks and wildlife sanctuaries located in the region. The significant rainfall received in southern India also supports high value agriculture in southern India, with crops like rice, sugarcane, and coffee being a major contributor to the country's economy. India's diverse agricultural landscape designed with holistic and region-specific approach, considering varied challenges faced by farmers across different states for adoption of cropping patterns. The crops grown across its vast landscapes and soils is according to its topology is detailed in Table 2.

Table 2. The landscape, topography and soil conditions for adoption of different cropping patterns in India

1	Alluvial Plains:	Indo-Gangetic Plains due to availability of irrigation, fertile soil and favorable climate supports crops Viz; maize and pulses as an inter-cropping dominated Rice-Wheat cropping pattern.
2	Plateau Regions:	Mixed cropping pattern of cereals, pulses and oilseeds sustained in the dry land regions with low rainfall, like the Deccan and Central Highlands. Jowar, bajra, pulses and groundnut are common crops.
3	Eastern Coast:	Rice-Rice pattern is found due to high temperatures, humid climate due to presence of lakes and rivers. In this region paddy is grown both during kharif and rabi seasons.
4	Western Coast:	Paddy is grown during kharif, while coconut and banana are the perennial crops. Coconut-Paddy-Banana pattern dominates amid high temperatures and rainfall.
5	Southern Region:	Rice-Ragi-Maize pattern cropping is common due to undulating topography and mixed soils. Rice is grown in low lying fields, while ragi and maize are grown in the upland regions.
6	Himalayan Region:	Wheat-Maize pattern widely grown in the upper Himalayan valleys due to short growing seasons. Apple and other temperate orchards are grown well.

Cropping Patterns Followed

India is known for rich agricultural heritage and diverse cropping patterns with vast geographical and climatic conditions prevailing favorable environment conditions for growing various crops. The monsoon is the deciding factor for agriculture growth in India. The major crops grown in India have been classified into two forms: Cash Crops; tea, coffee, sugarcane, oilseeds, cotton, horticulture crops, and jute and Food Crops viz; corn, rice, wheat, pulses, and millets. On the contrary, India's climate determines cropping patterns based on climatic conditions, including temperature, rainfall, and humidity and guide the farmers in selection of crops suitable for their regions. The soil type varying nutrient levels, water-holding capacity, and drainage characteristics of different soils impact crop selection and adaptability. The water availability through irrigation facilities or rainfall patterns influences crop choices and water requirements. The market demand for various crops ensures the profitability and marketability of the produce. The climatic based changes observed in production and sustainability due to factors like increasing irrigation, introduction of high-yielding varieties, development of new crops suitable in irrigated and drought conditions. The government provides subsidies and support cultivate specific crops as per the choices of farmers for achieving overall productivity (Acharya, 1998; Acharya, 2000). Indian governmental support research and extension activities for adoption and dissemination of technical knowhow and provide incentives to the farmers for good yield performance.

The widespread adoption of high yielding crop varieties introduced in Indian agriculture system during two seasons; Kharif and Rabi Season. The programme for adoption of high-yielding varieties (HYVs) in India began in the 1960s, transforming the country's agricultural landscape. This initiative was part of the green revolution aimed to increase food production and reduce hunger. The High-Yielding Varieties launched in the kharif season of 1966 promoted HYVs of paddy, wheat, maize, jowar, and bajra in areas with assured rainfall or irrigation facilities. These crop varieties developed adopted well in different seasons, including the kharif (monsoon) season and the rabi (winter) season. Initially, Punjab and Haryana were the first to adopt HYVs, with remarkable success in wheat production. The other regions were in rest of India, including Western Uttar Pradesh, Gujarat, and Maharashtra. The adoption of HYVs in India has had a significant impact on the country's food security and agricultural productivity. However, it has also raised concerns about environmental sustainability, equity, and the dependence on a few crop varieties. The cultivation season in India begins with the arrival of monsoons in India, and crops are sown at the beginning of the monsoon in June are harvested from September to October. The timelines of cultivation and harvest varied from state to state. The water is the most important criterion for production and Kharif crops demand a good amount of rainfall for cultivation and output production. Some examples of Kharif crops are cotton, rice,

maize, sorghum, bajra, and soybean. The Rabi crops are grown in the winter season from October or November and the crop is harvested in spring season. This type of crop demands continuous water as they are sown in dry seasons. Rabi crops are wheat, linseed, mustard, pulses, oats, and barley. The crops grown in both seasons, greatly impact the prices of vegetables and grains. ICAR and State Agricultural Universities (SAUs) have entrusted the development of high yielding, high quality and climate resilient varieties suited to different agro climatic conditions with matching production and protection technologies. The All India Coordinated Research Project (AICRP) was established in 1965 with an objective to conduct multi-location testing of newly developed crop varieties and technologies, The focus was on crop improvement, crop protection, and resource management through various agricultural universities, research institutions, and ICAR institutes to implement research projects. The promotion of agriculture research and education pursued for crop improvement, new variety development, animal breeding and health, fisheries and dairy development involving various research institutions, universities and state governments with the implementation of research projects and technology transfer to farmers. AICRP played a crucial role in developing and testing HYVs of wheat, rice, maize, and other crops, developed drought-tolerant varieties of crops like wheat, rice, and chickpea and disease-resistance in wheat, rice, and potato The continuous support of ICAR improved crop varieties with desirable traits like high yield, disease resistance, and drought tolerance in maize, sorghum, and pearl millet giving emphasis on genetically modified crops like Bt cotton and Bt brinjal. AICRP and ICAR's efforts led to significant increases in food production, making India self-sufficient in food grains. By improved crop productivity the development and dissemination of improved crop varieties led to increase crop productivity and reduced crop losses. The adoption of improved crop varieties and technologies increased farmer income and improved their livelihoods. The projects operated in network mode enhanced the productivity of different crops adopting multi-disciplinary and multi-location approach in cereals viz; maize, sugarcane, wheat and rice, oilseeds, pulses forages varieties improvement. The identification of stable potential genotypes plays an important role in variety improvement is recommended for large number of varieties for field crops with efficient crop management system to suit the diverse agro-climatic conditions (Chauhan et al., 2016; Agarwal et al., 2018). While considering agriculture as an avocation seriousness in productivity is considered on several factors like availability quality inputs such as land, water, seeds and fertilizers, access to credit system, crop insurance, storage and marketing. These issues are well taken by government to support the farming community. The key prospering agricultural states engaged in production of different crops, processing, value addition and post-harvest activities are given in Table 3.

Table 3. Prosperous Indian agricultural states engaged in production of different crops

1	Punjab	Known as the Granary of India, Punjab is renowned for its wheat and rice production. It is also a major producer of cotton and sugarcane.
2	Uttar Pradesh	This state is the largest producer of sugarcane, wheat, and potatoes in India. It also contributes significantly to the production of rice, pulses, and oilseeds
3	Maharashtra	Maharashtra is the leading producer of cotton, sugarcane, and grapes in India. It also supports rice, maize, wheat, and pulses production.
4	Madhya Pradesh	This state is a major producer of soybeans, wheat, and pulses. It also contributes to the production of rice, cotton, and sugarcane.
5	Rajasthan	Rajasthan is the largest producer of bajra (pearl millet) in India. It is also known for its production of wheat, pulses, and oilseeds
6	Bihar	Bihar is a major producer of rice, wheat, and maize. It also contributes to the production of pulses, oilseeds, and sugarcane.
7	Andhra Pradesh	This state is known for its production of rice, sugarcane, and cotton. It also contributes to the production of chilliest, tobacco, and oilseeds.
8	Karnataka	Karnataka is a major producer of coffee, sugarcane, and rice. It is also known for its production of cotton, pulses, and oilseeds.
9	Tamil Nadu	This state is the leading producer of coconuts, bananas, and sugarcane in India. It also contributes to the production of rice, pulses, and oilseeds.
10	West Bengal	The state is a major producer of rice, jute, and tea. It also contributes to the production of wheat, pulses, and oilseeds. All the states play a crucial role in ensuring food security and contributing to the agricultural economy of India.

Animal Husbandry and Breeding

The scientific and technological intervention in animal breeding programs urgently taken up as a priority as animal husbandry is a significant contributor to India's agricultural sector, providing employment, income, and food security for millions of people. The National Livestock Mission was launched in 2014 to improve livestock productivity, reduce poverty, increase farmers' incomes, and conserve and develop

indigenous cattle breeds. It also aimed to enhance the productivity of these breeds and promote their use in agriculture. The Artificial Insemination Program, which began in the 1950s, helped improve cattle productivity through artificial insemination. Additionally, Embryo Transfer Technology (ETT) was used to further improve cattle productivity by transferring embryos from high-quality donor cows to recipient cows, thereby enhancing the genetic quality of the cattle. ETT also helped increase cattle productivity by transferring embryos from high-yielding donor cows, reduced risk of disease transmission between donor and recipient cows. Artificial Insemination (AI) in buffalo and cows widely used in reproductive technology in India to improve cattle productivity. It involves injecting semen from high-quality bulls into cows or buffalo to improve their reproductive performance. Operation Flood mission launched in the 1970s, used AI to improve cattle productivity and increase milk production in India. National Dairy Development Board (NDDB) has implemented AI programs across India, improving cattle productivity and increasing milk production. ICAR has developed artificial insemination programs for cattle and buffalo, improving their reproductive performance and increasing productivity. The application of embryo transfer technology (ETT) helped improvement of cattle and buffaloes with good quality breeds and success rate ultimately to demonstrate commercial production of farm animals for higher milk productivity (Misra et al., 2005). The technologies such as artificial insemination, frozen semen production, progeny-testing and ETT implemented after proper evaluation and wherever required validated to give a fillip for conservation, preservation and up gradation of breeds. On the contrary, the Indian cattle Zebu have been exported to several countries, including Brazil, for their exceptional heat tolerance, disease resistance, and high milk production. Brazil's climate is ideal for Zebu cattle, and they have become a crucial part of the country's dairy industry. The Girolando breed, developed in Brazil, is a cross between the Indian Gir breed and the Holstein breed, known for its high milk production. Zebu cattle are known for their distinctive hump, large ears, and heat tolerance. They are also resistant to diseases and parasites, making them well-suited for tropical climates. The introduction of Zebu cattle has significantly impacted the dairy industry in Brazil and Girolando breed is responsible for 80% milk production in Brazil.

India's milk production touched a target of 230.58 MT in 2023-24, makes India, the World's largest milk producer, accounting for more than 25 percentage of the world's milk production. The Gir cow originally from Gujarat state of India is the highest milk producing cow breed in India, yielding 50–80 liters of milk per day. This breed is known for its productivity, adaptability to different climates, and resistance to diseases and parasites. The increase the population of crossbreds with artificial insemination program increases the profitability of the farmers and dairy industry (Wakchaure et al., 2015). India's premier research institute the Central Institute for Research on Buffaloes (CIRB) under ICAR in Hisar has improved the Murrah buffalo breed and for disseminating its semen to farmers and buffalo for fertilization of cows. The

genetic studies and signature analysis in milch dairy breed were carried out by Tyagi et al. (2021). This breed found most suitable breed in dairy production. The Murrah buffalo sell at very high price as the success of dairy farm depends upon its efficient production and reproduction. The studies on genetic and non-genetic factors influences the performance traits in lactation, milk yield dry period, birth weight, calf mortality, calving interval per conception and conception rate was reported by Sarkar et al. (2005). This study helped in designing more effective breeding program in addition to understand different parameters of performance traits.

India is blessed with vast aquatic resources to promote sustainable development in the fisheries and aquaculture sector. Fisheries provides food, employment and prosperity to the people. The vast area of water resources available in the country provides huge scope for expansion of aquaculture for the production of finfish and shellfish. The fisheries sector contributes to the national income, exports, food as well as employment generation both in inland and coastal areas. India stand 2nd in fish production with its 8 percent growth share in the global fish productivity and recorded high production of 17.45 MT production in 2023-24 (Agro Spectrum, 2023). Blue revolution through fisheries promotion is addressing the growing demand for fish and fishery products, boosting the income of fisher folk and farmers engaged in aquaculture. The Ministry of Fisheries, Animal Husbandry and Dairying is giving major focus on development of fisheries in India for adoption of modern fishing practices, expansion of aquaculture activities, and promotion of fish seed production and technology transfer. The scheme also emphasizes the conservation and sustainable activities to increase fish production, increasing the income of fisher folk. (Ghosh et al., 2019; Sarkar et al., 2020; Patro et al., 2021). Blue Revolution is instrument in sustainable and economic wellbeing of fishing community by investing in modern technologies contributing to meet the growing demand for fish and enhancing India's food and nutritional security

Launching of Agriculture Promotion Schemes

The government of India is instrumental to address income disparities among farmers and promote sustainable agricultural growth. The National Food Security Mission (NFSM) mission launched in 2007 to increase the production of rice, wheat, and pulses, ensuring food security and price stabilization I brought impact on production and stability of food grains and pulses in India (Patel and Parmar, 2020). The introduction of Soil Health Card scheme helps farmers optimize fertilizer use, reduce input costs, and improve crop yields while maintaining soil health (Kumar et al., 2020). It has also demonstrated improved nutrient management practices, leading to enhanced crop yield and reduce environmental impact. The scheme is bringing awareness in farmers about the soil health and nutrient management practices utilizing efficient use of resources (Singh and Singh, 2019). Continuous evaluation and refinement of the

scheme addressing the gap issues and further effectiveness in supporting soil conservation and agricultural productivity (Joshi et al., 2018). Under the Pradhan Mantri Fasal Bima Yojana (PMFBY), farmers pay a nominal premium, and rest of the premium is equally shared by the central and state governments. Several research studies have examined the impact of PMFBY on farmers' resilience and income stability (Garg and Kishore, 2020; Jain et al., 2021). This has helped in adoption of modern agricultural practices by farmers and reducing credit constraints faced by farmers, especially during adverse climatic events. The impact of RKVY on agricultural growth and rural development led to significant improvements in crop productivity and farmers' income with adoption of innovative practices and innovative agriculture technologies. (Shinde and Pawar, 2017; Bhasme and Jadhav, 2019). The evaluation and monitoring contribute the enhancement of farm productivity and improving the overall well-being of the farmers.

The National agricultural Market (e-NAM) platform established for agricultural marketing and farmers' welfare in assuring better price realization for farmers and reduced post-harvest losses. Bringing awareness among farmers about the scheme and formation of farmer clusters are collectively implemented for organic farming, sharing knowledge, and training access. The farmers are trained on market dynamics for induced benefits to dispose of their surplus produce and trained on dissemination of market outreach addressing challenges of learning intelligent selling techniques for their better remuneration and socioeconomic welfare (Tripathi et al., 2023). Several research studies have examined the impact of RKVY on agricultural productivity, soil health, and environmental conservation encouraging organic farming practices enhancing soil health, reducing the environmental impact of agriculture, and supporting the well-being of farmers. Kisan Credit Card (KCC) scheme introduced allows farmers to purchase agriculture supplies such as seeds, fertilizers, and insecticides as well as withdraw cash to meet their production-related needs. The KCC was designed to make it easier for borrowers to obtain short-term credit from formal financial institutions (Gaikar et al., 2021). The initiatives improved farmers' access to formal credit and reduced their dependency on informal money lenders. By providing financial support for agricultural activities, KCC contributes enhancing farm productivity, income stability, and overall rural development. Pradhan Mantri Krishi Sinchan Yojana (PMKSY) launched with an aim to utilize water Per Drop More Crop (PDMC) with watershed development focusing on increasing the area under irrigation, promoting precision irrigation techniques, and enhancing the productivity of water through efficient water management practices. While addressing the challenges faced by farmers the government is implementing diverse areas by supporting crop insurance, irrigation, technology adoption, and market linkages. A systematic review of these schemes provided valuable impact and effectiveness described by Reddy and Rani (2019) and Sharma and Kumar (2021). The critical outcomes and contributions to farm sector, income enhancement, and rural livelihoods

challenges identified for offering better remuneration to farmers (Prakash and Singh, 2018). PMKSY scheme has emerged as a vital initiative in promoting the sustainable agricultural development and water conservation focusing on irrigation, infrastructure development and water use efficiency.

National Mission on Natural Farming

India is giving emphasis to Organic farming to encourage farmers to adopt natural farming, a chemical-free agricultural practice that integrates local livestock and diverse cropping systems adapted to the local environment over the next two years. The initiative will be implemented across 15,000 clusters in Gram Panchayats, reaching hundred million farmers and introducing natural farming over 7.5 lakh hectares. Indian Union Cabinet has approved National Mission on Natural Farming (NMNF) as a standalone centrally-sponsored scheme under the Ministry of Agriculture & Farmers' Welfare to encourage farmers to adopt natural farming, a chemical-free agricultural practice that integrates local livestock and diverse cropping systems. This approach follows local agro-ecological principles, leveraging traditional knowledge and location-specific technologies adapted to the local environment. The mission's goal is to promote sustainable farming practices that provide safe, nutritious food for all, while helping farmers reduce input costs and dependence on externally purchased inputs. The NMNF is designed to scientifically revive agricultural practices, promoting sustainability, climate resilience, and healthy food for both farmers and consumers. Around 2,000 Model Demonstration Farms will be established at Krishi Vigyan Kendras (KVKs), Agricultural Universities (AUs), and farmers' fields, supported by experienced Farmer Master Trainers. The effectiveness of different extension methods used by KVKs beneficiaries are well documented (Kumar et al., 2024). The mission will explore synergies with existing government schemes and infrastructures to enhance local livestock populations, develop demonstration farms, and establish market linkages through local markets. It is proposed to involve agriculture students in the mission to promote natural farming practices.

India's Vision on Agriculture

The Agriculture Development Strategy to 2025 and Vision 2030, is a strategic document projected with multifaceted approach, aims to ensure the food security, produce comparative and competitive agricultural commodities, develop clean, safe and sustainable agriculture and shift agriculture gradually with modernization of technology. The government is addressing the need of farmers for food, income, and livelihood. Major emphasis is given on utilization of natural resource for better health and environment, employment generation and growth to achieve UN Sustainable Development Agenda 2030, emphasizing achieving the sustainable development goal from its green revolution success (NITI Aayog, India, 2023). To fulfil the vision India launched PM KISAN Yojana to support small and marginal farmers with lavish budget

allocation to agriculture sector and major subsidies for food, fertilizers, and petroleum. The domestic agricultural marketing policies framed to create a fair and efficient marketing system to bring reforms, create market access to farmers for their produce (Acharya, 2001) The state has institutional framework by strengthening the role of institutional framework NABARD (National Bank for Agriculture and Rural Development), ICAR, APMC (Agricultural Market Produce Market Committee), and Food Corporation of India giving emphasis on Institutional Financing, Cooperative farming. The community-driven awareness for doubling farmer income awakened lowering seed and fertilizer input costs. The Government portal brings all APMC Mandis on one platform and establishing market for all agricultural produce. The government is supported crop insurance program that brings multiple stakeholders into a single window through PMFBY. The emerging technologies like remote sensing and GIS technology, block chain, robotics, drones, and artificial intelligence in private and public partnership introduced with Information Technology (IT) in agriculture. The initiation of Kisan Call Centre, Agri Market App, and Kisan Suvidha App with digitalization introduced and drone technology subsidies up to 100% of the cost of agriculture for drone purchase is approved by farm machinery training institutes. The government of India has established National Food Security Mission (NFSM) to enhance agricultural productivity and improve the availability of essential food grains for the country's population. It supports farmers through the distribution of high-yielding seeds, improved technologies, and the adoption of best agricultural practices and give emphasis on water management and soil health for sustainable and inclusive growth in food grain production. NFSM program has yielded positive and significant impact on increasing the production and productivity of rice, wheat and pulses, thereby helping in nutritional security of the masses. The performance was evaluated and the impact of NFSM on agricultural productivity, food security, and farmer welfare was examined (Kumar and Singh, 2017; Kumar and Jha, 2020). The NFSM led to increase the yield and production of rice, wheat, and pulses, reducing the country's dependence on food grain imports and improving the availability of essential food commodities in the market.

Overcoming with the Challenges

In India, agro-based industries presently are textile industry, vegetable oil industry, coffee industry, leather goods industry, and tea industry. Some of the challenges faced by the agro-based industries are perishable nature of goods the agriculture sector. The share of agriculture in India has registered an average annual growth rate of 4.18% and is declining due to the rapid growth of industrial and service sector. Agriculture employs about 42% of India's workforce. India's food grains production touched a record 329.68 million tonnes in 2022-23 despite climate change challenges (The Economic Times News, 2024). Agricultural exports grew by 19.92% in 2021-22,

reaching USD 50.21 billion and the major export items includes rice, wheat, cotton, and spices. The key issues affecting agricultural productivity includes the decreasing sizes of agricultural land holdings, continued dependence on the monsoon, inadequate access to irrigation, imbalanced use of soil nutrients resulting in loss of fertility of soil, uneven access to modern technology in different parts of the country, lack of access to formal agricultural credit, limited procurement of food grains by government agencies, and failure to provide remunerative prices to farmers. The farmers also face numerous challenges, including disputed land holdings, depleted groundwater reserves, poor soil quality, rising input costs, and low crop productivity. India's agricultural land is highly fragmented, with the average farm size decreasing from 2.3 hectares in 1970-71 to 1.08 hectares in 2015-16. As per 2015-16, 86.1% of Indian farmers are small and marginal (SMF) having a landholding size smaller than 2 hectares. More of these farmers live in five Indian states of Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra and Andhra Pradesh with fragmented lands adopting mechanization in agriculture. It is a bigger challenge before them to implement modern farming techniques or invest in technology, leading to lower productivity and income for farmers. Further, it has become imperative to spread the irrigation network in India as the monsoon in India is erratic and untimely. Although good development signs seen in Indian agriculture sector, India's overall development and the improved welfare of rural, poor hinge on addressing various critical challenges in the agricultural sector are documented as:

1. Increasing Agricultural Yield Per Unit of Land: Limited availability of cultivable land and water resources calls for raising productivity per unit of land to increase yields, diversify to value-added crops; and reduce costs, wastages, and pilferage. For the enhancement of agricultural productivity, India need focus on modernizing farming techniques and adopting precision agriculture, which uses technology like GPS and data analytics to optimize field-level management. The investments in research and development helped develop high-yield, climate-resilient crop varieties seeds, fertilizers, and credit for small farmers to boosting for better productivity output.

2. Poverty alleviation: Rural poverty and as non-farm employment accessible to rural masses reduces the dependence and over-employment in the sector. Reducing rural poverty through inclusive growth and access to education and vocational training need to be imparted to empower marginalized groups, including women and landless laborers, with new skills for both agricultural and non-farm employment. This will be a boon for agricultural sector by developing rural infrastructure, such as roads, electricity, and internet connectivity to create new economic opportunities. Further Strengthening microfinance and cooperative societies will help provide financial resources to the rural poor.

3. Aligning agriculture to the food security: The Green Revolution and agricultural intensification led to self-sufficiency in food-grains, declining food prices, and reduction in rural poverty. Aligning agricultural growth with food security is focusing on increasing crop diversification to reduce dependency on cereals and promote nutrient-rich crops like pulses, fruits, and vegetables. While conserving natural resources India is strengthening supply chains and storage infrastructure that will reduce post-harvest losses and ensure food availability. However, enhancing public-private partnerships drive innovation in agriculture, and policies need tailoring to incentivize smallholder farmers to adopt modern technologies that boost yields and ensure food security.

4. Chemical Fertilizers, and Manures: Manures are plant and animal wastes are used as sources of plant nutrients. They release nutrients after their decomposition. The manures are the organic materials derived from animal, human and plant residues which contain plant nutrients in complex organic forms. Naturally occurring or synthetic chemicals containing plant nutrients are called fertilizers. Manures with low nutrient content per unit quantity have longer residual effect besides improving soil physical properties compared to fertilizer with high nutrient content. The depletion of soil fertility, leading to low productivity and the yield of the crop is lowest in the world. These grave issues can be addressed with scientific solution with adoption of organic farming for soil health and human welfare.

5. The Poor Condition of Farm Laborers: Conditions of Farm laborers are in a bad state. They received minimum profit from agriculture. This sector has not increased income. It has not raised their living standard; instead, it is declining agriculture's growth. The market is filled with intermediaries and local traders. These middlemen have become so powerful that they have considerable control over prices. They try to gain maximum profit from the Farmer's produce. The issue is becoming grave with the incoming of powerful corporate player who attempts to destabilize the market to profit from their products. In this fight, the ultimate victim is the Farmer, who faces the brunt, need adequate attention.

6. Inefficient Transportation System: Farmers in developing countries have a hard time transporting their produce to markets due to lack of roads, vehicles and money. They often have to carry their produce from the farm to local markets on foot or by bicycle, which can be challenging and time-consuming. The products of horticulture produce viz; fruits, vegetables, and flowers and animal and dairy products and fish required immediate transportation. The lack of adequate transport facility affects sale of produce at very low prices because they cannot transport it to places where there is better demand for food. A well-connected transport system is required for the timely delivery of produce from the field to the market. It ensures that products should reach to market without delay. Currently, rural areas are not well connected with the urban

market, hindering not been incentivized to adopt the latest technology due to financial constraints.

7. Water Resources and Irrigation System: Irrigation is the process of applying water to the crops artificially to fulfil their water requirements. Nutrients may also be provided to the crops through irrigation. The various sources of water for irrigation are wells, ponds, lakes, canals, tube-wells and even dams. Irrigation offers moisture required for growth and development, germination and other related functions. The sector is the largest consumer of water in India. The limited water availability for agriculture is not adequate and increasing competition between industries, domestic use affects the production. This calls attention for augmenting supply through rainwater harvesting, recharging aquifers, and renovation of existing wells and ponds for through improved irrigation practices, including sprinkler and drip irrigation and use of groundwater to achieve a conjunctive use of rain, river, ground, sea and treated sewage water.

8. Agriculture Credit and Crop Insurance: The reform in this area is key to enhancing small farm productivity making affordable credit available for farmers by way of crop insurance. The creation of opportunities for assured and remunerative sale of produce will determine the economic well-being and sustainability of the farming sector. Thus, market reform must be linked to production planning with government-led support interventions.

9. Reducing Post-Harvest Losses: India loses a significant portion of its agricultural produce due to inadequate storage and transportation. The ICAR-Central Institute of Post-Harvest Engineering and Technology, annual post-harvest losses are estimated at 11810100 US dollars. The cold storage capacity in India can only accommodate about 11% of the country's total produce. This leads to distress sales by farmers during harvest seasons, further reducing their income potential. The post-harvest losses, particularly for perishables, remain a major challenge in India's food value chain. Thus, enhancing storage and grading facilities, and upgrading transportation networks are the key areas need to be addressed.

10. Agri-Tech aAgribusiness: The sector anticipates and use of digital technology with the Agri-tech market expected to drive Agri-tech growth in India. The adoption of precision farming, drone technology, and AI-driven solutions remains low. Introduction of IoT-based real-time data systems, and drone technology enabled productivity and profitability would expand comprehensive farmer data such as soil conditions details to specify crops and help in decision-making process to support agricultural innovation promotion efficiency. The key strategies need to develop to align production with market demand, improving post-harvest infrastructure with digital supply chain solutions, improve quality standards, and export market.

11. Food Processing Sector: The Indian food processing market anticipated to hit US\$ 535 billion by 2025-26, growing at a CAGR of over 15%. This has felt the need to fortify the food processing value chain by moving forward by giving emphasis on promoting cluster development and supporting micro-processing units encouraging public-private partnerships. The facilitating access to broader markets, particularly through FPOs (Farmer Producer Organizations) will enhance farmer's income and market positioning. Initiatives like PMKSY and the Pradhan Mantri Formalization of Micro Food Processing Enterprises Scheme (PMFME) the welcome steps in the right direction.

CONCLUSION

Agriculture in India has vast growth potential, and the government has launched several initiatives to boost economic growth, job creation, and agricultural development. These efforts support farmers, expand markets, and promote organic farming, with a focus on horticulture through the National Horticulture Mission. The government also emphasizes the animal husbandry, dairy, and fisheries sectors due to their high productivity and resources. Key strategies include cultivating crops in different agro-climatic zones, promoting agroforestry and horticulture, and leveraging technology to reduce costs and increase yields. The Food Security Mission aims to improve food access, reduce waste, and ensure food reaches the poor, supporting livelihoods and poverty reduction.

Acknowledgements

The author acknowledges to all the Indian government departments for gathering the data, publications of Google research scholars' manuscripts including various other statistical reports, websites information for preparing the manuscript.

Conflict of Interest

Author declares that there is no conflict of interest.

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