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Advance Research under Modern Techniques and Agricultural Practices in Agronomy: A Review

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study offered readers a chance to learn more about the changing landscape of Indian agronomy research by highlighting important advancements in soil science, plant breeding, crop management, and sustainable practices. However, it is difficult to escape the effects of resource scarcity, global warming, and the difficulties associated with assimilating new technologies. In addition to precision planting, the essay explores ideas like agroforestry, organic farming, and water conservation to support sustainable agriculture. The significance of soil science is demonstrated by digital soil mapping, nutrient management, and soil health evaluation. The shift from conventional to biotechnology approaches and how they have been implemented to preserve plant variety are discussed in the section on crop breeding. Reducing the environmental impact of agricultural methods, supporting agroecological systems, and encouraging biodiversity conservation are other priorities of advanced agronomic research. Translating these advances into efficient practices that benefit producers and the environment requires cooperation between scientists, farmers, and politicians.

Keywords: Agricultural technology; crop management global warming; resource scarcity; sustainable agriculture.

1. INTRODUCTION

For decades, India's economy has been based mostly on agriculture, which is essential to the country's large population's ability to survive and earn a living. The discipline of agronomy has seen tremendous change in recent decades due to advances in science, technology, and the need to address the issues of sustainable development and food security. The goal of this thorough analysis is to examine current achievements in agronomy research in the Indian context, highlighting significant advancements that have influenced and are still influencing the country's agricultural environment. An important turning point in India's agrarian history was the Green Revolution in the 1960s, which brought high-yielding crop varieties and contemporary agricultural techniques. The necessity of ecologically friendly and sustainable agricultural practices has, nonetheless, come to light more and more in the decades that have followed. This has prompted academics in India to aggressively investigate and put into practice creative approaches that strike a balance between the needs of greater productivity and ecological stewardship. Precision agricultural methods have become popular in crop management, which is one noteworthy area of progress. In an effort to maximize inputs and raise agricultural yields, farmers are progressively implementing technology like remote sensing, GPS-guided tractors, and data analytics. Because precision farming techniques use less water, fertilizer, and pesticide, they not only increase productivity but also help save resources. In India, sustainable farming methods have become a vital component of modern agronomy. Agroforestry, conservation tillage, and organic farming are becoming popular substitutes for traditional practices. These methods support biodiversity preservation and climate change mitigation in addition to enhancing soil health. It has been shown that combining classical knowledge with contemporary methods is very successful in producing long-lasting results. Simultaneously, improvements in soil science have been essential to comprehending and improving soil fertility. In India, agronomic research now includes soil conservation, nutrient management, and soil health management techniques (Saikanth et al., 2023; Kumari et al., 2024). To maximize crop performance and advance long-term soil sustainability, researchers are investigating new soil amendments, microbial treatments, and precision nutrient administration techniques. With the creation of genetically engineered crops with enhanced nutritional value, drought tolerance, and insect resistance, the fields of crop breeding and genetics have advanced significantly (Ali, et al. 2024). In order to provide food security for India's growing population, these developments seek to meet the dual difficulties of raising agricultural yield and adjusting to shifting climatic circumstances. Beyond precision farming, artificial intelligence, machine learning, and sensor technologies are all part of agronomy's technological integration. These tools give farmers the ability to make well-informed decisions and maximize agricultural operations by enabling real-time monitoring, decision support systems, and predictive modeling. But despite these developments, problems still exist. Socioeconomic inequality, water shortage, and climate change remain major barriers to sustainable agronomy in India.

Developing resilient and adaptable agricultural systems necessitates an interdisciplinary and comprehensive strategy that brings together farmers, scientists, and policymakers.

2. EVOLUTION OF RESEARCH UNDER AGRONOMY

Changes in agricultural methods and the pursuit of sustainable solutions to guarantee food security have led to a significant development in agronomy research in India. Early on, Indian agriculture was mostly based on conventional techniques that were influenced by experiential knowledge and local wisdom. With the introduction of high-yielding crop varieties, irrigation innovations, and chemical fertilizers, the Green Revolution represented a turning point in Indian agronomy and resulted in a notable rise in agricultural production. The revolutionary potential of technology in agriculture was demonstrated at this time. Environmental concerns and the need for long-term production have led to a major movement in agriculture in recent years toward sustainable practices. Organic farming and conservation agriculture have becoming more popular as substitutes for traditional techniques. In India, agronomy research has changed significantly as a result of technological breakthroughs. In India, agronomy research has changed significantly as a result of technological breakthroughs. Farmers' approaches to cultivation have been revolutionized by the use of data analytics, remote sensing, and precision farming. This advancement is not without difficulties, though. Indian agriculture is seriously threatened by soil erosion, water shortages, and climate change.

3. CROP MANAGEMENT

Crop management is essential to achieving the highest possible level of agricultural output, and India has made great strides in this area recently. These developments cover a variety of techniques meant to improve sustainability, resource efficiency, and crop productivity. The use of precision agricultural technologies is one notable advancement. Using sensors, data analytics, and satellite imaging, precision farming tracks and controls crop variability in real time. The integration of these technology has been made easier in India by programs like the National e-Governance Plan for Agriculture (NeGPA), which enables farmers to make knowledgeable decisions on pest management, fertilization, and irrigation. Practices in conservation agriculture have also become more popular. Remainder management and conservation tillage contribute to better soil health, less erosion, and improved water retention. In places like Punjab and Haryana, the use of direct-seeding and zero-tillage methods has reduced environmental effect while also conserving soil moisture. Furthermore, in light of shifting climatic trends, the implementation of climate-smart agricultural methods has become essential. Crop management now includes the use of climate-resilient seeds, drought-tolerant crop types, and enhanced water management techniques. For example, a research by Singh et al. (2020) emphasizes the benefits of using drought-resistant maize cultivars in areas where water shortage is a problem. The usefulness of precision irrigation systems in maximizing water usage efficiency in cotton cultivation is also highlighted in the study of Patel et al. (2019).

3.1 Agricultural Practices

A comprehensive method of farming, sustainable agriculture aims to strike a balance between social justice, environmental stewardship, and financial success. Adopting sustainable methods is crucial in India, because a sizable section of the population is employed in agriculture. These practices will aid in improving production control. It will reduce production costs and eliminate agrochemical expenditures, resulting in increased yield, improved quality pricing, and increased revenue. This article examines important sustainable farming methods in India with an emphasis on the socioeconomic and environmental effects of these methods.

A. **Organic Farming:** Organic fertilizers are naturally occurring mineral sources that require little human involvement, mostly physical extraction, according to Huntley et al. (1997). In India, organic farming has become more popular as a sustainable substitute for traditional farming. Organic farming lessens the environmental effect of chemical inputs while promoting biodiversity and soil health by eschewing synthetic pesticides and fertilizers. One notable example of achievement is Sikkim, which in 2016 became the first completely organic state in India. Obstacles to switching to organic farming include expenses and difficulties. The main obstacles to switching to organic farming are cited as ignorance, a lack of government assistance, productivity concerns, and dread of the future.

B. **Water Conservation and Management:** In many regions of India, the lack of water is a serious problem. Watershed management, effective irrigation systems, and rainwater collection are examples of sustainable farming methods. A more sustainable method of farming in water-stressed areas is ensured by strategies like drip irrigation and the encouragement of drought-resistant crops, which assist to maximize water consumption.
C. **Agroforestry:** There are several advantages to using agroforestry to incorporate trees into agricultural areas. Through the sale of timber and non-timber forest products, it increases biodiversity, boosts soil fertility, and gives farmers access to new revenue sources. Additionally, agroforestry helps sequester carbon, which lessens the effects of climate change.
D. **Conservation Agriculture:** Crop rotation, permanent soil cover, and little soil disturbance are all components of conservation agriculture. These methods lessen soil erosion, improve soil structure, and retain water. The adoption of conservation agriculture in India is being aided by the promotion of cover crops and zero-tillage farming, especially in areas like Punjab and Haryana.
E. **Precision Farming**: Technology is used in precision farming to enhance harvests and optimize inputs. For precise crop monitoring and management in India, precision farming makes use of sensors, satellite imaging, and data analytics. By applying inputs like fertilizers and insecticides correctly, this method not only maximizes efficiency but also reduces the environmental impact.
F. **Crop Diversity and Seed Conservation:** Sustainable agriculture depends on maintaining historic seed types and encouraging crop variety. Traditional crops are frequently resistant to pests and diseases and well-suited to the local environment. Programs like community seed banks are essential for maintaining agricultural variety, guaranteeing food security, and saving native seeds.

3.2 Precision Farming

Using cutting-edge technologies to maximize several parts of farming techniques is known as precision farming, or precision agriculture. Precision farming technology adoption has the potential to completely transform conventional agricultural practices in India, where agriculture is a major economic driver. The main precision farming technologies, their uses, and their effects on Indian agriculture are examined in this article. India has to deal with issues including population increase, dwindling arable land, and erratic weather patterns. One way to increase agricultural production while using less resources is through precision farming. It entails integrating sensors, automation, and information technology at different phases of agricultural production.

A. **GPS Technology:** Precision farming relies heavily on the technology of the Global Positioning System (GPS). Farmers may use it to plan their operations, map their fields precisely, and keep an eye on the movement of their agricultural equipment. In India, field management is made more effective with GPS-guided tractors and equipment, which minimize overlaps and maximize resource use.
B. **Remote Sensing: NRSC (National Remote Sensing Centre). (2018)** Drones and satellite photos are examples of remote sensing technology that offer real-time data on insect infestations, soil conditions, and crop health. These technologies provide an affordable way to monitor wide areas in the Indian agricultural landscape, allowing for prompt interventions and improving farmer decision-making.
C. **Variable Rate Technology (VRT):** Depending on the unique requirements of various regions, VRT enables farmers to administer inputs like water, fertilizer, and pesticides at varied rates throughout a field. VRT guarantees the best possible resource allocation in India, where soil properties differ greatly, improving agricultural yields and lessening the impact on the environment.
D. **Precision Irrigation:** A major problem in many regions of India is water shortage. By directing water precisely to the root zone, precision irrigation systems—such as drip and sprinkler systems—help save water. In areas where water is scarce, these technologies improve water-use efficiency, which is essential for sustainable agriculture.
E. **IoT and Sensor Technologies:** Sensor technologies and the Internet of Things (IoT) are essential for gathering and

evaluating field data. IoT-enabled gadgets assist farmers in India with real-time monitoring of crop health, temperature, and soil moisture, allowing for proactive decision-making and lowering the chance of crop failure.

F. **Data Analytics and Farm Management Software:** Farm management software and data analytics solutions offer important insights into crop production, resource use, and overall farm productivity. Indian farmers are now able to optimize their agricultural methods, make data-driven decisions, and increase overall output thanks to this technology.

3.3 Recent in Soil Science

A key factor in agricultural production is soil science, and new developments in this area have a big impact on India's sustainable farming methods. A rapidly expanding population and mounting demands on agricultural resources have made it critical to comprehend and enhance soil health.

A. **Soil Health Assessment and Monitoring:** Soil health evaluation has been transformed by recent developments in remote sensing and sensor technology. These technologies have been used for real-time soil condition monitoring in India through programs such as the National Mission for Sustainable Agriculture (NMSA). By combining ground-based sensors with satellite data, farmers may make well-informed decisions on irrigation and fertilizer management. Laishram et al. define soil health as a more comprehensive idea that encompasses the ability of soil to sustain plant, animal, and human life as a living system. On the other hand, soil quality refers to a particular type of soil's ability to support a specific purpose, like crop production.

B. **Integrated Nutrient Management:** In India, precision agriculture methods have become popular because they allow for the accurate delivery of nutrients according to the unique requirements of the soil. Using site-specific nutrient management (SSNM) techniques, which maximize fertilizer delivery while lowering environmental impact and improving nutrient usage efficiency, is one example of this.

C. **Microbial Interventions:** In soil science research, utilizing the power of soil bacteria has taken center stage. Research on using helpful bacteria to improve crops has showed encouraging results in India. Incorporating biofertilizers with mycorrhizal fungus and nitrogen-fixing bacteria into farming techniques has promoted environmentally acceptable and sustainable substitutes for conventional fertilizers.

D. **Soil Carbon Sequestration:** Enhanced carbon sequestration can increase soil microbial mass (Fierer, 2017) and the network complexity of soil communities, including keystone microbe and mycorrhizae species that are crucial for plant life, soil life, and carbon cycling (Xue et al., 2020). In India, methods like cover crops and agroforestry have been investigated to improve carbon sequestration in agricultural soils. Research projects highlight the significance of these measures for enhancing overall soil fertility and structure as well as for climate resistance. In addition to improving soil quality and productivity, the "sequestering" of carbon has a major impact on capturing atmospheric CO_2, which is primarily the result of emissions from burning fossil fuels and other sources of carbon emissions (Schoonover & Crim, 2015; Sundermeier,2005; Viscarra Rossel et al.2016).

E. **Digital Soil Mapping:** Characterizing soil qualities at different scales has become more popular because to digital soil mapping tools. Projects such as the Soil Information System (SIS) in India use these technologies to build extensive soil databases. This facilitates precision farming, land-use planning, and a deeper comprehension of regional soil variances.

F. **Soil Conservation and Erosion Control:** An essential component of sustainable agriculture is addressing soil erosion. India has used cutting-edge methods to stop soil erosion, including contour plowing, cover crops, and the use of geotextiles. These methods support sustainable land use and water conservation in addition to protecting the topsoil.

3.4 Crop Breeding and Genetics

In order to increase agricultural output and guarantee food security, crop breeding and genetics are essential. Improvements in crop breeding and genetics are crucial in India, since agriculture is the backbone of the economy and provides food for a sizable population.

A. **Traditional and Modern Techniques:** Indian agriculture has always selected and grown crops based on desired features using conventional breeding techniques. However, a move toward contemporary methods was signaled by the green revolution in the middle of the 20th century. Crop yields have increased dramatically thanks to the development of high-yielding varieties (HYVs) through a systematic breeding effort. In order to alleviate food shortages, semi-dwarf rice and wheat cultivars were introduced, revolutionizing grain production.
B. **Resistance to Biotic and Abiotic Stress:** Crops in India's many agroclimatic zones confront a number of difficulties, such as pests, illnesses, and environmental stressors. Genetically resistant cultivars have been made possible by advances in genetics. For example, the discovery of Bt cotton and other crops resistant to common pests or illnesses have successfully reduced the need for chemical pesticides.
C. **Genomic Approaches and Marker-Assisted Selection:** Crop breeding has changed as a result of genomic technologies, which have improved our knowledge of plant genetics. Breeders can more effectively choose plants with desired features by using marker-assisted selection (MAS). This has been especially important for crops like rice and wheat in India, where breeding efforts have found and included key genes linked to characteristics like disease resistance or drought tolerance.
D. **Crop Diversity and Conservation:** India boasts a diverse range of traditional crops and a high agro-biodiversity. Conservation and use of this diversity are part of agricultural genetics efforts. The preservation of indigenous varieties, adaptability to shifting environmental circumstances, and traditional agricultural knowledge are all made possible by initiatives like the creation of gene banks and seed vaults.
E. **Biotechnological Interventions:** Crop breeding has changed dramatically as a result of biotechnology. Despite its controversy, genetically modified (GM) crops have been adopted in India to solve certain issues. Bt cotton has gained popularity because it is designed to produce toxins that are toxic to some pests. Nonetheless, there is ongoing discussion on the socioeconomic and environmental effects of genetically modified crops.
F. **Public and Private Collaboration:** Crop breeding in India has advanced thanks in large part to cooperation between governmental research institutes and businesses. While private businesses offer market-driven strategies and economic viability, public institutions support basic research. In order to translate research findings into workable solutions for farmers, this cooperation is crucial.

3.5 Integrating Technology in Agronomy

The use of cutting-edge agronomic technology has revolutionized Indian agriculture. This transition is essential as the nation struggles with issues including climate change, population growth, and the need for sustainable farming methods. A number of technical developments have significantly improved farm management overall, production, and resource efficiency.

A. **Precision Agriculture:** GPS technology, sensors, and data analytics are used in precision agriculture to maximize crop farming management at the field level. Precision farming has become popular in India, allowing farmers to make informed decisions based on data. Drones and GPS-guided tractors help with accurate watering, fertilization, and sowing, which increases crop yields and resource efficiency.
B. **Remote Sensing and Satellite Technology:** When combined with satellite photos, remote sensing technologies offer important information on crop health, soil conditions, and water availability. These tools have been crucial in monitoring vast agricultural landscapes in India, spotting any problems, and facilitating prompt action. Real-time data is available to farmers, enabling them to reduce risks and make wise decisions.
C. **Smart Irrigation Systems:** One major issue facing Indian agriculture is water constraint. Water utilization is optimized using smart irrigation systems that are outfitted with sensors and automation.

Farmers can precisely irrigate crops thanks to technologies like drip irrigation and soil moisture monitors, which minimize waste and guarantee effective water management.

- **D. Digital Farming Apps:** The creation and uptake of digital agricultural apps have been made easier by the widespread use of smartphones. Farmers may use these applications to learn about market pricing, weather forecasts, and best agricultural practices. These applications give Indian farmers access to real-time data and professional guidance, enabling them to make well-informed crop management decisions.
- **E. Biotechnology and Crop Improvement:** Genetics and agricultural breeding have been transformed by technological breakthroughs. To solve particular issues encountered by Indian farmers, genetically modified (GM) crops with features like insect resistance and higher yield have been produced. Solutions for improving crop resilience and lowering losses are provided via biotechnological treatments.
- **F. Agricultural Management Software:** With its extensive facilities for organizing, tracking, and evaluating agricultural operations, farm management software has grown in popularity in India. These systems provide financial tracking, inventory control, and crop planning, all of which help to make agricultural operations more streamlined and effective.
- **G. Digital literacy:** Building digital villages based just on the overlay of digital technology and agricultural information generation is insufficient; the foundation is the development of farmers' digital literacy and rural wisdom. Digital information technology must constantly permeate and assist the contemporary production of agricultural and rural regions, as most farmers have long lacked sophisticated digital literacy instruction. Improving the digital literacy of farmers is a pressing issue that must be resolved to build digital villages. Issues like a glaring ignorance of network security, a severe lack of capacity to increase digital income, and a very limited ability to use mobile media have become more and more noticeable. The usage of computers and the Internet does not immediately translate into digital literacy, and proficiency and knowledge may become a new barrier.

3.6 Research Gaps

Even with improvements in farming methods, there are still a lot of unanswered questions. The long-term effects of integrated agricultural methods on biodiversity, soil health, and climate resilience are one important topic. In order to fully comprehend these effects, longitudinal research is required. Research on the socioeconomic facets of integrated farming, such as how it affects gender roles, income distribution, and rural lives, is also essential. The creation of affordable, environmentally friendly technological solutions that are suited to the requirements of small and marginal farmers is another field of study.

3.7 Role of Policy and Government Support

It is impossible to exaggerate the importance of government assistance and policy in advancing integrated agricultural methods. It is crucial to implement policies that assist farmers financially and technically, reward sustainable farming methods, and foster innovation and research in sustainable agriculture. It is also essential for the government to promote organic and sustainable products among customers, provide fair prices, and make it easier for produce from integrated agricultural systems to reach markets [73]. Furthermore, policies must be adaptive and flexible in order to respond to the changing demands of the agriculture industry.

3.8 Challenges and Future Directions

Agronomy research in India has several obstacles that need for creative answers in order to promote sustainable agricultural growth. These difficulties are examined in this section along with possible avenues for further study and implementation.

- **A. Resource Scarcity and Climate Change:** India has resource constraint, which is made worse by the country's expanding population and erratic weather patterns. Agriculture is seriously threatened by water shortages in particular. To lessen the effects of climate change, future research should concentrate on creating resilient farming systems, precision irrigation methods, and crop types that need less water.
- **B. Soil Degradation and Nutrient Management:** A serious problem that

affects agricultural yield and food security is soil deterioration. To improve soil fertility and lessen erosion, researchers must investigate sustainable soil management techniques including cover crops, organic farming, and agroforestry. Maintaining soil health can also be greatly aided by improving nutrient management techniques.

C. **Pest and Disease Management:** In India, agricultural production are constantly threatened by pests and diseases. Future studies should concentrate on integrated pest management (IPM) strategies that include resistant crop cultivars and biological control techniques. Additionally crucial are the development of early detection technologies and the encouragement of farmer education on efficient pest management techniques.
D. **Technological Adoption by Farmers:** Even though technology is quickly changing agriculture throughout the world, Indian farmers are still having difficulty implementing these innovations. In order to improve farmers' technical literacy, future research should focus on the socioeconomic aspects that affect technology adoption, provide user-friendly interfaces, and offer focused training programs.
E. **Sustainable Crop Practices:** Long-term agricultural profitability depends on promoting sustainable farming techniques. Diversified farming systems, crop rotation schedules, and agroecological techniques suited to India's many agroclimatic zones should all be investigated in research. Resilience to pests and illnesses can be enhanced by highlighting the value of biodiversity in agricultural settings.
F. **Market Access and Fair Pricing:** In India, farmers frequently struggle to get their goods into marketplaces and get reasonable pricing. Future studies should support laws that provide farmers the freedom to bargain for fair pricing and investigate cutting-edge alternatives like blockchain technology for transparent supply networks. Enhancing farmers' cooperatives can also provide them more negotiating leverage in the marketplace.
G. **Policy Support and Institutional Frameworks:** For agronomy research interventions to be successful, a strong institutional support system and policy framework are necessary. To have an impact on evidence-based policy decisions, researchers should actively interact with politicians. Research findings may be implemented more quickly at the local level by promoting partnerships between government agencies, nonprofit groups, and research institutions.
H. **Capacity Building and Farmer Education:** Adoption of sustainable agronomic methods depends on increasing farmers' ability via education and training initiatives. To successfully spread information among farmers, future research should concentrate on creating specialized training materials, instructional materials, and extension services. A resilient and sustainable agricultural future in India may be achieved by tackling these issues and following the suggested future directions in agronomy research. Researchers may make a substantial contribution to improving food security, environmental sustainability, and the standard of living for farmers nationwide by fusing scientific discoveries with workable solutions.

4. CONCLUSION

All things considered; Indian agronomy science is at a crossroads. It must contend with the wide variety of traditions on the one hand and the ever-changing kaleidoscope of innovation on the other. Although the Green Revolution was a revolutionary time, sustainable solutions are needed to address today's problems. These blend soil science, ecologically friendly farming practices, and precision farming techniques. The confluence of genetics, agricultural breeding, and technology holds promise for resolving issues with achieving food security. The issues of resource scarcity, climate change, and barriers to technological adoption are ever-present. An integrated strategy that includes institutional frameworks, governmental assistance, and farmer education is required to achieve these objectives. New methods like precision agriculture and organic farming will be the cornerstones of agronomic endeavours in the future. Given these challenges, agronomy research must proceed in a way that is based on the ideas of sustainability, resilience, and adaptation. Agronomy can lead India's agriculture toward a future where environmental values and production are respected by fostering relationships, using technology advancements, and focusing on socioeconomic integration.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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