Agricultural Extension in Northeast India: Harnessing Artificial Intelligence (AI) and the Internet of Things (IoT) for Sustainable Development

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Abstract

Agriculture is the cornerstone of the economy in Northeast India, employing a significant segment of the population relies on agriculture, making technological advancements essential for addressing key challenges in the sector. The convergence of Artificial Intelligence (AI) and the Internet of Things (IoT) offers a ground-breaking solution that facilitates real-time data collection, predictive analytics and automated strategic planning for farmers data collection, predictive analytics, and automated guidance in farm management. With decades of agricultural advancements, it is evident that as global food demand continues to rise, integrating AI and IoT into agriculture is not merely an innovation but a necessity for enhancing productivity, sustainability and efficient resource management. This study explores the contribution of AI and IoT in agricultural extension services across Northeast India, with a focus on their applications, benefits, and associated challenges. AI-driven technologies—such as machine learning, computer vision, and predictive analytics—enhance crop monitoring, pest control, and precision agriculture. Similarly, IoT-enabled smart sensors, drones, and automated systems facilitate data-driven farming, optimizing resource utilization and decision-making processes. Drones, and automated irrigation systems contribute to improved resource management and higher crop yields. Additionally, AI-based Decision Support Systems (DSS) empower farmers by providing data-driven insights for optimized farming practices. Despite the potential advantages, the widespread adoption of AI and IoT in Northeast India's agricultural sector is hindered by infrastructural limitations, fragmented landholdings, and inadequate institutional support. Effective integration of these technologies requires policy interventions, capacity-building initiatives, and enhanced collaboration between public and private stakeholders.AI and IoT can revolutionize agricultural extension services, promoting sustainable farming practices and rural development in Northeast India.

Keywords: Artificial Intelligence, Sustainable, Development, Extension, North east, IoT, Applications

Introduction

Agriculture is the backbone of Northeast India, employing a significant portion of the population. With decades of scholarly insight and technological evolution, it is evident that the alignment of AI as well as IoT technology holds immense capability to transform agricultural practices, driving unprecedented efficiency and innovation. address these issues by offering real-time data, predictive insights, and automated solutions to farmers. With the global population estimation is to reach nearly 10 billion by 2050, the requirement for agricultural produce is expected to rise by approximately 50% compared to 2013 levels (FAO, 2017). Currently, crop production occupies over 37.7% of the global land area, highlighting the critical role of agriculture in food security and economic development. Agriculture remains a vital contributor to national income and employment generation, particularly in growing nations. The incorporation of AI and IoT into agriculture is revolutionizing the industry and transforming farming practices worldwide, including in Northeast India, by enhancing productivity, sustainability, and operational efficiency. This review paper examines the current Implementation, benefits and limitations of AI and IoT in agricultural extension services in Northeast India, drawing insights from recent research. The agricultural sector is instrumental in economic prosperity, significantly contributing to the economies of both developed and developing nations. In rural areas, advancements in agriculture have driven a shift for notable increment in per capita income, emphasizing the requirement for a stronger focus on the sector. In India, agriculture contributes approximately 18% to the GDP and provides employment to nearly 50% of the workforce. Strengthening agricultural development can drive rural progress, eventually leading to rural transformation and broader structural changes (Mogili & Deepak, 2018; Shah et al., 2019). Across industries, the acceptance of technologies haveto led to significant advancements, and agriculture is no exception (Kakkad et al., 2019).

Agricultural extension is essential in rural development of Northeast India because of the region's distinctive geographical and socio-cultural landscape. This region consists of eight states—Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Tripura, and Sikkim—each with its own agricultural methods and challenges. With abundant natural resources and diverse farming practices, agriculture remains the key means of living for more than 70% of the population. (Antara Ghosal et al.) Farming in Northeast India is largely based on indigenous knowledge and traditional methods, which are often environmentally sustainable. Unlike other parts of India that experienced significant changes due to the Green Revolution, this region continues to rely on time-tested cultivation and irrigation techniques that are inherently scientific. (Antara Ghosal et al.) However, several obstacles, including small and scattered landholdings, inadequate infrastructure, and weak institutional support, limit the region's agricultural growth. (K. Bharadwaj et al.)

Role of Knowledge Transfer Services in Agriculture

Knowledge Transfer Services are crucial in enhancing agricultural productivity, profitability, and sustainability. These services act as a bridge between research and practical farming, facilitating the dissemination of knowledge, technology, and best practices among farmers. Agricultural extension services significantly contribute to agricultural output and financial gains. For example, in Bangladesh, these services have demonstrated their effectiveness in enhance rice enhancing productivity and profitability by granting farmers access to essential resources and support to subsidies, market information, and improved farming techniques (M. J. Alam et al.). Similarly, in Uganda, extension services improve farmers' income by promoting modern farming practices, such as crop rotation and pest management, which lead to higher yields and reduced costs. (Joseph Lwanga.). Extension services are instrumental in advancing sustainable farming methods. They help farmers adopt environmentally friendly techniques, like soil and water conservation, which play a vital role in long-term agricultural sustainability. These services also address broader social objectives, including community development and social equity, by ensuring equitable access to resources and supporting community cohesion. The contribution of private advisory services is progressively turning into important as they complement or replace public extension services. These private services are often more demand-driven and responsive to farmers' needs, providing specialized advice on high-value crops and linking farmers to markets (Krishna M. Singh et al.). However, both private and public sectors must work together to ensure comprehensive support for farmers. (W. Rivera et al.). Agricultural Extension services are key to enhancing productivity, profitability, and sustainability in agriculture. They play a crucial role in bridging the gap between research and practice, promoting sustainable practices, and addressing food security. However, to enhance their effectiveness, these services must overcome existing challenges through reforms and increased collaboration between public and private sectors.

Benefits of AI and IoT in Agricultural Extension

The application of AI and IoT in farming provides multiple advantages, such as enhanced productivity, reduced resource wastage, and enhanced decision-making capabilities. AI technologies such as advanced machine intelligence and visual analytics help in analysing large datasets to provide actionable insights for farmers, thereby improving crop management and reducing environmental impact (T. Fadiji et al.) IoT applications, such as drones and smart sensors, enable efficient monitoring of crop health and soil conditions, resulting in improved resource management and higher crop yields. (N. Misra et al.). The fusion of Artificial Intelligence (AI) As well as the Internet of Things (IoT), it serves as revolutionizing modern agriculture by enhancing these technologies enhance efficiency, efficiency and environmental sustainability by enabling the collection and analysis of massive datasets, commonly known as 'big data.'

Which allows for monitor and optimize agricultural processes (N. Misra et al.). The convergence of AI and IoT, known as the Artificial Intelligence of Things (AIoT), is particularly transformative, providing solutions for challenges such as pest management, crop monitoring, and resource optimization. (Dalhatu Muhammed et al).

Applications of AI and IoT in Agriculture

AI and IoT technologies are applied in various aspects of agriculture, including smart farming, precision agriculture, and sustainable farming practices. Smart farming utilizes IoT sensors and AI algorithms to automate tasks such as irrigation, pest control, and crop monitoring, thereby reducing labor costs and environmental impacts (Elsayed Said Mohamed et al.). Precision agriculture benefits from high-throughput phenotyping and remote sensing technologies, which provide real-time data for informed decision-making on fertilization, irrigation, and pest management. (E. Elbasi et al.) Additionally, AI and IoT facilitate the development of smart farm machinery and autonomous agricultural robots, which perform tasks like harvesting and weed detection.

AI Applications in Crop Monitoring and Advisory Services

"Artificial Intelligence (AI) is increasingly being integrated into agriculture, providing innovative solutions for crop monitoring and advisory services. This advancement aims to improve productivity, efficiency, and sustainability in farming. AI-driven technologies, including machine learning, computer vision, combined with IoT, these technologies are applied to assess crop health, forecast yields, and optimize resource utilization. These technologies are revolutionizing crop monitoring by delivering precise, real-time insights into crop health and soil conditions. For example, AI-powered tools like hyperspectral imaging and 3D laser scanning collect detailed crop health data, enabling farmers to make well-informed decisions." (M. Javaid et al.) The integration of AI with IoT devices allows for continuous monitoring of environmental conditions, which is crucial for maintaining crop health. Remote sensing and UAVs further enhance monitoring capabilities by providing comprehensive field surveys and high-precision tracking of crop growth. (Dalhatu Muhammed et al.).AI-driven predictive analytics play a crucial role in advisory services by forecasting weather conditions, pest outbreaks, and optimal planting times. These analytics help farmers make data-driven decisions to improve crop yields and reduce resource wastage. AI models can predict crop diseases and pests early, allowing for timely interventions and minimizing crop losses. Additionally, AI systems can suggest nutrient management strategies to enhance soil quality and crop productivity. (Suman Kumar Swarnkar et al.).AI applications in crop monitoring and advisory services are revolutionizing agriculture by providing intelligent, data-driven solutions. These technologies enhance crop health monitoring, predictive analytics, and resource optimization, leading to more sustainable and productive farming practices. Continued research and investment

in AI technologies are essential to overcome existing challenges and fully realize their potential in agriculture.

AI-Based Decision Support Systems for Farmers

The incorporation of AI into farming has revolutionized decision-making processes, providing farmers with advanced tools to enhance productivity, sustainability and efficiency. AI-based Decision Support Systems (DSS) are pivotal in this transformation, offering data-driven insights and recommendations that empower farmers to make informed decisions.AI-driven DSS in agriculture leverage diverse technologies, incorporating machine learning, data mining, and big-data analytics, to optimize farm management. These systems enable precise monitoring and management of agricultural activities, from crop selection to resource allocation. For instance, Agro DSS is a cloud-based system that allows farmers to upload data, utilize predictive modeling, and understand dependencies within their domain, as demonstrated in a case study on pest population dynamics. (R. Rupnik et al.) Similarly, a cloud-enabled crop recommendation platform uses machine learning algorithms to assist farmers in selecting crops based on various parameters, enhancing precision farming. In developing and emerging economies, AI-driven tools are crucial for transforming agricultural decision-making. These tools integrate big-data analytics, remote sensing, and machine learning to improve efficiency and productivity. Real-time monitoring and data analysis enable timely decisions, reducing pesticide use and improving crop yields. Customizing these technologies to local contexts ensures their effective integration into agricultural practices, making them accessible and culturally relevant. (Ume Chukwuma et al.).AI-powered DSS also contribute to sustainable agriculture by promoting environmentally friendly practices. For example, an AI-powered system using a chatbot interface provides real-time insights and personalized advice on sustainable farming methods, aiming to boost productivity while minimizing environmental impact.. Additionally, AI-driven farm management systems utilize predictive analytics and geo-integrated monitoring to optimize resource allocation, reducing waste and enhancing sustainability (L. Armstrong et al.). Recent advancements in AI techniques, such as artificial neural networks, support vector machines, and association rule mining, have improved the functionality of DSS in agriculture. These techniques support decision-making by providing actionable insights and recommendations based on complex data analysis5. Moreover, smart agriculture systems using IoT and cloud-based platforms facilitate remote monitoring and data processing, offering farmers valuable information to improve their farming practices. (Muhammad Junaid et al.).AI-based Decision Support Systems are transforming agriculture by providing farmers with advanced tools for data-driven decision-making. These systems enhance productivity, sustainability, and efficiency, particularly in developing economies where they can significantly impact agricultural practices. By integrating AI technologies, farmers can optimize resource use, improve

crop yields, and adopt sustainable farming methods, ultimately contributing to a more secure and sustainable food future.

Smart Farming and Precision Agriculture

Smart farming and precision agriculture represent a transformative approach to modern agriculture, leveraging advanced technologies to enhance productivity, sustainability, and efficiency. These practices are increasingly vital in addressing the challenges of feeding a growing global population while minimizing environmental impacts. This paper explores the innovations, applications, and challenges associated with smart farming and precision agriculture.

Innovations in Precision Agriculture

Precision agriculture employs cutting-edge technologies such as the Internet of Things (IoT), machine learning (ML), and smart sensors to optimize agricultural practices. These technologies enable data-driven decision-making, allowing farmers to maximize crop yields and reduce waste (Ravesa Akhter et al.). The integration of IoT and ML facilitates the prediction of soil parameters, crop yield, and disease detection, enhancing the overall efficiency of farming operations. (Abhinav Sharma et al.).AI was being used to dissect data from colourful sources similar as satellite imagery, rainfall vaticinators, and soil detectors to give growers with practicable perceptivity. This helped optimize the use of coffers like water, diseases, and fungicides, performing in increased crop yield and reduced environmental impact.

Applications of Smart Farming

Smart farming encompasses a range of applications, including site-specific management, autonomous vehicles, and drones for precision planting and harvesting. These technologies allow for targeted use of inputs, reducing both private and environmental costs. Additionally, smart sensors and data analytics play a crucial role in monitoring crop and livestock conditions, ensuring optimal resource use and productivity. In the agricultural sector, AI and IoT are driving a digital revolution through smart farming and precision agriculture. These technologies assist farmers in decision-making, improving crop yield, pest control, and soil health in real-time. Despite being a major agrarian country, India's adoption of digital solutions in agriculture is still in its early stages, with many applications lacking uniqueness and specificity.

Crop Monitoring and complaint Discovery: AI- powered systems were being developed to cover crops and descry conditions and pests beforehand. This allowed growers to take timely action and help large- scale crop losses. Agriculturalists frequently visit their farms to monitor the condition of plants and crop. This monitoring is time consuming. Conventional farms monitoring techniques and

inspections give low crop production, attack of severe diseases parasites. Adequate amount of water, fertilizers, and nutrients can improve the yield and at the same time reduces the cost. In order to assist farmers and landowner, we designed and developed an agent-based crop monitoring system. The objective of this research is to develop an agent-based system to help the agriculturists to monitor the crops remotely by using recent technology and hence advise the farmers to take appropriate measures. The system is divided into main two main parts. First one is data acquisition and the other one is recommendation part. The readings of crucial environmental parameters are taken and sent to a central computer service. Color processing techniques are used to find the nitrogen deficiency in the green plants. Manual leaf color chart has been replaced by electronic one which is capable of providing sufficient information about future scenario of nitrogen content in the plants. The system uses real time information and recommends an appropriate solution of the problem caused by environmental stresses. In case of any critical situation, the system generates warnings in the form of an email, to be sent to the landowners or agriculturist. (A. Hanif, A,2019)

Prophetic Analytics: Over the decades, agricultural advancements have continuously evolved, leveraging emerging technologies to optimize productivity and sustainability. The application of Artificial Intelligence (AI) in agriculture has reached a pivotal stage, where AI-driven algorithms are now employed to forecast crop output based on ancient data and prevailing conditions. This forecasting ability helps farmers make well-informed choices about crop planning, storage management, and distribution strategies, enhancing efficiency and optimizing resource use. The analysis encompassed a comprehensive range of agricultural and climatic variables, including crop type, year, season, and the specific climatic conditions of various Indian states during the crop's growth cycle. To increase the model's performance, categorical factors like crop type and season were systematically one-hot encoded. The core objective was to develop a robust Deep Neural Network (DNN) capable of accurately predicting crop yields, with hyperparameters meticulously optimized through Genetic Algorithms (GAs) to maximize the R^2 score. Through rigorous fine-tuning, the most effective model attained an R^2 of 0.92, accounting for 92% of the variation in crop yields—demonstrating an exceptionally high level of predictive accuracy. To further enhance model transparency and interpretability, Explainable AI (XAI) techniques, particularly Local Interpretable Model-Agnostic Explanations (LIME), were employed to assess feature significance. This analysis underscored the critical influence of crop-related variables, prompting the integration of an additional dataset to classify the most suitable crops based on detailed soil and climatic parameters. The classification task was executed using another GA-optimized DNN, strategically designed to maximize accuracy. The findings reaffirm the efficacy of this approach in both yield estimation and the recognition of optimal crops, illustrating the transformative potential of advanced machine learning methodologies in modern agricultural

decision-making. These advancements underscore the necessity for continuous advancements in the agriculture sector to ensure food security, sustainability and adaptability in response to the face of evolving climatic and economic challenges. (Ivan P. Malashin, et.al.2024)

Market Access and Price Prediction: AI- driven platforms were being developed to give growers with request information, including commodity prices and demand vaticinators. This helped growers to informed opinions regarding the timing and location to send their yield. Over time, the prices of agricultural commodities have fluctuated exhibited significant volatility, fluctuating unpredictably and impacting the broader economy. Accurate price forecasting is crucial for farmers, enabling them to make informed decisions about crop selection based on projected market trends. Given the seasonal nature of agricultural product pricing, early awareness of price variations can substantially enhance farmers' Return on Investment (ROI). This study aims to develop apredictive model for agricultural commodity prices, utilizing a neural network-based approach implemented through the Neuroph framework on the Java platform. Historical price data, along with real-time updates, are integrated into a comprehensive dataset covering multiple states and five key crops. Predictions are made available through a mobile application on Android, supplemented by a web-based interface that presents processed commodity rates in graphical form. By leveraging these visual insights, agricultural experts can analyze market trends and relay critical price information to farmers. The system is built to deliver location-specific price forecasts, ensuring that farmers receive relevant and timely data to optimize their decision-making and financial outcomes. (Sagar Pathane et.al,2015)

Farm Management Systems: AI- powered ranch operation tools were being used to streamline colourful processes similar as irrigation scheduling, planting, and harvesting. These tools aimed to ameliorate overall ranch productivity and reduce homemade labour. Crop yield estimation has now improved in terms of decision-making capability since it has significantly yielded 92% accuracy levels by using AI-driven predictive models. Further, studies indicate that the maintenance cost is decreased by 18% and fuel consumption is decreased by 15% in optimized operations with AI-based farm machinery management systems. The agriculture industry can increase productivity and sustainability to a greater extent by implementing AI in the management of farms to overcome the problems arising out of the world's ever-increasing population. (Mrutyunjay Padhiary et.al.,2025)

Education and Advisory Services: AI- grounded mobile apps and platforms were being used to deliver substantiated agrarian advice to growers. These platforms handed guidance on stylish practices, rainfall vaticination, and pest operation. Green Genie is a mobile-friendly application designed to transform agricultural management for farmers

by offering a comprehensive suite of tools tailored to their needs. The app aims to enhance productivity and sustainability in farming through various innovative features. One of the primary functionalities of Green Genie is its crop disease diagnosis system, which employs advanced algorithms to identify potential diseases based on user-submitted images. By providing immediate and actionable recommendations for treatment and fertilizers, the app empowers farmers to tackle crop health issues proactively. In addition to disease management, Green Genie connects farmers with local agricultural experts, facilitating access to professional advice and support. This feature is crucial for farmers seeking guidance on best practices, pest control, and efficient resource utilization. Furthermore, the app offers crop suggestions based on real-time weather data, assisting farmers in making well-informed choices about what to plant and when to harvest. The integrated marketplace within Green Genie enables farmers to buy and sell agricultural products, from fertilizers to seeds, directly through the app. This not only streamlines the procurement process but also enhances access to market for farmers, allowing them to maximize profits. Additionally, the app includes a farm yield calculation module that assists farmers in estimating potential harvests based on various factors, including crop type, soil characteristics and climatic conditions. This feature promotes better planning and resource management. To further enhance user experience, Green Genie incorporates a chat bot designed to answer agricultural queries in real time, providing immediate assistance for common issues and concerns. This multifaceted approach makes Green Genie an invaluable tool for modern farmers, no matter their scale of operation. By combining these diverse functionalities into a single platform, Green Genie not only addresses the pressing challenges faced by farmers but also fosters a more sustainable agricultural ecosystem. Ultimately, the app is poised to redefine how farmers manage their operations, contributing to greater productivity, profitability, and sustainability in the agricultural sector. (Swarnil Sambhaji Shinde)

Soil Health Monitoring: AI technologies were being employed to assess soil health and fertility, guiding growers in making informed opinions about soil operation practices, optimize the force chain. It has created a pall- grounded result that gathers information from growers, including data from air images, land water detectors, and other sources. They use picture recognition capabilities to help growers in entering the applicable information, ways, and coffers at the applicable time to gain the stylish eventuality a yield, Jivabhumi It's developing an intelligent request to optimize force and demand for husbandry, which is constantly inadequate, Blue River Technologies combines computer vision, robotics, and AI to reduce the cost and volume of fungicides used, IBM India Private Limited and the Government of India agreed to conduct an airman study in the sections of Bhopal, Rajkot, and Nanded, AI sowing App- Microsoft.

Case Studies in Northeast India

Several initiatives in Northeast India have showcased the potential of AI and IoT:

- Assam Agri-tech Pilot Project: AI-driven models were used to detect pest infestations in tea plantations.
- Smart Irrigation in Meghalaya: IoT-based drip irrigation systems improved water efficiency in vegetable farming.

AI-powered Crop Advisory in Arunachal Pradesh: Farmers received customized recommendations via mobile applications

Conclusion

Agriculture remains the backbone of Northeast India, employing a substantial part of the population and shaping the region's socio-economic landscape. Despite the difficulties posed by hilly terrain, erratic rainfall, and limited access to modern agricultural resources, the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) presents transformative solutions. By leveraging real-time data, predictive analytics, and automation, AI and IoT technologies can enhance productivity, resource efficiency, and sustainability in agricultural practices. Agricultural extension services play a crucial role in bridging the gap between research and practical farming. The integration of AI-driven decision support systems and IoT-enabled smart farming techniques It has the capability to transform the dissemination of agricultural knowledge, ensuring that farmers receive timely and precise advisory services. Global examples from countries such as Bangladesh and Uganda highlight the success of technology-driven agricultural extension in improving farm incomes, productivity, and sustainability. The Northeast Indian agricultural landscape, characterized by its reliance on traditional and indigenous farming practices, can benefit significantly from these advancements while preserving ecological balance and local knowledge systems. The adoption of AI and IoT in agriculture offers numerous benefits, including optimized resource allocation, early identification of insects, pests and diseases, improved irrigation management, and real-time monitoring of soil and crop health. However, the successful implementation of these advancements requires overcoming Obstacles like infrastructural constraints, digital literacy among farmers, and financial accessibility. Strengthening public-private partnerships, enhancing institutional support, and investing in farmer education programs are critical to ensuring extensive use of AI and IoT-driven agricultural practices in Northeast India. As global food demand continues to rise, with agricultural production needing to increase by approximately 50% by 2050, Technology's impact on sustainable farming is more important than ever. The evolution of agriculture in the future in Northeast India lies in a balanced approach that integrates advanced technological solutions with traditional farming wisdom. With targeted policy interventions, investment in digital infrastructure, and collaborative efforts between research institutions, government bodies, and private stakeholders, AI and IoT can reshape the agricultural landscape of

Northeast India, fostering economic growth, food security, and environmental sustainability.

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