Feasibility of Integrated Ann Model for Agriculture Farming: A Systematic Review Paper

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ABSTRACT

Artificial Neural Networks (ANNs) have surfaced as a potent transformative influence in smart agriculture, significantly improving soil, crop, irrigation, disease, pest, weed management, and decision support systems. ANNs excel at recognizing non-linearity and intricate relationships among variables such as soil nutrients, soil temperature, whether temperature and leaf characteristics help to detect and predict crop health. Crop suitability concerning soil characteristics, crop yields, soil fertility level, irrigation and fertilizer time tables, weed and disease prediction are the other areas where these models find immense usage..

Combining ANN models with cutting-edge remote sensing technologies, like UAVs fitted with high-resolution cameras, spectral sensors, and IoT devices, enhances their predictive precision. This results in more reliable outcomes for farmers and helps to minimize all pre-harvesting losses.Through continuous research and development, ANNs were set to take on an increasingly crucial role in revolutionizing agricultural methods, boosting efficiency, and improving productivity for a sustainable future.ANN models in farming is aligned with SDGs established under national agriculture mission of our nation for 2021-2025, Tamil Nadu precision farming mission and national AI mission. This review paper fills the gap between soil health, crop prediction, crop yield, scientific irrigation, and fertilizer uses.It directly and indirectly contributes towards enhancing soil fertility that can lead to sustainable agriculture.

Keywords:- Artificial Neural Networks (ANNs), Soil health management, Crop prediction , Crop yield, Sustainable Agriculture

1.INTRODUCTION

Agriculture is fundamental to economic activity, food security, and sustainable development. However, it has become unsustainable due to traditional practices, including excessive use of fertilizers, pesticides, unscientific irrigation, and cultivating crops unsuitable for specific soils with continuously increasing food demand. These methods harm soil health, the nutrient value of crops, and lead to major consequences such as crop yield ,environment sustainability and ultimately affecting human health. Additionally, burning, slash-and-burn, and climate change effects such as altered growing seasons and water scarcity threaten crop yields and food security.

It is observed that " one-third of all food produced (around 2.5 billion tons) is wasted yearly. One-third of total food waste occurs in the food production stage. A study by Boston Consulting Group (BCG) estimates this wasted food is worth $230 billion. Researchers tend to include all types of food waste in their estimations, as it is better to find ways to prevent these materials from reaching landfills. Sometimes, “food inedible byproducts could be used as feedstock for other products, help the supply chain of agriculture organizations, and improve production processes"(Global Food Waste in 2025). Additionally, 6% of the world's GHG emissions come from food waste. “Pathogens and pests significantly impact crop yield, causing annual losses estimated at $220 billion” (Ristaino et al., 2021). To minimize all these losses, we need to introduce emerging technologies such as ANN, UAVs fitted with high-resolution cameras for collecting real-time hyperspectral data of soils, crops, and weather, spectral sensors, and IoT devices for improving soil health, crop prediction, crop yield prediction, diseases, and weed control.

A case study illustrating unsustainable crop production in India involves farmers in a drought prone region focusing on water-intensive crops like rice and sugarcane in different parts of India such as Panjab, Haryana, Western Uttar Pradesh, Madhya Pradesh, and TamilNadu, leading to groundwater depletion and soil degradation despite the region's unsuitable climate and soil conditions. In India, the minimum cost of a soil health card after the state government subsidy is Rs.190. However, most farmers in India do not do soil health checkups due to the difficulty in getting accessibility and awareness. In this review paper, we highlight the development of a cost effective and real-time prediction of soil health, crop prediction, and yield through the use of the ANN model.

2.REVIEW OF LITERATURE

2.1 SOIL HEALTH MANAGEMENT

Soil is critically essential to sustainable agriculture practices and crop sustainable development. Soil stores water, nutrients, and proteins to make all resources available for crop growth and crop nutrient development. However, farming deals with choices and unsustainability from season to season; climate change influences weather, the prices of agricultural resources fluctuate, soil erosion, crops are not viable for that particular soil, weeds, and pests are harmful to crop development, and climate change impacts all farming activities. A study led by IIT Bombay found that the Western Ghats region is experiencing a high rate of soil erosion, with

Tamil Nadu shows the highest soil loss rate. According to **the Revised Universal Soil Loss Equation (RUSLE),**" **30%** of India's landmass is experiencing **"minor" soil erosion**, 3% facing **"catastrophic"** topsoil loss. The RUSLE considers factors such as predicted crop loss, rainfall, soil erodibility, excess use of fertilizer, unscientific irrigation practices, and land management practices as significant factors for soil degradation".

A comprehensive overview of all soil types and their conditions will improve crop yield. Also, it helps conserve soil resources. It is helpful for operations, practices, and treatments to enhance soil health variables. Scientific methods of composting and manure improve soil porosity and aggregation. A suitable aggregation indicates the addition of organic materials essential to preventing soil crust formation. This comprehensive knowledge of soil and crop health helps to adopt suitable tillage systems to prevent soil physical degradation. Availability of organic materials is crucial in improving soil health . Production of vegetables and other edible crops is often significantly affected by soil-borne pathogens that require control through soil management" . Sensitivity to soil erosion integrated within soil health assessment recognizes that soil's ability to resist change and recover varies. Also, Soils take a long time to recover in their original form .

2.2 ARTIFICIAL NEURAL NETWORKS (ANNS) AS PREDICTORS OF SOIL FERTILITY

By training on extensive soil datasets that include samples of soil and their associated properties such as weather, temperature, humidity, and rainfall data, artificial neural networks (ANNs) can correctly capture the complex spatial and temporal variations of soil variables such as soil temperature, soil moisture, pH value, soil nutrient content, and carbon content. ANNs facilitate the understanding of soil characteristics, enabling accurate predictions, adequate fertilizer requirement, and water requirement of particular crops and providing valuable insights to inform decisions regarding land use, agriculture, and environment sustainability (Panduranga et al.,2024; maravedis et al. 2022, Babar et al.,2024, and Pandey et al. 2024). ANN provides real-time understanding and predictive capability, aiding efficient and sustainable soil management (Hosseini et al.,2023).

After analyzing the existing literature review, we found that we could predict the soil's physical, chemical, and biological properties, such as Nitrate leaching, pH, soil texture(M.Bilgili et al.,2011), monthly mean soil temperature(Oztarkm et al.,2011; Mirzaei-Paiaman,2012), soil moisture, soil enzyme activities(S.Tajik et al.,2012), hydraulic conductivity , organic carbon concentration(Li QQ et al.,2013), soil macronutrients such as N, P and K and micronutrients such as Zn, Fe, Cu and Mn. Researchers have found artificial neural networks (ANN) as a prediction approach for soil properties based on various inputs, and ANN models are more precise, accurate, and cost-effective compared to other regression models [Guo PT et al.,2013, Kolassa J et al.,2017, Ng W et al.,2019 and Heung B et al.,2016]—Case studies explored in this regard throw us better insights for better Soil Management.

3. ESTIMATORS OF SOIL PHYSICAL PROPERTIES

3.1 SOIL MEAN TEMPERATURE

Soil temperature is an essential meteorological variable that affects the soil's chemical, physical, and biological properties(Feketeová, Z et al.,2021). The ground temperature depends on canopy plantation, GHG emissions, soil texture, water retention rate, and environmental circumstances. Artificial Neural Network (ANN) is used to perform mathematical modelling to learn patterns and relationships in soil temperature and other observed data variables [Jebamlar et al.,2021]." ANN can recognize complex online correlations between environmental variables and soil temperature"[Oztarkm et al.,2011]. For predicting soil temperature, ANN models performed better than traditional regression models and Support Vector Machines and showed higher accuracy and reality, especially when ANN models were trained on big datasets [Mirzaei-Paiaman et al.,2012; Morteza Amiri et al.,2015]. According to Biazar et al.," the integrated artificial neural network and Sperm Swarm Optimization (SSO) models (ANN-SSO) were more accurate tools for soil temperature forecasting than the original artificial neural network model among various soil depths in Florida(USA).

3.2 SOIL WATER RETENTION AND INFILTRATION RATE

The soil water retention curve (WRC) of a soil is determined by soil texture, structure, porosity, grain size distribution, and soil moisture, and infiltration rate is predicted through the use of soil texture data such as particle-size distribution and porosity.WRC and infiltration rate help to predict the water requirement of crops. Modern deep and spring irrigation technologies enhance soil fertility and scientific water utilization.ANN models are a more accurate, precise, time-saving, and costeffective tool compared to other multiple regression models(Bharti B et al.,2017; Chatterjee S et

al.,2019, Mirzaei-Paiaman et al.,2012).ANN model is very helpful in developing countries such as India because the maximum of farmers in India is marginal and small.CNN(Convolutional neural network) has been successful in the extraction of features from the soil images and spectral data in order to predict soil nutrient and moisture levels (Bharadiya et al., 2023) and Recurrent Neural Networks (RNNs) (Hassan et al., 2023)

4. ESTIMATOR OF SOIL CHEMICAL PROPERTIES

4.1 ELECTRICAL CONDUCTIVITY AND CARBON CONTENT

Electrical conductivity (EC) strongly correlates with soil properties such as pH, soil nutrient holding capacity, and composition(Grubbs RA et al.,2019; Serrano JM et al.,2017; Uribeetxebarria et al.,2018). Sanches et al. (2018). described soil pH and developed models for lime recommendation based on geographical analysis that could predict Electrical conductivity. Electrical conductivity helps analyze soil compaction(Pentos K et al.,2021) and composition (Uribeetxebarria et al.,2018).

Soil organic carbon content analysis is closely linked with regional climate change and carbon cycles(Stockmannu et al.,2013). Machine learning models such as Support vector regression(SVR)(Ballabioc et al.,2019), boosted regression tree(Wang B et al.,2018), Random forest(Subburayalu SK et al.,2013) and artificial neural network(Li QQ et al.,2013) are used to predict carbon content in the soil and ANNs models outperformed compare to other models (Kang Y et al.,2020).ANN models are critical for identifying correlations between soil properties and environmental factors(Were K et al.,2015).

4.2 CROP AND YIELD ESTIMATORS

Currently, in India, farmers face many difficulties in adequately using agricultural resources such as land, fertilizers, crop suitability, soil and environmental conditions, and poor decisionmaking related to soil health and crop prediction. According to the **Ministry of Agriculture & Farmers Welfare report "Impact of Climate Change on Agriculture,"** "The climate change impact assessment was carried out using the crop simulation models by incorporating the projected climates of 2050 & 2080. Without adopting adaptation measures, rainfed rice yields in India are projected to reduce by 20% in 2050 and 47% in 2080 scenarios, while irrigated rice yields are projected to reduce by 3.5% in 2050 and 5% in 2080 scenarios. Climate change is projected to reduce wheat yield by 19.3% in 2050 and 40% in 2080 scenarios towards the end of the century, with significant spatial and temporal variations. Climate change is projected to reduce *kharif* maize yields by 18% and 23% in 2050 and 2080 scenarios. Climate change reduces crop yields and lowers the nutritional quality of produce. Extreme events like droughts affect food and nutrient consumption, and their impact on farmers"(Impact of Climate Change Report on Agriculture., 2023). Accurate crop selection is most important for sustainable farming, increasing farmer's income, improving the nutrient levels in crops, and long-term sustainability of soil. For that, we need cost-effective, highly accurate, precise, and real-time prediction-based automated decision-making systems like ANN models(Khatri Chhetri et al., 2017). Automated crop prediction systems consider climate, weather, environmental factors, and soil parameters to play a critical role in minimizing crop and soil health-related losses(Canton et al., 2021; Markhof, Ponzini & Wollburg, 2022).

Crop prediction is essential for maximizing crop yields, soil health, water management, disease management, and food security. Historical crop performance, weather patterns, and soil conditions play an essential role in predicting which crops will thrive in specific soil and environmental conditions (Elbasi et al.,2023; Suraliandi et al.,2021; Shinnal et al.,,2021 Chitragar et al.,2016; Masrie et al., 2017). Accurate predictions help farmers make efficient decision-making

about planting and resource allocation, such as irrigation, pesticides, and fertilizer requirements(Durai and Shamili et al.,2022).

Crop yields are affected by other factors such as missing hills, floating hills, number of seedlings per hill, and hill distance (Basir Samual MD et al.,2022),and availability of oxygen on roots.We need to use sensors such as Mec 10 to measure soil parameters and DHT 22 sensor to measure the air temperature for higher accuracy (Ramzan et al.,2024).

Ramzan et al. (2024) have developed an ANN model for crop prediction using soil and temperature sensors, and they have taken parameters such as Temperature, soil texture, soil nutrients such as N, P, and K, humidity, pH, and electrical conductivity to crop prediction.ANN model outperforms existing models such as Logistic Regression, Ada boosting classifier, Gaussian NBC classifier, and Support vector regression.

Thimmegowda et al.,2025 built an ANN model for rice yield prediction in ten districts of Karnataka. They have collected long-term historical yield data from the "Directorate of Economics and Statistics(Government of Karnataka)" and daily weather parameters such as temperature, morning and evening relative humidity, and rainfall pattern from the India Meteorological Department(https://mausam.imd.gov.in) and this ANN model has predicted with high accuracy. Temperature, moisture content, and humidity were considered critical factors for achieving reasonable growth of crops.

After the extensive literature review, no integrated ANN model estimates soil health, crop prediction, and crop yield with scientific water and fertilizer utilization while considering all critical variables such as electrical conductivity, water retention power of the soil, macro, and micronutrients in the soil for promoting a sustainable and circular agriculture economy.

The literature has brought out the importance of a major principle of sustainable agriculture namely estimators of soil protection and development amidst various other constraining factors such as high/low/no rainfall,depleting water bodies ,increasing problems in pest and diseases management due to climate change.

5. METHODOLOGY OF THE STUDY

This paper is aimed at developing a systematic review of literature in identifying some of the crucial factors influencing sustainable agriculture practices in terms of soil physical and chemical properties, crop and yield management. The estimators identified are then used to design the architecture of ANN model.The proposed system's architecture illustrates how each component interacts with each other. The proposed system uses two datasets: soil and crop image datasets collected from different sources such as satellites, drones, and phones, and the other dataset, which is publicly available weather data, soil mean temperature, and soil texture map dataset. The real-time sensing of the environmental and soil parameters will be done using real-time data of soil and weather data for crop prediction and crop yield prediction based on soil indicators and historical yield,climate conditions respectively.

6.CONCEPTUAL DESIGN OF ANN MODEL

The proposed ANN model has one input layer, hidden layers, and one output layer, as mentioned in Figure 1. We use input datasets such as soil and crop images, weather and soil data, crop data, and historical crop yield data in the input layer. Then, we will convert the RGB image into a hyperspectral image using a convolutional neural network(CNN) or

Generative Adversarial Network (GAN). We will do a Spectro-photo analysis of this hyperspectral image and try to analyse different soil properties, such as soil texture, pH, electrical conductivity, soil composition, carbon content, and macro and micro chemical elements.Then, we will use this data to find soil properties such as water retention power, soil compactness for soil penetration resistance, and infiltration rate.As a final output, we will use all the data to get the final output, such as crop prediction, crop yield prediction, irrigation, and fertilizer utilization in real time.

7. THEORETICAL & PRACTICAL IMPLICATIONS

Sustainable agriculture requires not only theoretical understanding of the ecological principles of food production but needs to explore various sustainable practices that need to be implemented. Firstly, this study can help to organize and synthesize the data as to how the different components of the agricultural system interact with each other. Secondly, it helps to build upon the knowledge base of the farmers and make them ready to accept new technologies.Next, this study can contribute to mitigate long term consequences unsustainable agricultural practices that erodes soil nutrition and crop yield that causes food security imbalances.

In terms of practical application the paper would help build the requirement of setting up centralized image big data sets of soil and different crops utilizing satellites and UAVs for training ANN models for higher accuracy aligns with Startup India, Stand Up India, and Make in India. It also calls for more women to be trained in UAV technology to gather specific crop and soil data as a large number of women are engaged in farming activities and will stress on the requirement for training programs for farmers related to emerging technologies, such as artificial intelligence in agriculture.

8. SCOPE FOR FUTURE STUDY

Lack of big data sets of different soil and crops for training ANN models, training of farmers to utilize these emerging technologies, response time and accuracy, implementation methods, flexibility, and high cost of data collection calls the researchers to explore more datasets in this area. This calls for an empirical study to test the ANN model developed.

9. CONCLUSION

In conclusion, ANN models help predict soil health assessment reports, crop prediction, crop yield prediction, irrigation, and fertilizer requirements based on soil and crop-specific requirements. It helps to reduce governments' fertilizer and energy import bills through utilizing "modified fertilizers"(a mixture of organic and nano fertilizers based on soil and crop requirements).ANN models provide real-time prediction with high accuracy and consider climate change patterns. It benefits soil health, increasing crop yields and diversifying crops.ANN models reduce government spending related to setting up physical soil health laboratories.ANN Models help to empower women by providing training in drone/UAV technology for collecting soil and crop data in localized data centers. It improves farmers' decision-making and helps to predict new crop diseases through analysis of crop characteristics. There is a vast scope of research on artificial intelligence in agriculture, such as sustainable supply chain management, operation management of different agriculture products, logistics, and food waste management for promoting a sustainable and circular agriculture economy.

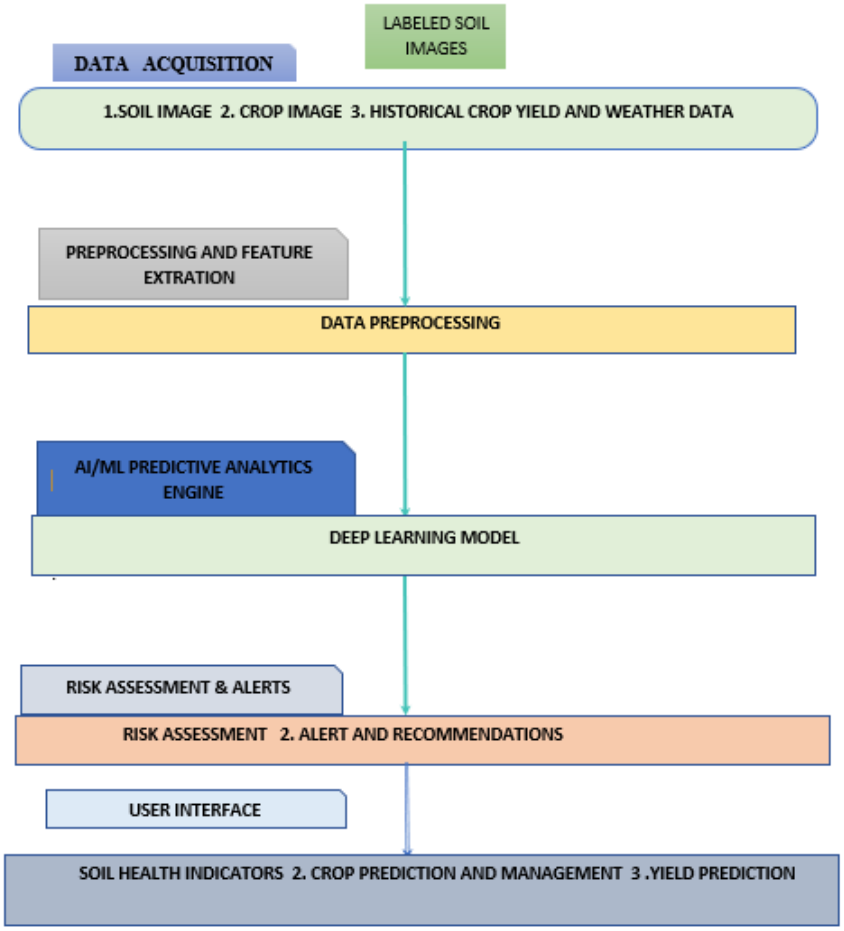

FIGURE 1

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