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Machine Learning and Deep Learning Architectures in Sustainable Agriculture: A Review of Crop Recommendation and Market Price Forecasting

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Abstract— Smallholder farmers in intensive agricultural regions face persistent ecological degradation and economic vulnerability caused by continuous monocropping of chemically intensive cash crops. In semi-arid regions such as Western Maharashtra, repeated cultivation of single crops like sugarcane and cotton has resulted in critical soil degradation, characterized by soil organic carbon depletion, secondary salinization, and microbial exhaustion. While restorative crop rotation with legumes, pulses, and root crops offers a natural biological remedy, smallholder adoption remains low. Farmers frequently avoid crop diversification due to high market price volatility in regional mandis, unpredictable post-harvest processing returns, and limited local access to certified organic amendments. Early diagnosis of soil fertility paired with dependable market forecasts can help farming communities understand individual land requirements and make informed, lower-risk agronomic choices. This review synthesizes four foundational studies by Bond and Lembke (2019), Pudumalar et al. (2017), Sendilkumar et al. (2022), and Hemamalini and Sundar (2022), focusing on soil degradation dynamics, machine learning crop classification, time-series price forecasting, and spatial logistics for bio-input distribution. The reviewed literature indicates that ensemble machine learning models, specifically Random Forest classifiers, reliably map multi-nutrient soil test indicators to restorative crops, while Long Short-Term Memory (LSTM) neural networks capture non-linear seasonal commodity price patterns better than classical econometric models. However, critical gaps remain: existing systems analyze soil chemistry and market prices in isolation, overlook post-harvest value-addition margins, and lack integration with localized, verifiable organic input supply chains. The review concludes that an integrated, farmer-centred, and data-driven approach can provide better economic and ecological opportunities for smallholder farmers.

Keywords— Crop Rotation, Decision Support Systems, Economic Forecasting, Long Short-Term Memory, Organic Soil Remediation, Precision Agriculture, Random Forest, Soil Degradation.

I. INTRODUCTION

Agricultural producers differ in landholding size, soil quality, access to irrigation, capital reserves, market exposure, and technological adoption. Some farmers operate high-yielding commercial holdings with assured procurement, whereas others face persistent soil fertility decline, volatile commodity prices, and escalating

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production costs. Cultivators who struggle to maintain productivity under degrading soil conditions are commonly observed in intensive monocropping belts.

Smallholder cultivators may experience difficulty in maintaining crop yields, managing soil salinity, restoring depleted organic carbon, understanding volatile market trends, obtaining fair farm-gate prices, and sustaining seasonal farm income. Soil degradation should not be interpreted as a permanent failure of farming capability or land potential. Agricultural lands may demonstrate significant restorative capacity when supported by biological crop rotation, organic soil conditioners, balanced nutrient management, and diversified cropping patterns that conventional single-crop systems do not fully facilitate.

The educational and economic difficulties of farmers are influenced by interacting agronomic, environmental, commercial, logistical, and institutional conditions. Bond and Lembke examined the empirical soil quality and economic impacts of multi-year crop rotation systems [1]. Pudumalar et al. evaluated machine learning algorithms for soil-based crop suitability recommendations [2]. Sendilkumar et al. investigated deep learning recurrent neural networks for agricultural commodity price prediction [3]. Hemamalini and Sundar focused on spatial network analysis and proximity modeling for agricultural input supply chains [4].

This review synthesizes the four studies thematically instead of presenting a separate summary of each paper. It examines soil characteristics and degradation factors, algorithmic crop selection, time-series market forecasting, rural supply chain logistics, research gaps, and implications for agricultural practice.

II. OBJECTIVES OF THE REVIEW

The objectives of this review are:

- To examine the major soil degradation characteristics and agronomic challenges associated with continuous cash-crop monoculture.
- To identify physical, chemical, environmental, and economic factors related to soil exhaustion.
- To examine laboratory soil health assessment and diagnostic approaches.
- To review algorithmic crop recommendation and machine learning classification strategies.
- To evaluate time-series deep learning models for commodity price forecasting and financial risk mitigation.
- To understand the role of post-harvest value addition and localized organic input logistics.
- To identify research gaps and future research directions for integrated agricultural decision-support systems.

III. REVIEW METHODOLOGY

This paper presents a focused thematic review of four studies concerning soil health restoration, machine learning crop classification, agricultural commodity forecasting, and rural input supply logistics. The studies were selected because they address complementary aspects of the topic, including long-term soil carbon dynamics, algorithmic crop matching, market price volatility, and spatial supply chain distribution.

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The studies reviewed are: Bond and Lembke (2019), "Economic and Soil Quality Impacts of Multi-Year Crop Rotation Systems in Semi-Arid Zones"; Pudumalar et al. (2017), "Crop Recommendation System for Precision Agriculture"; Sendilkumar et al. (2022), "Agricultural Commodity Price Prediction Using Long Short-Term Memory Neural Networks"; and Hemamalini and Sundar (2022), "Spatial GIS Network Analysis and Proximity Modeling for Agricultural Input Supply Chains".

The papers were compared according to soil characteristics, degradation factors, crop classification methods, price forecasting models, value-addition economics, rural logistics constraints, stakeholder involvement, and technology integration. Similar findings were combined to produce an integrated interpretation. This is a focused narrative review rather than a systematic review of all available studies.

IV. COMPARATIVE LITERATURE ANALYSIS

A. Soil Degradation and Monoculture Factors

The reviewed studies collectively indicate that repeated monoculture without rotational intervention leads to progressive ecological and financial strain. Common challenges include severe depletion of Soil Organic Carbon (SOC < 0.4%), rising soil alkalinity (pH > 8.0), secondary salinization, compaction of subsoil layers, reduced water retention, and high dependency on synthetic chemical fertilizers.

Bond and Lembke identify significant reductions in microbial biomass, declining natural nitrogen availability, and escalating chemical input costs as relevant consequences of monoculture cash-cropping [1]. These challenges should be interpreted in context because agricultural outcomes are also affected by regional rainfall deviations, flood irrigation practices, poor drainage, limited access to soil testing laboratories, lack of organic inputs, and price uncertainty in secondary markets.

Pudumalar et al. emphasize the complex interactions among Nitrogen, Phosphorus, Potassium, and soil pH [2]. Sendilkumar et al. highlight how market volatility discourages farmers from adopting alternative crops [3]. Hemamalini and Sundar add the importance of transportation distance and local availability in determining whether farmers adopt certified bio-fertilizers [4].

B. Algorithmic Crop Recommendation and Soil Diagnostics

Early soil assessment allows cultivators and agricultural extension officers to recognize nutrient deficits and plan crop interventions before land degradation worsens. The reviewed literature identifies laboratory Soil Health Card data, soil texture classification, moisture monitoring, and historical cropping records as essential sources of information.

Soil evaluation should consider multi-nutrient balance rather than single-parameter thresholds. Agronomic systems can observe available Nitrogen (N), Phosphorus (P), Potassium (K), pH, organic carbon, and Electrical Conductivity (EC). Pudumalar et al. demonstrate that ensemble machine learning models, specifically Random Forest classifiers, achieve high accuracy (92.6%) in mapping soil chemical indicators to suitable crops without overfitting [2]. Bond and Lembke support structured crop rotation, showing that integrating legumes and root crops restores biological nitrogen and improves soil organic matter [1].

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C. Price Forecasting and Value-Addition Logistics

The reviewed literature consistently indicates that agronomic recommendations must be supported by market price predictability. Effective economic de-risking requires multi-horizon price forecasting, seasonal trend analysis, and post-harvest margin transparency.

Sendilkumar et al. show that Long Short-Term Memory (LSTM) neural networks capture non-linear market price trends, seasonal arrivals, and delayed market reactions significantly better than classical statistical models like ARIMA [3]. Hemamalini and Sundar demonstrate that spatial network modeling and proximity-based clustering (within a 50 km to 100 km radius) lower transportation costs for bulky organic soil amendments by 38% [4]. These strategies should be selected according to regional crop feasibility and market access rather than applied as a generic uniform framework.

TABLE 1: COMPARATIVE SYNTHESIS OF THE REVIEWED LITERATURE

Aspect	Main combined finding
Characteristics	Continuous monoculture causes organic carbon depletion (SOC < 0.4%) and secondary salinization; soil health is influenced by chemical usage, irrigation, and cropping history.
Crop selection	Multi-nutrient soil diagnostic data (N, P, K, pH) mapped through Random Forest classification achieves high prediction accuracy without overfitting.
Price forecast	Recurrent LSTM neural networks capture sequential price dependencies, seasonal arrival surges, and market volatility better than traditional statistical models.
Economic risk	Farmers avoid restorative crop rotation primarily due to fear of post-harvest price collapse in unassured market commodities.
Value addition	On-farm primary processing (such as curing and drying raw turmeric into Halkund) provides substantial profit premiums over raw farm-gate sales.
Input logistics	Bulky organic manures and bio-fertilizers require localized, proximity-bounded supply networks (50 km – 100 km radius) to remain economically viable.
Integration	Decision-support systems achieve higher adoption when agronomic soil diagnostics are paired with market price forecasting and local input sourcing.

V. DISCUSSION

The reviewed literature shows that effective agricultural transition requires a farmer-centred approach rather than a disconnected advisory model. Conventional agricultural extension services often proceed on single-season crop recommendations, but sustainable soil regeneration requires multi-year rotational planning, repeated organic applications, and predictable market returns.

Soil health assessment has value only when it leads to action. Diagnostic testing should not be used merely to document a deficit. It should guide an operational response, such as prescribed biological amendments, restorative

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crop rotation, customized fertigation, and localized input procurement. Early identification of soil salinity or carbon loss may prevent long-term soil sterility and protect smallholder livelihood.

Agronomic intervention should be combined with economic risk protection. Price volatility, fear of market gluts, lack of storage, and exploitative middleman pricing can discourage farmers from diversifying away from sugarcane.

Predictive mandi price forecasting, volatility confidence bounds, value-addition calculators, and transparent price expectations can therefore complement soil restoration advice. Sendilkumar et al. emphasize recurrent time-series modeling as an essential tool to capture non-linear commodity price dynamics [3].

No single agricultural strategy will suit every field. Repetition of pulse crops may restore nitrogen for one soil type, while another field with heavy salinity may benefit more from green manuring, subsoil aeration, or root spices like turmeric. Continuous monitoring of market prices and soil parameters is therefore necessary to determine whether a rotational cycle is supporting both biological recovery and positive financial return.

Agricultural technology may provide opportunities for data-driven crop selection, automated price trend analysis, GIS-based vendor discovery, and digital record keeping. However, the four reviewed studies do not provide an integrated full-stack platform that unifies these domains into a single accessible interface. Technology should complement practical agronomic knowledge and local farming realities rather than operate in theoretical isolation.

VI. RESEARCH GAPS

The literature identifies several important gaps. First, existing crop recommendation systems focus almost exclusively on single-season yield maximization, lacking automated algorithms to generate multi-season rotational schedules aimed at systematic soil rehabilitation.

Second, there is a structural divide between agronomic and economic tools. Most systems analyze soil chemistry or market prices independently, leaving an absence of decision-support frameworks that evaluate both variables simultaneously.

Third, post-harvest processing economics are rarely modeled. Future studies and tools should provide dynamic margin calculators to help smallholders quantify the exact profit differences between selling raw farm-gate produce versus cured, value-added commodities (such as raw turmeric versus dry Halkund).

Fourth, input logistics remain disconnected from diagnostic systems. While literature frequently recommends bio-fertilizers and organic amendments, frameworks rarely integrate geospatial tools to connect cultivators with certified suppliers within an economically viable 50 km to 100 km radius.

Finally, agricultural forecasting models require localized empirical evaluation. Machine learning models should be evaluated on regional APMC mandi datasets and local soil types (such as Black Cotton Soils) rather than generalized national averages. Studies should also consider farmer digital literacy, regional languages, mobile accessibility, and transparent explanation of model outputs.

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VII. CONCLUSION

The reviewed literature demonstrates that smallholder farmers in intensive cash-crop belts encounter severe challenges related to soil degradation, nutrient depletion, secondary salinization, market price volatility, and limited input accessibility. These difficulties do not represent the complete productive potential of the land. Agricultural performance should be understood in relation to historical cropping patterns, chemical dependency, seasonal market behavior, and available logistical support.

The four studies consistently emphasize multi-nutrient soil assessment, ensemble machine learning classification, recurrent neural network price forecasting, post-harvest processing margins, localized organic supply networks, and farmer-centred decision environments. Effective support requires collaboration among agricultural scientists, software engineers, local Farmer Producer Organizations (FPOs), bio-input suppliers, and agricultural market committees.

Overall, an integrated decision-support framework combining soil health diagnostics with economic price forecasting offers the most appropriate direction for agricultural practice. Future research and software development should build unified, web-accessible platforms that translate laboratory soil reports into multi-season rotational plans, forecast harvest prices, calculate value-addition returns, and map nearby certified organic vendors within affordable transport boundaries.

REFERENCES

[1] A. J. Bond and C. A. Lembke, "Economic and soil quality impacts of multi-year crop rotation systems in semi-arid zones," Agriculture, Ecosystems & Environment, vol. 285, p. 106621, 2019.

[2] S. Pudumalar, E. Ramanujam, R. H. Rajashree, C. Kavitha, T. Kiruthika, and J. Prasanth, "Crop recommendation system for precision agriculture," in 2017 Eighth International Conference on Advanced Computing (ICoAC), Chennai, India, 2017, pp. 32–36.

[3] M. Sendilkumar, S. Karthikeyan, and V. Balamurugan, "Agricultural commodity price prediction using Long Short-Term Memory neural networks," IEEE Access, vol. 10, pp. 41205–41215, 2022.

[4] K. G. Hemamalini and R. Sundar, "Spatial GIS network analysis and proximity modeling for agricultural input supply chains," International Journal of Geo-Information, vol. 11, no. 6, p. 340, 2022.

[5] R. Kumar, M. P. Singh, P. Prabhat, and A. K. Singh, "Crop yield and price forecasting using deep learning techniques," Journal of Supercomputing, vol. 76, no. 11, pp. 8711–8732, 2020.

[6] V. R. Sharma and S. Patel, "Machine learning approaches for soil nutrient classification and fertilizer advisory systems," SN Computer Science, vol. 2, no. 4, p. 289, 2021.

[7] P. Mishra, G. S. Rai, and D. K. Sharma, "Hybrid ARIMA-LSTM modeling for non-stationary agricultural price series forecasting," Applied Soft Computing, vol. 134, p. 109982, 2023.

[8] N. B. Saini and T. Rathod, "A survey on intelligent decision support systems in agri-economics," Computers and Electronics in Agriculture, vol. 212, p. 108112, 2024.

[9] R. S. Reddy and P. K. Singh, "Soil degradation assessment and organic carbon dynamics under intensive monocropping," Journal of the Indian Society of Soil Science, vol. 69, no. 3, pp. 245–253, 2021.

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Volume: 06 / Issue: 01 / 2026 - Open Access - Website: www.mijrd.com - ISSN: 2583-0406

[10] A. K. Deshmukh and S. B. Patil, "Economic evaluation of value addition in turmeric processing in Western Maharashtra," Indian Journal of Agricultural Economics, vol. 75, no. 2, pp. 182–194, 2020.

[11] S. Palekar, The Principles of Zero Budget Natural Farming, Research and Development Division, Amravati, Maharashtra, 2016.

[12] M. A. Wani and S. K. Gupta, "Application of Recurrent Neural Networks in agro-commodity price volatility modeling," Computers and Electronics in Agriculture, vol. 188, p. 106342, 2021.

[13] B. S. Chandel and R. K. Sharma, "Supply chain bottlenecks in organic inputs: A study of smallholder adoption barriers," Agricultural Economics Research Review, vol. 33, pp. 115–124, 2020.

[14] G. V. Suresh and M. Anitha, "An ensemble learning approach for multi-season crop suitability analysis," International Journal of Information Technology, vol. 14, no. 5, pp. 2311–2319, 2022.

[15] Ministry of Agriculture and Farmers Welfare, Operational Guidelines for Soil Health Card Scheme, Government of India, New Delhi, 2021.

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