Chapter 7

Integrating Explainable AI, Deep Learning, and Causal Inference to Unveil Salinity Stress Responses in Lavandula Dentata:

A Study Under Co-Cultivation Systems in the Context of Climate Change

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DOI: 10.4018/979-8-3693-9132-7.ch007

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ABSTRACT

This chapter explores the salinity stress response of Lavandula dentata under monoculture and co-cultivation with halophytes (Atriplex prostrata, Plantago macrorhiza) using an integrative approach combining explainable artificial intelligence, deep learning, and causal inference. Dimensionality reduction (PCA, t-SNE, UMAP) and clustering algorithms (K-Means, DBSCAN) identified stress- and culture-dependent phenotypic patterns, while supervised learning models (Random Forest, MLP) predicted cultivation conditions with high accuracy, highlighting the key role of root volume, proline, and water content. SHAP values offered model interpretability, and causal inference quantified the direct effects of co-cultivation on biomass. Results revealed that co-cultivation mitigates certain stress traits but may reduce biomass, suggesting trade-offs in physiological adaptation. This chapter demonstrates how data-driven frameworks can support agroecological strategies for salt-affected environments under climate change.

1. INTRODUCTION

The rapid growth of the global population will reach nearly 10 billion by the year 2050, which will increase more pressure on food systems globally than ever. To satiate preparing food in the 2050's global food production must increase by approximately 60-110% (Godoy et al., 2021; Noh et al., 2024). This has not been made easier because of the various environmental stressors, and abiotic stresses from climate change, are some of the most crucial. Among abiotic stresses, soil salinity is one of the most limiting factors that affect crop productivity, which impacts the yields and quality of the food produced (Ye et al., 2019; Soni et al., 2024). Approximately 20% of the world's irrigated land - an area of 62 million hectares - is affected by salinization (Etesami & Noori, 2019; Bazihizina et al., 2024). In South Asia, alone there are over 52 million hectares at risk (Mandal et al., 2018). Salt stress directly affects a plant's ability to take up water and nutrients, causes an ionic imbalance and toxicity (primarily due to Na^+ and Cl^- ions), and incurs oxidative stress, which adversely affects a plant's physiology and stunts its growth. (Singh et al., 2024).

Salinization is a global threat to food security not only through the impact on individual plants. The United Nations Environment Programme (UNEP) estimates that salinity issues affect 20% of the world's arable land and 50% of irrigated farmland worldwide (Omuto et al., 2024). According to the World Bank, at least 24% of all irrigated land is affected by salinity and at least 50% of unproductive land in

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Anupama Mishra, Bineet Kumar Joshi, Varsha Arya, Avadhesh Kumar Guptaand Kwok Tai Chui (2022). *International Journal of Software Science and Computational Intelligence (pp. 1-10).*

www.irma-international.org/article/detection-of-distributed-denial-of-service-ddos-attacks-using-computational-intelligence-and-majority-vote-based-ensemble-approach/309707