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Soil Degradation and its Challenges to Agricultural Production Resilience: an Overview from a Soil Traits Perspective

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ABSTRACT
Soil degradation is a major problem that threatens the resilience of agricultural production due to the decline in soil's ability to support sustainable plant growth. This study aims to examine soil degradation and its challenges to agricultural production resilience from the perspective of soil traits. The method used is a literature review with a narrative review approach to previous scientific research articles. The literature analyzed comprises publications from the last ten years that are relevant to soil degradation, soil physical and chemical properties, and agricultural productivity. The results show that the degradation of soil physical properties—such as compaction, structural damage, and erosion—as well as the degradation of soil chemical properties, especially the decline in organic matter and nutrient imbalances, significantly affects the decline and instability of agricultural production. Literature synthesis confirms that soil degradation is a strategic challenge in maintaining the long-term resilience of agricultural production. Therefore, a soil quality-based approach is needed to support the sustainability of agricultural systems.

Keyword: Soil Degradation; Physical Properties of Soil; Soil Chemical Properties; Agricultural Production; Soil Quality.

INTRODUCTION

Soil is a fundamental resource in agricultural systems because it serves as a medium for plant growth, provides nutrients and water, and supports agroecosystem stability. Good soil quality is a major prerequisite for sustainable agricultural production and long-term food security (Abdalla et al., 2018; Bünemann et al., 2018; Pandey et al., 2023). However, various reports indicate that land degradation is increasingly widespread in agricultural regions worldwide due to agricultural intensification, land-use changes, and climate change pressures (Lal, 2015; FAO, 2017).

Soil degradation refers to a decline in soil capacity to perform its productive and ecological functions, characterized by changes in its physical, chemical, and biological properties (García-González et al., 2018; Lal, 2015; Qi et al., 2024). Numerous studies confirm that degradation of soil physical properties—such as compaction, structural damage, and erosion—reduces water infiltration, soil aeration, and plant-available water (Keesstra et al., 2016; Oldeman et al., 2019). Meanwhile, degradation of soil chemical properties, particularly declines in organic matter content and nutrient imbalances, directly impairs soil fertility and agricultural yields (Jayaraman et al., 2021; Kassam et al., 2020; Palm et al., 2014; Qiu & Zhao, 2023).

Several previous studies have addressed soil degradation in the context of agricultural productivity. Lal (2015) shows that soil degradation is a primary factor in declining global

food production capacity. Rahman et al. (2020) report that intensive farming practices in the tropics accelerate degradation of soil physical and chemical properties, leading to crop yield instability. Meanwhile, Bünemann et al. (2018) emphasize soil quality indicators as tools for evaluating soil degradation and agricultural system sustainability.

Nonetheless, most previous studies address soil degradation partially, focusing on specific soil indicators, locations, or commodities. Research on soil erosion (Keesstra et al., 2016), organic matter degradation (Palm et al., 2014), or standalone soil quality assessments (Doran & Zeiss, 2015) dominates the literature. Studies integrating changes in soil physical and chemical properties as degradation indicators in relation to agricultural production resilience remain limited, particularly comprehensive literature reviews.

Based on the analysis of previous research, there is a research gap in the form of the absence of a synthesis of literature that comprehensively links soil degradation from the perspective of soil physical and chemical properties with the challenge of agricultural production resilience. This research offers novelty by presenting an integrated literature review that links soil trait-based soil degradation indicators with their implications for the stability and sustainability of agricultural production. This approach is expected to enrich a conceptual understanding of the role of soil quality in supporting agricultural production resilience.

This study aims to examine soil degradation through changes in the physical and chemical properties of soils reported in various scientific literature, as well as analyze its relationship with agricultural production resilience. In addition, this study synthesizes the results of previous research to obtain a comprehensive picture of the impact of soil degradation on the sustainability of agricultural production. The results of this study are expected to be a conceptual basis for sustainable land management in an effort to increase the resilience of agricultural production.

METHOD

This study used the literature review method with a narrative review approach. The study was carried out by examining and synthesizing the results of previous research that discussed soil degradation and its effect on agricultural production resilience, especially from changes in the physical and chemical properties of the soil. Literature was obtained from scientific databases such as Google Scholar, Scopus, and ScienceDirect using the keywords soil degradation, soil quality, soil physical properties, soil chemical properties, and agricultural productivity. The selected articles are publications from the last 10 years, in Indonesian or English, and relevant to the agricultural context.

The analysis was carried out qualitative-descriptive by grouping and comparing research findings related to soil degradation indicators and their impact on agricultural production. The results of the analysis are presented in the form of a synthesis narrative to obtain a comprehensive picture of the challenges of soil degradation to the resilience of agricultural production.

RESULTS AND DISCUSSION

Based on the results of a review of 10 major scientific articles published in the last ten years, the literature analyzed includes global, regional, and national studies on soil degradation and its implications for agricultural production. The literature consists of conceptual studies (Lal, 2015; FAO, 2017), a study of soil quality indicators (Doran & Zeiss, 2015; Bünemann et al., 2018), as well as empirical research linking soil degradation to agricultural productivity in various land-use systems (Palm et al., 2014; Rahman et al., 2020; Utomo et al., 2018; Nunes et al., 2021). In general, all articles show that soil degradation is the main limiting factor in maintaining the sustainability and resilience of agricultural production.

Table 1. Comparison of Soil Degradation and Agricultural Production studies

No	Author & Year	Study Focus	Aspects of Soil Properties	Key Findings	Relevance to the Article
1	**Lal (2015)**	Global soil degradation	Physical & chemical	Soil degradation reduces production capacity and food security	Key conceptual foundations
2	**FAO (2017)**	The status of the world's land degradation	Soil quality	Degrading soil quality threatens agricultural sustainability	Context Global
3	**Bünemann et al. (2018)**	Soil quality indicators	Physical & chemical	Soil traits as key indicators of degradation	Supports the soil nature approach
4	**Oldeman et al. (2019)**	Land degradation assessment	Physical	Soil erosion and compaction reduce land productivity	Physical impact of degradation
5	**Palm et al. (2014)**	Soil fertility decline	Chemistry	The decrease in C-organic and nutrients has a direct impact on crop yields	Chemical–production relationship
6	**Keesstra et al. (2016)**	Soil degradation & ecosystem services	Physical	Damaged soil structure degrades the function of agricultural ecosystems	Ecological linkages
7	**Doran & Zeiss (2015)**	Soil health concept	Soil quality	Soil health determines the sustainability of production	Basis of soil health concept
8	**Rahman et al. (2020)**	Degradation of tropical soils	Physical & chemical	Agricultural intensification accelerates soil degradation	Developing country context
9	**Utomo et al. (2018)**	Degradation of Indonesia's agricultural land	Chemistry	Decline in organic matter in intensive agricultural soil	National relevance
10	**Nunes et al. (2021)**	Soil quality & productivity	Physical	Soil quality is directly proportional to crop stability	Reinforcement of production arguments

Based on the results of the study, soil degradation has consistently been reported to have a negative impact on the resilience of agricultural production. Most studies emphasize that changes in soil physical properties such as compaction, decreased porosity, and erosion (Lal, 2015; Keesstra et al., 2016) have a direct effect on the ability of the soil to provide water and air for plants.

In addition, degradation of soil chemical properties, particularly the decrease in the content of organic matter and essential nutrients, is reported to be the main factor in the decline in agricultural land productivity (Palm et al., 2014; Utomo et al., 2018). Recent literature also confirms that soil quality is a key indicator of the sustainability of agricultural systems, especially in the face of intensification and climate change pressures (Bünemann et al., 2018; Nunes et al., 2021).

Degradation of Soil Physical Properties

The results show that the degradation of soil physical properties is the most consistent aspect reported in various studies. Lal (2015) and Oldeman et al. (2019) emphasized that soil erosion and compaction are the forms of physical degradation that have the most impact on the production capacity of agricultural land. Keesstra et al. (2016) added that damage to soil structures leads to decreased infiltration and increased surface runoff, which accelerates the loss of the top soil layer.

Bünemann et al. (2018) and Nunes et al. (2021) show that increased bulk density and decreased soil porosity are directly related to decreased root efficiency and water availability for plants. These findings are in line with the FAO report (2017) which states that the degradation of soil physical properties contributes greatly to crop yield instability, especially on intensive agricultural land and marginal land. Thus, the degradation of the physical properties of the soil plays a role as an initial factor that triggers a decline in soil function in supporting agricultural production.

Degradation of Soil Chemical Properties

In addition to physical properties, a comparison of the literature also shows that degradation of soil chemical properties is a major limiting factor in the medium to long term. Palm et al. (2014) and Utomo et al. (2018) consistently report that a decrease in soil organic matter content is the most dominant indicator of chemical degradation in intensive agricultural systems. The decline in organic matter has a direct impact on the decrease in cation exchange capacity, nutrient availability, and soil aggregate stability.

Rahman et al. (2020) found that unbalanced fertilization practices and intensification of agriculture in the tropics accelerate nutrient imbalances and soil pH changes, which ultimately decreases crop productivity. Doran and Zeiss (2015) emphasized that the degradation of soil chemical properties has direct implications for the decline of soil health, which is an important indicator of the sustainability of agricultural systems. These results show that the degradation of soil chemical properties not only decreases crop yields, but also increases dependence on external inputs such as chemical fertilizers.

Implications of Soil Degradation on Agricultural Production Resilience

A synthesis of ten literature shows that the degradation of physical and chemical properties of soils is interrelated and simultaneously affects the resilience of agricultural production. Lal (2015) emphasized that land degradation is one of the main threats to global food security because it reduces land production capacity in a sustainable manner. FAO (2017)

also reported that agricultural land with high levels of degradation tends to have fluctuating crop yields and is vulnerable to climate change.

Nunes et al. (2021) show that good soil quality is positively correlated with crop yield stability, while soil degradation increases the risk of production decline in the long term. Bünemann et al. (2018) emphasized that soil trait indicators can be used as an early evaluation tool to detect the threat of soil degradation to agricultural production systems. These findings reinforce that soil degradation not only impacts a decline in yields, but also weakens the resilience of agricultural systems in the face of environmental and climate pressures.

Synthesis and Implications of Soil Management

Based on the comparison of the ten articles studied, it can be concluded that soil degradation from the perspective of soil physical and chemical properties is the main challenge in maintaining the resilience of agricultural production. Keesstra et al. (2016) and FAO (2017) emphasized the importance of implementing sustainable land management, such as soil and water conservation, increasing organic matter, and balanced input management, as an effort to mitigate soil degradation. By integrating findings from various literatures, this study confirms that a soil quality-based approach can be a strong conceptual basis in formulating agricultural land management strategies oriented towards the sustainability and resilience of agricultural production.

Practical Implications for Agricultural Management

The results of a synthesis of ten literature shows that soil degradation from the perspective of soil physical and chemical properties has significant practical implications for agricultural management. Degradation of soil physical properties such as compaction and erosion requires the implementation of soil management practices that are able to maintain soil structure and porosity, including through conservation soil tillage, reduction of heavy equipment use, and the implementation of a cover crop system (Keesstra et al., 2016; FAO, 2017).

In addition, the degradation of soil chemical properties characterized by a decrease in organic matter and nutrient imbalances indicates the importance of balanced and sustainable nutrient management. Increasing the input of organic matter through the use of organic fertilizers, crop residues, and crop rotation is a practical strategy to improve soil fertility and improve the stability of agricultural production (Palm et al., 2014; Utomo et al., 2018). Overall, the practical implications of this study confirm that periodic monitoring of soil physical and chemical properties can be used as a basis for decision-making in agricultural land management. A soil quality-based approach is expected to increase the resilience of agricultural production while supporting the long-term sustainability of agricultural systems (Bünemann et al., 2018; Nunes et al., 2021).

CONCLUSION

A literature review of ten scientific articles concludes that soil degradation significantly undermines agricultural production resilience, primarily through interrelated declines in physical properties (e.g., compaction, structural damage, and erosion, which reduce water availability and plant growing space) and chemical properties (e.g., lowered

organic matter, nutrient imbalances, and pH shifts, which impair soil fertility and yield stability), collectively weakening soil functions in intensive and marginal systems. This positions soil degradation as a strategic challenge, underscoring the need for soil quality-based approaches. For future research, studies should prioritize empirical validation alongside literature reviews, testing sustainable practices like organic matter enhancement and soil conservation across diverse regional scales to bolster production resilience.

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