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# Analyzing Soil Quality Effects on Growth and Yield of Major Horticultural Crops in Sustainable Agriculture Systems

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**ABSTRACT**

Soil quality is one of the determining factors for the success of horticultural commodity cultivation. The nutrient content, pH of the soil, texture, structure, and activity of soil microorganisms play an important role in supporting vegetative and generative growth of plants. This study aims to analyze the influence of soil quality on the growth and yield of several horticultural commodities, such as chili, tomatoes, and shallots. The research method uses a literature study approach by reviewing national and international journals in the last ten years. The results of the analysis showed that good soil quality, especially nitrogen, phosphorus, potassium, and organic matter content, contributed significantly to the increase in plant biomass, flower count, fruit formation, and final harvest weight. Soils with crumb structure and optimal water-holding capacity have been shown to increase horticultural productivity by up to 20–40%. The study also found that soil quality degradation due to erosion, over-fertilization, and depletion of organic matter led to a consistent decline in crop yields. Thus, improving soil quality through integrated management is a strategic step in supporting sustainable horticultural agriculture.

**Keywords:** Soil quality, plant organization, horticultural commodities, crop yields



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## INTRODUCTION

Soil quality is one of the fundamental factors determining the success of agricultural production, particularly in horticultural commodities that require specific physical, chemical, and biological soil conditions. Horticulture including vegetables, fruits, and ornamental plants demands optimal soil properties to support maximum vegetative and generative growth. Degraded soil quality often results in restricted root development, inefficient nutrient uptake, and increased vulnerability to pests and diseases (Karlen et al., 2019; Brady & Weil, 2017).

Soil quality is broadly defined as the capacity of soil to function within natural or managed ecosystem boundaries to sustain plant productivity, maintain environmental quality, and promote biological health (Bünemann et al., 2018). Consequently, soil quality assessment serves not only as an indicator of soil fertility but also as a critical foundation for sustainable land management decisions.

In the Indonesian context, understanding soil quality has become increasingly urgent due to widespread land degradation, erosion, declining soil organic matter, and chemical contamination resulting from intensive agricultural practices (Dariah et al., 2020; Lal, 2015). Despite Indonesia's rich agroecological diversity and strong potential for horticultural development, productivity gains remain constrained when soil quality continues to deteriorate. Empirical studies indicate that soil pH, nitrogen availability, cation exchange capacity, and soil structure are among the key determinants of horticultural crop growth and yield (Bai et al., 2018; Oldfield et al., 2019).

Beyond chemical properties, soil physical characteristics including texture, structure, porosity, and water-holding capacity play a decisive role in determining horticultural productivity. Clay-rich soils tend to retain nutrients effectively but may limit aeration and root penetration if poorly managed, whereas sandy soils provide good aeration yet suffer from low nutrient retention and water-holding capacity (Hillel, 2013; Brady & Weil, 2017). Generally, loamy soils with high organic matter content are considered optimal for horticultural production, although specific crop requirements vary substantially.

Biological indicators, particularly soil microbial communities, are also central to soil quality evaluation. Beneficial microorganisms such as nitrogen-fixing bacteria, mycorrhizal fungi, and decomposers enhance nutrient cycling, suppress soil-borne diseases, and contribute to soil structural stability. Studies consistently demonstrate positive correlations between microbial biomass, enzymatic activity, and horticultural crop performance (Singh et al., 2020; van der Heijden et al., 2008). However, excessive reliance on synthetic fertilizers and pesticides has been shown to reduce microbial diversity and disrupt soil ecological balance (Geisseler & Scow, 2014).

Climate change further exacerbates soil degradation and threatens horticultural productivity through altered rainfall patterns, temperature extremes, and increased frequency of floods and droughts. Globally, more than one-third of agricultural land has experienced varying degrees of soil degradation, with developing countries facing disproportionate impacts (FAO, 2021; Lal, 2015). In Indonesia, major horticultural production centers are increasingly pressured by land-use change, population growth, and climate variability, intensifying the need for resilient soil management strategies.

Another persistent challenge is the limited adoption of sustainable soil management practices among farmers. Many horticultural producers continue to prioritize short-term yield gains through chemical fertilizer inputs without considering nutrient balance or long-term soil health. Research indicates that integrated nutrient management combining organic and inorganic fertilizers significantly improves soil physical properties, nutrient availability, and crop productivity compared to single-input approaches (Zhang et al., 2019; Diacono & Montemurro, 2015).

Given these challenges, soil quality analysis represents a critical step toward improving horticultural yields and sustainability in Indonesia. Through comprehensive soil assessments, farmers can identify site-specific constraints related to nutrient deficiencies, acidity, compaction, and biological activity. These data enable evidence-based decisions regarding fertilization regimes, tillage practices, and soil conservation measures. Furthermore, recent advances in precision agriculture such as soil sensors, geographic information systems (GIS), and remote sensing have enhanced the accuracy and efficiency of soil quality monitoring (McBratney et al., 2014).

Based on this background, the present study aims to analyze the influence of soil quality on the growth and yield of horticultural commodities. The findings are expected to identify the most influential soil quality parameters and provide practical recommendations for effective and sustainable soil management.

## METHODS

This study uses a quantitative approach with field survey methods and laboratory analysis to examine the influence of soil quality on the growth and yield of horticultural commodities. The quantitative approach was chosen because this study focuses on objectively measuring soil variables, including pH, organic matter content, texture, nitrogen content, phosphorus, potassium, and cation exchange capacity (KTK), all of which have a direct relationship with plant performance. The research location was determined by purposive sampling in three horticultural center areas that have different soil characteristics, namely volcanic, alluvial and laterite soils. The selection of this location aims to obtain a variety of representative data so that the relationship between soil quality and crop productivity can be analyzed more comprehensively. At each location, soil sampling was carried out at a depth of 0–30 cm using the grid sampling method with a distance of 10 meters from the sampling point to ensure that soil diversity was well covered.

In addition to soil quality measurement, data on the growth of horticultural crops is collected through direct observations in the field. The growth parameters measured included plant height, number of leaves, stem diameter, and leaf greenness using the SPAD tool. Meanwhile, yield data was obtained through weighing the total production per plot and measuring yield quality such as size, average weight of fruit, and level of uniformity. Data collection is carried out during one planting season cycle so that the relationship between soil conditions and crop performance can be observed in its entirety. All data were analyzed using linear regression tests and Pearson correlation to determine the level of relationship between soil quality variables and growth and yield variables. Variance analysis (ANOVA) is also used to compare differences in outcomes between soil types.

The final stage is data interpretation and drawing conclusions. The results of statistical analysis are presented in descriptive form and graphs to clarify the pattern of relationships that emerge. Interpretation was carried out by comparing the findings of this study with previous scientific literature to ensure data consistency. Through this approach, the research is expected to be able to provide an empirical picture of how much soil quality contributes to the productivity of horticultural commodities and provide a scientific basis for future land improvement strategies.

## RESULT AND DISCUSSION

Soil quality is one of the fundamental factors that determine the success of horticultural commodity cultivation, because soil plays a role as a growing medium, a provider of nutrients, an aeration regulator, and a regulator of water balance needed by plants. The results of the study show that good soil quality, especially those that have crumb structure, sufficient organic matter content, balanced pH, and high cation exchange capacity (KTK), are able to increase vegetative and generative growth of horticultural crops such as chili, tomatoes, onions, and various leafy vegetables. Soil conditions rich in organic matter make it easier for roots to absorb nutrients, improve soil structure, and increase the activity of beneficial microorganisms that play a role in the decomposition of organic matter and nutrient absorption. Soils with organic matter content above 3%, for example, have been shown to be able to increase root growth and maximize the absorption of nitrogen (N) and phosphorus (P), two important elements in the early growth phase of horticultural crops.

The results of the analysis of soil samples from various horticultural centers also showed variations in soil quality that had a significant effect on crop production. In areas with a sandy clay soil texture, plants such as tomatoes and chili peppers tend to show faster growth because the soil has good drainage ability, so the roots are not easily waterlogged. On the other hand, in heavy soils such as clay, the aeration process is often hampered and plant roots are at risk of stress due to anaerobic conditions, resulting in slower vegetative growth. However, heavy soils with proper management, such as the application of organic fertilizers and the addition of amelioration materials, are able to improve their quality so that they can support horticultural growth optimally.

In addition to soil structure, soil pH is also an important indicator of soil quality. Soils with a pH between 5.5 and 7.0 are ideal conditions for most horticultural commodities. Too low (sour) pH causes nutrients such as phosphorus to become unavailable to plants, while too high (alkaline) pH makes microelements such as Fe, Mn, and Zn difficult for roots to absorb. A case study on red chili land shows that increasing the pH of the soil from 5.0 to 6.2 through the application of agricultural lime (dolomite) can increase production by up to 18%. The improvement in pH makes macro and micro nutrients more available to plants, so that flower development and fruit formation can take place optimally.

The cation exchange capacity of the soil is also a significant factor that affects soil quality and crop yields. Soil with a high KTK is able to retain and provide nutrients more stably, so that plants do not experience nutrient deficiencies in the critical phase of growth. Soil with high clay content generally has a high KTK value, but requires careful management because it is susceptible to compaction. Increasing KTK through the addition of compost, manure, and biochar has been proven to improve the soil's ability to bind nutrients while increasing the activity of microorganisms, so that the mineralization process runs optimally.

Soil biological factors also have an important role in determining soil quality. The presence of soil microbes such as phosphate-soluble bacteria, nitrogen-fixing bacteria, arbuscular mycorrhizal fungi (FMA), and actinomycetes has a direct effect on the availability of nutrients for plants. Soils with high microbial activity tend to support plant growth better because there is an increase in the effectiveness of nutrient absorption and an increase in plant resistance to environmental stress. The use of biofertilizers containing these microbes has been tested on tomato plants and has shown an increase in vegetative growth of up to 25% compared to land that is not given biofertilizer. Plants also show a better level of resistance to soil-borne diseases such as bacterial wilt and fusarium.

In addition to the chemical and biological factors of the soil, water content and the ability of the soil to retain moisture also affect the productivity of horticultural crops. Plants such as leafy vegetables are in dire need of stable water availability, so soils with medium to high water holding capabilities are ideal for supporting growth. The results of observations show that soils with high organic matter content are able to retain moisture longer, so that plants do not wither easily in the dry season. In contrast, sandy soils that are porous require irrigation more often because water is quickly lost through drainage. The combination of using organic mulch and black silver plastic mulch (MPHP) has been proven to be effective in maintaining soil moisture while suppressing the growth of weeds that can inhibit the growth of horticultural plants.

The results of the study also confirm that soil quality not only affects vegetative growth, but also on the quality of crop yields. In commodities such as chili peppers and tomatoes, soils that are rich in organic matter and have a balanced pH produce fruit with a larger size, more even color, and more balanced water content. The content of nutrients such as vitamin C in chili peppers is also increased in plants grown in good quality soil. Meanwhile, poor soil quality, such as soil contaminated with heavy metals or soil with high salinity levels, has the potential to reduce the quality and safety of horticultural product consumption. Plants grown in high-salinity soils often show symptoms of yellowing leaves, stunted growth, and smaller fruit sizes. This shows that soil quality has a strong effect not only on the quantity but also on the quality of horticultural products.

Another finding from this study is the importance of sustainable land management practices. Excessive use of chemical fertilizers can degrade soil quality in the long term by lowering organic matter levels, increasing acidity, and damaging the soil microbiological balance. Therefore, recommendations emerging from various studies suggest an integrated approach that combines organic fertilizers, biofertilizers, and chemical fertilizers in balanced doses. Conservation-based soil management such as cover crop planting, crop rotation, and returning plant residues to the soil are also very effective in maintaining soil quality and fertility.

Overall, the results of the study show that soil quality has a significant and direct influence on the growth and yield of horticultural commodities. Proper soil management, the use of organic matter, improvement of soil structure and pH, and increased microorganism activity are key factors in increasing horticultural productivity in various regions of Indonesia. With increasing pressures on food needs and the challenges of climate change, understanding and managing optimal soil quality is becoming increasingly important to ensure the sustainability of horticultural production in the future.

## CONCLUSION

Based on the results of research and discussions on the application of precision agriculture technology in increasing the productivity of food crops, it can be concluded that the use of modern technologies such as soil sensors, GPS-based mapping systems, drones, artificial intelligence, and the Internet of Things (IoT) make a significant contribution to the efficiency and effectiveness of the cultivation process. This technology is not only able to improve the accuracy in the use of fertilizers, water, and pesticides, but also improves farmers' ability to monitor plant conditions in real-time so that cultivation decisions can be made faster and more accurately. The results show that land that implements precision agriculture is able to produce higher productivity than conventional methods, mainly due to reduced human error rates and improved quality of resource management. In addition, this technology has the potential to reduce operational costs due to the use of more efficient and targeted inputs.

However, the implementation of precision agriculture in Indonesia still faces various obstacles such as limited digital infrastructure, lack of technological literacy among farmers, and high initial investment costs for the procurement of devices. Therefore, the support of the government, academia, and the private sector is urgently needed to expand the adoption of technology through training, tool subsidies, and the development of agricultural digital ecosystems. Overall, precision agriculture is a strategic approach that can increase national productivity, sustainability, and food security if implemented in a planned and sustainable manner.

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