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Impact of Long-Term Continuous Cropping on Soil Nutrient Depletion

Ni Luh Kartini[1], Moh Saifulloh[2], Ni Made Trigunasih[1*], Ni Made Suci Sukmawati[3], I Made Mega[1]

[1] Soil Sciences and Environment, Faculty of Agriculture Udayana University, Pb Sudirman Street, Denpasar, Indonesia

[2] Spatial Data Infrastructure Development Center (PPIDS) Udayana University, Pb Sudirman Street, Denpasar, Indonesia

[3] Faculty of Animals Husbandry, Udayana University, Pb Sudirman Street, Denpasar, Indonesia

* Corresponding author's e-mail: trigunasih@unud.ac.id

ABSTRACT

Long-term continuous cropping exacerbates nutrient loss and deteriorates soil quality. To achieve high yields and economic gains, continuous farming is often practiced, disregarding soil carrying capacity and degradation. This practice has been prevalent in the regions that serve as horticultural centers, supplying vegetables to various areas. This study aimed to elucidate the specific impacts of continuous cropping on soil chemical properties, providing new scientific insights into nutrient depletion in highland horticultural regions. By analyzing soil samples from agricultural lands with a history of prolonged continuous cultivation in Bali Province, this research sought to identify the previously unreported patterns of soil chemical property decline. Laboratory analyses quantified essential soil chemical properties based on established soil quality indices. The results revealed significant reductions in key nutrients, with nitrogen levels ranging from 0.10% to 0.38% and phosphorus levels from 1.84 ppm to 5.31 ppm. Additionally, soil properties such as cation exchange capacity (CEC) (20.68–22.23 me $100g^{-1}$), base saturation (38.71–47.62%), and organic carbon (1.56–2.96%) exhibited moderate limitations. These findings underscore the susceptibility of soil chemical properties to continuous cropping systems and their adverse effects on agricultural productivity. A limitation of this study is the focus on soil samples from a single season, without accounting for climatic variability, suggesting a need for future time-series analyses. This research uniquely demonstrated the significant nutrient depletion associated with prolonged continuous cultivation. To mitigate these effects, the authors advocate for crop rotation, incorporation of crop residues into the soil, and the use of organic fertilizers to preserve soil health, sustain long-term agricultural productivity, and maintain environmental balance.

Keywords: crop rotation, horticulture, soil chemical, monoculture, soil fertility, soil quality, soil degradation, Bali Province.

INTRODUCTION

The sustainability of global agriculture is increasingly under threat due to the degradation of essential soil nutrients. Nitrogen (N) and potassium (K) are critical for plant growth and productivity, yet they are highly susceptible to depletion under conventional intensive agricultural systems. These systems, often characterized by continuous monoculture and the absence of crop rotation or soil resting periods, exacerbate nutrient loss and lead to a decline in soil quality. The consequences of such practices are far-reaching, impacting not only agricultural productivity, but also the broader environmental balance.

Bali, renowned as a popular tourist destination among international visitors (Chin et al., 2017), faces a unique challenge in this context. The demand for vegetables, fruits, and horticultural commodities in tourist facilities, such as hotels, restaurants, and supermarkets continues to rise with the increasing number of both international and domestic tourists (Batt and Parining, 2000). The primary sources of horticultural commodities on the island are located in highland areas, such as Kintamani Sub-district, Petang Sub-district, particularly Plaga Village, and Baturiti Sub-district (Utama, 2021; Budiasa and Ambarawati, 2014). These regions, situated along highland terrains formed by volcanic processes at elevations ranging from 500 to 2500 meters above sea level, benefit from high rainfall that supports the growth of horticultural crops (Trigunasih and Saifulloh, 2022).

However, the agricultural practices in these regions are predominantly monoculture and continuous cultivation. This system is implemented to meet the supply demands of the tourism industry as well as general public consumption. While economically advantageous, such practices can disrupt environmental balance and soil health. Repetitive cultivation of the same crops depletes the soil of vital nutrients faster than they can be naturally replenished, resulting in soils that are less fertile and more prone to erosion, ultimately threatening the long-term viability of agricultural lands. Research from diverse agricultural regions around the world has consistently shown that nitrogen and potassium are among the most affected nutrients in intensively farmed soils. For instance, studies in both temperate and tropical regions have documented significant declines in these nutrients, leading to reduced crop yields and increased reliance on chemical fertilizers. Such reliance not only poses economic challenges for farmers but also contributes to environmental problems, such as water pollution and greenhouse gas emissions.

Monoculture farming and continuous agricultural activities can negatively impact the chemical properties of soil. One significant effect is the degradation of soil CEC. Research by Loke et al. (2014) indicates that intensive farming can reduce CEC, subsequently lowering soil fertility and crop productivity. Additionally, soil base saturation can be affected, indicating soil quality degradation. The soils subjected to continuous cultivation without crop rotation or the addition of organic matter experience a decline in base saturation, leading to decreased availability of essential nutrients, such as calcium, magnesium, and potassium (Alemayehu et al., 2020). Excessive use of nitrogen fertilizers can lower soil pH, making the soil more acidic. Highly acidic soils can hinder plant growth and reduce the availability of certain nutrients (Daba et al., 2021). Continuous farming practices without the addition of organic matter can reduce soil organic carbon content, ultimately impacting soil fertility and crop productivity. Besides organic carbon, macronutrients like nitrogen (N), phosphorus (P), and potassium (K) are also of concern (Page et al., 2020; Y. Wang et al., 2021). Continuous farming can lead to a decline in the levels of these nutrients in the soil. The agricultural land cultivated intensively without crop rotation or the addition of organic fertilizers experiences a decrease in the N, P, and K levels. The reduction in these nutrient levels can lower crop productivity and disrupt soil ecosystem balance (Pervaiz et al., 2020).

Soil degradation due to intensive agricultural activities impacts not only crop productivity but also environmental stability. Soil erosion is a major issue in the areas with intensive cultivation (Wuepper et al., 2020). Erosion can strip away the topsoil rich in organic matter and nutrients, thereby reducing the ability of soil to support plant growth and leading to the loss of essential nutrients, worsening soil conditions (Alewell et al., 2020; Demir et al., 2023). Moreover, unsustainable agricultural practices can accelerate soil degradation processes and cause irreversible damage (Kartini et al., 2023).

Previous researchers have reported that soil chemical properties are easily degraded due to anthropogenic influences (Bhayunagiri and Saifulloh, 2022) and are particularly prone to leaching, especially on steep topography (Trigunasih et al., 2023). A study evaluating agricultural soil quality in Indonesia by Mujiyo et al. (2021) found that all samples indicated low soil quality levels due to the low availability of soil nutrients, particularly phosphorus. However, a subsequent study reported differing results, showing soil quality levels ranging from high to very high (Sumarniasih et al., 2022).

Generally, earlier researchers analyzed complex parameters using a minimum dataset of ten indicators, which often resulted in anomalies in the physical, chemical, and biological properties of the soil. The latest studies, however, indicated that soil chemical factors play a significant role in soil quality assessment, focusing on such indicators as pH, calcium, carbon, and sodium (Mulyono et al., 2019). Overall, their findings have not thoroughly addressed nutrient depletion or examined it comprehensively. Therefore, the conducted research delves deeper into soil chemical properties, as they encompass essential nutrients required by plants in large quantities. The authors chose to conduct a case study in the highland horticultural centers of Bali Province, where long-term continuous cropping systems have been practiced. The hypothesis is that in these areas, nutrient levels are significantly depleted due to frequent soil tillage and planting without allowing fallow periods.

Considering that previous research focused solely on soil quality indices in lowland agricultural areas, this study concentrated on continuous farming practices in highland regions. This focus represents the novelty of this research and bridges the gap left by prior studies that only examined lowland agricultural lands with relatively similar but less extreme farming activities compared to the studied case. This study aimed to investigate the chemical properties of soil under continuous farming practices in the highland horticultural centers of Bali. By analyzing the soil samples from these key areas, the authors aimed to quantify nutrient loss and identify the most effective strategies for sustainable soil management.

DATA AND METHODS

Study area overview

The Baturiti Sub-district is predominantly characterized by dry agricultural land, situated at elevations ranging from 300 to 2000 meters above sea level (Figure 1). The region features undulating to very steep slopes and experiences relatively high annual rainfall (Trigunasih and Saifulloh, 2022). The horticultural products cultivated here include various vegetables and fruits. On the basis of agricultural census data in 2019, the seasonal horticultural production in Baturiti surpassed 50.000 tons, comprising crops, such as cabbage, and tomatoes. The harvested areas were 183 hectares for cabbage, 443 ha for Chinese cabbage, 224 hectares for tomatoes, and 222 ha for chili peppers. Among these, tomatoes had the highest productivity at 154.353 tons ha^{-1}, followed by cabbage at 264 tons ha^{-1}, Chinese cabbage at 96.618 tons ha^{-1}, and chili peppers at 21.489 tons ha^{-1}.

Perennial horticultural crops in this region include durian and banana plants. Durian had the highest productivity, yielding an average of 0.19 tons yr^{-1}, whereas banana plants produced over 14.2 tons ha^{-1}. However, in 2020, the seasonal horticultural production decreased to 30.000 tons. The harvested areas for cabbage were reduced to 126 ha, Chinese cabbage to 409 ha, tomatoes to 149 ha, and chili peppers to 220 ha. Chinese cabbage had the highest productivity in 2020 at 61,889 tons ha^{-1}, followed by cabbage at 333.33

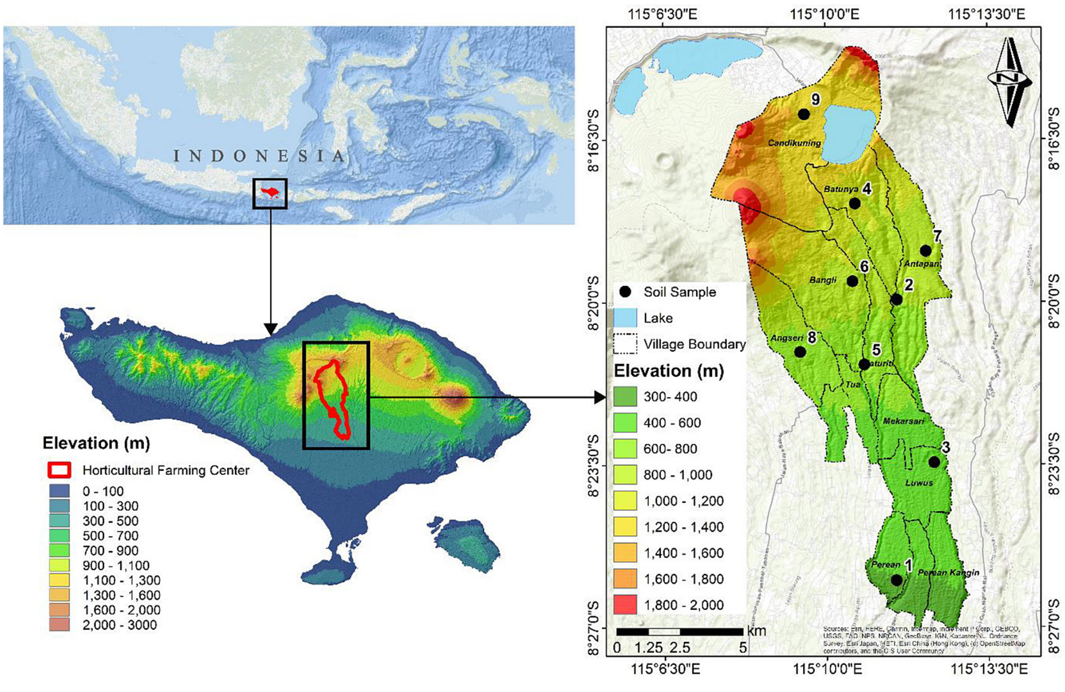

Figure 1. The research site is in Bali Province, Indonesia, within a tropical region. The study area is situated in the highlands, with soil samples collected from highland horticultural agricultural land. The geographic coordinates are 8°17'12.29"S - 8°26'11.87"S and 115°9'53.98"E - 115°11'23.61"E

tons/ha, tomatoes at 31.617 tons ha^{-1}, and chili peppers at 8.122 tons ha^{-1}. The research area is a major commodity production center in Bali Province, where farmers on small plots of land practice continuous cropping systems with synthetic fertilizer inputs, often disregarding proper dosage, over an extended period. Although this practice can boost production in the short term, it leads to the deterioration of soil chemical properties and nutrient depletion in the long term. The land management practices that prioritize economic gain without considering environmental sustainability result in the exploitation of agricultural land. Long-term observations of horticultural agriculture were conducted, primarily in samples II, IV, V, VI, VII, VIII, and IX, which involved continuous cultivation practices. In contrast, samples I and III, located in the lower lands, exhibited different agricultural management patterns, including a crop rotation system.

Soil sampling

Soil samples for this study were collected from a depth of 0–30 cm to assess the chemical properties of the soil in intensive horticultural farming areas. This depth was chosen because nutrients are typically concentrated within this range, as supported by previous research (Mulyono et al., 2019; Romadhon et al., 2024). Soil sampling was conducted in October 2022, taking into account elevation differences and focusing on continuous cropping systems. Intensive agricultural land with an area of more than one hectare found in the field was selected. Subsequently, five points within that area were randomly selected and combined into a composite sample. In this study, there was no control soil sample; instead, differentiation was based on elevation levels. Generally, at relatively low elevations, agricultural practices are better managed with proper cropping patterns, whereas at higher elevations, land management is less structured with excessive use of chemical fertilizers to achieve high yields. Composite soil samples were taken from various points within the fields to ensure representativeness and to avoid nutrient accumulation or deviation at specific points. Additionally, differences in land elevation were considered during sampling due to their close relationship with nutrient availability and leaching processes caused by runoff and other natural phenomena (Figure 1). The collected samples were then transported to the laboratory for chemical analysis.

Laboratory soil testing

The laboratory analysis involved seven key soil chemical properties. Organic carbon content (C-organic) was determined using the (Walkley and Black, 1934) method, and soil pH was measured using the H_2O 1:2.5 method. CEC and base saturation were extracted using NH_4OAc 1 N pH 7. Phosphorus (P) and potassium (K) were extracted with the Bray-1 method (Eik and Hanway, 1986), and nitrogen (N) was analyzed using the Kjeldahl method proposed by Bremner (1960). A brief summary of soil test methods in the laboratory can be seen in Table 1.

Mapping soil chemical properties

Mapping of soil chemical properties in this research used the Kriging method in the Geographic Information System (GIS) application. Kriging is a geostatistical interpolation method in ArcGIS used to predict spatially continuous soil chemical properties from discrete sample points. This method not only estimates unknown values but also provides a measure of the prediction uncertainty. The process begins with variogram modeling, which analyzes the spatial structure of the data by quantifying the spatial correlation among sample points. This variogram model is

Table 1. Methods for analyzing soil samples in the laboratory

ParameterS	Unit	Method
Organic carbon	%	Walkley and Black
pH		H_2O 1: 2.5
Cation exchange capacity	me/100 gr	Extraction NH_4OAc 1 N pH7
Base saturation	%	Extraction NH_4OAc 1 N pH7
Available phosphorus (P), available potassium (K)	ppm	Bray-1
Total nitrogen (N)	%	Kjeldahl

critical, as it influences the weights assigned to sample points during interpolation. Using this model, Kriging assigns weights to each sample point, giving more influence to those closer to the prediction location. ArcGIS offers various Kriging methods, such as Ordinary Kriging, which assumes a constant but unknown mean across the study area, and Universal Kriging, which accounts for data trends. The result is a continuous surface map representing the spatial distribution of soil chemical properties, enabling researchers to identify patterns and make informed soil management decisions. Kriging is preferred in soil science due to its ability to produce accurate and reliable interpolations, essential for understanding and managing soil variability effectively.

Determination of soil chemical limiting factors

The determination of limiting factors for soil chemical properties was based on the relative weights proposed by Lal (1993) and refined by (Larson and Pierce, 1994). Larson and Pierce (1994) presented an approach to measure the inherent and dynamic dimensions of soil quality using minimum data sets and pedotransfer functions, combined with statistical quality control procedures and models. Additionally, they explored designing a sustainable land management system integrated with process quality control procedures to ensure the system's quality performance. For example, organic carbon content between 5–10% is considered to have no limiting factors, while values below 0.5% are categorized as extremely limiting. Soil pH in the range of 6–7 is considered non-limiting, whereas a pH below 5 is deemed extreme. A CEC value greater than 40 me 100 g^{-1} is considered non-limiting, while values below 5 me 100 g^{-1} are categorized as extreme. Base saturation with values above 70% is considered non-limiting, while values below 20% are categorized as extreme. Other indicators, such as N, P, and K, are similarly categorized, as summarized in Table 2.

Testing soil chemical properties is crucial in managing soil fertility and quality, particularly in intensive horticultural lands. Organic carbon plays a critical role in improving soil structure, increasing water-holding capacity, and providing essential nutrients. Soil pH affects nutrient availability and the activity of microorganisms essential for plant growth. Cation exchange capacity and base saturation reflect the ability of soil to retain essential nutrient cations, such as calcium, magnesium, and potassium. Soil phosphorus and potassium levels are direct indicators of the availability of essential nutrients for plant growth.

RESULTS

Soil chemical properties

This study observed seven soil chemical properties: pH, organic carbon (C-organic), cation-exchange capacity (CEC), base saturation (BS), total nitrogen (N-total), available phosphorus (P-available), and available potassium (K-available) are presented in Table 3.

The analysis showed that the CEC values at the study locations ranged from moderate to high. The CEC values for Samples I to IX were 31.09, 27.83, 20.68, 28.88, 28.82, 27.88, 22.23, 27.12, and 14.98 me 100g^{-1}, respectively (Table 3). These differences in CEC values were attributed to variations in clay and organic matter content at each location. The soils with high CEC are

Table 2. Limiting factors and relative weighting of soil quality indicators

Limiting factors and relative weighting						
No.	Indicator	Without (1)	Light (2)	Moderate (3)	Heavy (4)	Extreme (5)
1	Organic carbon (%)	5–10	3–5	1–3	0.5–1	< 0.5
2	pH	6.0–7.0	5.8–6.0	5.4–5.8	5.0–5.4	< 5.0
3	Cation exchange capacity (me 100 g^{-1})	> 40	25–40	17–24	5–16	< 5
4	Base saturation (%)	> 70	51–70	36–50	20–30	< 20
5	Nutrients N, P, and K					
6	Total nitrogen (%)	> 0.51	0.51–0.75	0.21–0.50	0.10–0.2	< 0.10
7	Available phosphorus (ppm)	> 35	26–35	16–25	10–15	< 10
8	Available potassium (ppm)	> 1.0	0.6–1.0	0.3–0.5	0.10–0.2	< 0.1

better at absorbing and providing nutrients compared to soils with low CEC. High organic matter or clay content increases CEC, thus reducing nutrient leaching (Tahir and Marschner, 2017). Base saturation (BS) values for Samples I to IX were 38.71%, 58.01%, 53.06%, 69.17%, 82.44%, 65.12%, 87.62%, 47.62%, and 38.71%, respectively (Table 3). These varying BS values indicate differences in the availability of base cations at each location. Samples I, VII, and IX had lower BS values, possibly due to base loss from leaching during the rainy season. Samples II, III, IV, and VI had high BS values, while Samples V and VII had very high BS values, indicating sufficient base cation availability for plant needs (Chaganti et al., 2021).

The soil pH values for Samples I to IX were 6.72, 6.90, 6.74, 6.79, 6.75, 6.77, 6.86, 6.54, and 7.05, respectively (Table 3). All pH values were neutral, optimal for nutrient absorption by plants. Neutral soil pH (6–7) facilitates nutrient dissolution in water and reduces the presence of toxic elements for plants (Penn and Camberato, 2019). C-organic values for Samples I to IX were 1.56%, 3.72%, 2.07%, 2.54%, 2.14%, 3.37%, 1.65%, 3.36%, and 2.96%, respectively (Table 3). Samples II, VI, and VIII had high C-organic content, possibly due to the addition of organic fertilizers, such as manure. The soils with high organic matter content can improve physical, chemical, and biological soil properties, increase CEC, and provide optimal conditions for plant growth (Ozores-Hampton et al., 2011).

The N-total values for Samples I to IX were 0.14%, 0.38%, 0.14%, 0.16%, 0.16%, 0.32%, 0.10%, 0.28%, and 0.22%, respectively (Table 3). Moderate N-total values were found in Samples II, VI, VIII, and IX, while low N-total values were found in Samples I, III, IV, V, and VII. These variations were due to differences in soil management patterns and farmers' practices of returning crop residues to the land (X. Wang et al., 2020). The P-available values for Samples I to IX were 169.93 ppm, 105.25 ppm, 17.17 ppm, 37.97 ppm, 5.31 ppm, 14.96 ppm, 303.30 ppm, 1.84 ppm, and 323.96 ppm, respectively. Samples V and VIII had very low P-available values, while Sample VI had low P-available values. Samples I, II, IV, VII, and IX had very high P-available values, attributed to the use of NPK Phonska fertilizer and intensive land management (Finalis et al., 2021). The K-available values for Samples I to IX were 202.62 ppm, 198.62 ppm, 121.36 ppm, 150.89 ppm, 104.48 ppm, 117.78 ppm, 252.95 ppm, 91.48 ppm, and 251.62 ppm, respectively (Table 3). The available K content in all locations was very high, indicating the high ability of soil to retain potassium and reduce leaching (Alfaro et al., 2004).

Soil chemical limiting factors

The weighting results showed that intensive agricultural land in each sample had limiting factors ranging from light to extreme, as shown in Figure 2. The cation exchange capacity indicator had light to moderate limiting factors. Samples I, II, IV, V, VI, VIII, and IX had light limiting factors with a relative weight of two, while Samples III and VII had moderate limiting factors with a relative weight of three. The high CEC values at the study locations were due to high clay content, which increases CEC because nutrients in clay soils are harder to leach. Finer soil textures have more clay and organic colloids, thus increasing CEC (Khaledian et al., 2017).

Table 3. Summary of soil chemical property analysis and limiting factor results

Sample	CEC (me $100g^{-1}$)	BS (%)	pH	C-Organic (%)	Nutrients		
					N-Total (%)	P-available (ppm)	K- available (ppm)
I	$31.09_{(2)}$	$38.71_{(3)}$	$6.72_{(1)}$	$1.56_{(3)}$	$0.14_{(4)}$	$169.93_{(1)}$	$202.69_{(1)}$
II	$27.83_{(2)}$	$58.01_{(2)}$	$6.90_{(1)}$	$3.72_{(2)}$	$0.38_{(3)}$	$105.25_{(1)}$	$198.62_{(1)}$
III	$20.68_{(3)}$	$53.06_{(2)}$	$6.74_{(1)}$	$2.07_{(3)}$	$0.14_{(4)}$	$17.17_{(3)}$	$121.36_{(1)}$
IV	$28.88_{(2)}$	$69.17_{(2)}$	$6.79_{(1)}$	$2.54_{(3)}$	$0.16_{(4)}$	$37.97_{(1)}$	$150.89_{(1)}$
V	$28.82_{(2)}$	$82.44_{(1)}$	$6.75_{(1)}$	$2.14_{(3)}$	$0.16_{(4)}$	$5.31_{(5)}$	$104.48_{(1)}$
VI	$27.88_{(2)}$	$65.12_{(2)}$	$6.77_{(1)}$	$3.37_{(2)}$	$0.32_{(3)}$	$14.96_{(4)}$	$117.78_{(1)}$
VII	$22.23_{(3)}$	$87.62_{(1)}$	$6.86_{(1)}$	$1.65_{(3)}$	$0.10_{(4)}$	$303.30_{(1)}$	$252.95_{(1)}$
VIII	$27.12_{(2)}$	$47.62_{(3)}$	$6.54_{(1)}$	$3.36_{(2)}$	$0.28_{(3)}$	$1.84_{(5)}$	$91.48_{(1)}$
IX	$29.78_{(2)}$	$38.71_{(3)}$	$7.05_{(1)}$	$2.96_{(3)}$	$0.22_{(3)}$	$323.96_{(1)}$	$251.62_{(1)}$

Note: limiting factors (1) none, (2) light, (3) moderate, (4) heavy, (5) extreme.

On the basis of the spatial distribution patterns, each chemical property of soil exhibits distinct variations. Low values of soil chemical properties are indicated by red, while high values are shown in blue (Figure 3). The largest horticultural farming centers are primarily located in the central part of the study area, extending towards the upstream highlands around Lake Beratan. The spatial patterns indicate that the three nutrients in the study area tend to be lower in the central horticultural centers, which utilize a continuous monoculture system. Additionally, other chemical properties, such as base saturation and cation exchange capacity, were found to be relatively low, with values of 43.44 and 25.72, respectively.

The BS of the soil showed variations from moderate to light limiting factors to no limiting factors. Samples I, VIII, and IX had moderate limiting factors with a relative weight of three. Samples II, III, IV, and VI had light limiting factors with a relative weight of two. Samples V and VII had no limiting factors with a relative weight of one. The high BS values at the study locations were due to high base content in neutral pH soils. Soil pH analysis showed that the soil at the study locations in each sample had no limiting factors with a relative weight of one. The soil pH was neutral, which is important for nutrient absorption by plants (Huang et al., 2017). The C-organic weighting showed that the soil at the study locations had moderate to light limiting factors. Samples I, III, IV, V, VII, and IX had moderate limiting factors with a relative weight of three. Samples II, VI, and VIII had light limiting factors with a relative weight of two. The high C-organic content was influenced by the soil texture, which was dominated by clay fractions, increasing C-organic content because clay holds water and affects air exchange (Hassink, 1994; Spohn and Stendahl, 2024).

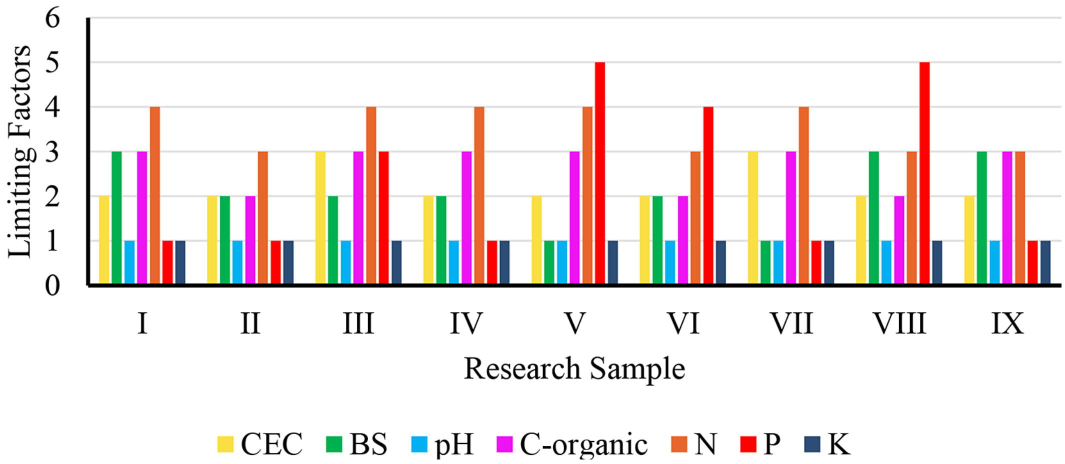

Figure 2. Graph of limiting factors for soil chemical properties; limiting factors (1) none, (2) light, (3) moderate, (4) heavy, (5) extreme

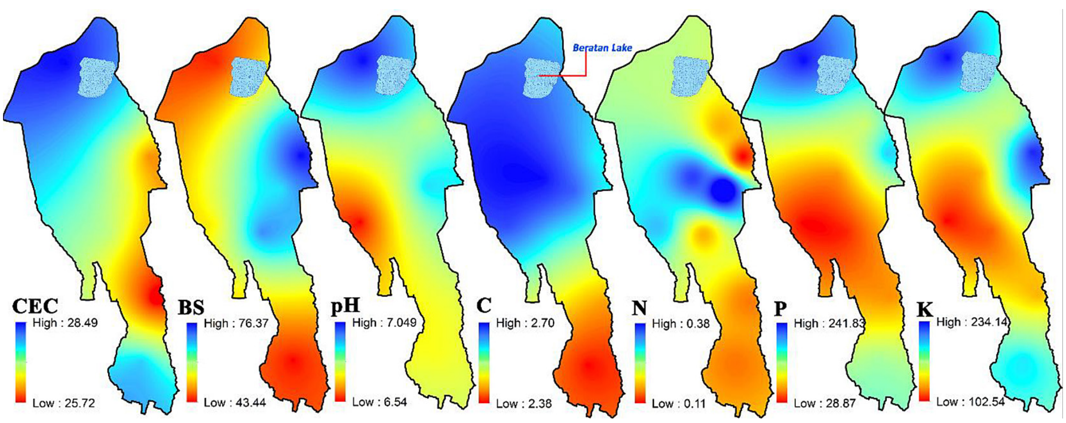

Figure 3. Spatial distribution of soil chemical properties in the study area

The N-total weighting showed heavy and moderate limiting factors. Samples I, III, IV, V, and VII had heavy limiting factors with a relative weight of four. Samples II, VI, VIII, and IX had moderate limiting factors with a relative weight of three. The low N content was due to highly mobile nature of nitrogen and tendency to volatilize, especially in high rainfall areas (Mathers et al., 2007). The P-available weighting showed extreme, heavy, moderate, and no limiting factors. Samples V and VIII had extreme limiting factors with a relative weight of five. Sample VI had a heavy limiting factor with a relative weight of four. Sample III had a moderate limiting factor with a relative weight of three. Samples I, II, IV, VII, and IX had no limiting factors with a relative weight of one. The K-available weighting showed that the soil at the study locations in each sample had no limiting factors with a relative weight of one. The high potassium values were due to the large CEC of the soil, which increases the ability of soil to hold K and reduce leaching (Das et al., 2022).

DISCUSSION

The chemical properties of soil are dynamic aspects crucial in determining soil fertility and supporting plant growth. This study examined the impact of continuous and monoculture horticultural farming on soil chemical properties in highland areas with high rainfall, loose soil texture, and susceptibility to erosion. These conditions make the soil vulnerable to degradation and becoming critical land, especially with long-term intensive farming practices.

Soil organic matter is primarily found on the soil surface and is greatly influenced by climate, land use type, landform, and human activity (Ning et al., 2022). Loss of organic matter significantly impacts crop production. Decomposed organic matter produces humus, which can improve the C-organic content of soil, as well as increase soil pH, cation exchange capacity (CEC), and nutrient uptake. In monoculture farming practices, especially if crop residues are not returned to the soil, organic matter content decreases, resulting in reduced soil fertility (Dămătîrcă et al., 2023). To prevent this decline, crop rotation and returning crop residues as compost are essential practices.

Soil acidity or pH indicates the level of soil acidity or alkalinity, which is crucial in determining nutrient availability and soil microorganism activity. Neutral soil pH (5.5–7) supports the development of microorganisms essential for organic matter decomposition and nutrient cycling (Jiao et al., 2021). In intensive farming systems, changes in pH caused by excessive fertilization or improper irrigation can disrupt microorganism balance and nutrient availability. Therefore, managing soil pH through appropriate crop rotation and organic matter use is necessary to maintain soil fertility.

CEC indicates the total amount of exchangeable cations on the negatively charged soil colloid surface. The higher the CEC, the better the soil's ion exchange and nutrient storage capacity. In intensive farming practices, without proper management of organic matter and soil texture, CEC values can decrease, reducing the ability of soil to absorb and store nutrients (Nguemezi et al., 2020). To address this, adding organic matter, such as compost and manure, should be done regularly. In high rainfall areas, such as the study locations, base saturation (BS) can decrease due to leaching processes, especially in intensive farming systems without proper fertilization management. Therefore, good fertilization management and the use of organic fertilizers can help maintain high BS levels.

Nitrogen is an essential nutrient that easily leaches and volatilizes from the soil. In high rainfall areas, nitrogen tends to leach into groundwater (Nguemezi et al., 2020). The monoculture practices that do not return crop residues can reduce the total nitrogen content in the soil, hindering plant growth and reducing crop yields. Therefore, crop rotation and returning crop residues are crucial practices to maintain nitrogen levels in the soil. Phosphorus is an essential nutrient needed for plant growth, but its availability in the soil is very low. In intensive farming, improper fertilization and poor soil management can lead to decreased phosphorus availability, especially in highly acidic or alkaline soil conditions. To increase phosphorus availability, the use of organic matter and crop rotation is highly recommended. Potassium is an essential nutrient for plant growth and comes from primary minerals in the soil and fertilizers. In farming systems that do not return crop residues or use fertilizers improperly, potassium availability can decrease, causing potassium leaching, especially in the soils with low pH and base saturation (Soumare et al., 2023). Returning crop residues to the soil and using organic fertilizers can help maintain high potassium levels.

Continuous and monoculture horticultural farming practices have serious implications for environmental balance and soil health. In highland areas with high rainfall, loose and easily eroded soils are prone to land degradation. Intensive farming without proper management of organic matter, pH, CEC, BS, and nutrient availability can lead to soil fertility decline, erosion, land degradation, nutrient imbalances, and decreased crop yields. To address these issues, conservation practices, such as crop rotation, organic matter use, proper water management, and returning crop residues to the soil are necessary. Crop rotation can help break pest and disease cycles, improve soil structure, and enhance soil fertility.

The limitations of this study include the small number of soil samples tested and the reliance on single-point observations, which did not account for climatic variability. Previous research indicates that climate change significantly impacts vegetation stress (Susila et al., 2024) and influences carbon stock dynamics (Sudarma et al., 2024) as well as soil erosion (Adnyana et al., 2024). International studies have also shown a strong correlation between soil quality indices and erosion (Mandal et al., 2023) as well as carbon stock levels (Ribeiro et al., 2022).

To address these limitations, future research should adopt a time-series approach to evaluate soil quality, considering the dynamic nature of climatic conditions. This approach would provide a more comprehensive understanding of how continuous cropping and climate variability jointly affect soil properties over time. Moreover, future studies should expand the sample size and include diverse agricultural settings to enhance the generalizability of the findings. It is crucial to investigate the interplay between soil nutrient depletion, erosion, and carbon sequestration in various climatic and topographical conditions.

CONCLUSIONS

This study revealed that long-term continuous cropping significantly degrades soil quality indicators, particularly soil chemical properties, from moderate to extreme levels. Moderate degradation was observed in cation exchange capacity, base saturation, and organic carbon levels. Severe and extreme degradation was found in the soil samples with poor land management, characterized by monoculture and continuous cropping systems. The conducted research identified nutrient depletion, specifically nitrogen and phosphorus, in long-term continuous cropping systems. Soil nitrogen levels were found to be critically low, ranging from 0.10% to 0.16%, and phosphorus levels ranged from 1.84 ppm to 5.31 ppm. In contrast, soils under crop rotation and fallow systems exhibited significantly higher nutrient content. This underscores the importance of adopting sustainable agricultural land management practices to prevent nutrient depletion and maintain soil health. The obtained findings highlight the detrimental effects of continuous monoculture on soil nutrient levels, emphasizing the need for practices such as crop rotation and fallow periods to enhance soil fertility and sustain agricultural productivity. This research contributes to the broader understanding of soil degradation and the critical importance of sustainable land management practices in agriculture.

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REFERENCES

1. Adnyana, I.W.S., As-syakur, A.R., Suyarto, R., Sunarta, I.N., Nuarsa, I.W., Diara, I.W., Saifulloh, M., Wiyanti. 2024. Geospatial technology for climate change: Influence of ENSO and IOD on soil erosion BT – Technological approaches for climate smart agriculture. In P. Kumar & Aishwarya (Eds.), 249–275. Springer International Publishing. https://doi.org/10.1007/978-3-031-52708-1_13
2. Alemayehu, G., Shibabaw, A., Adgo, E., Asch, F., Freyer, B. 2020. Crop rotation and organic matter application restore soil health and productivity of degraded highland crop farms in northwest Ethiopia. Cogent Food and Agriculture, 6(1). https://doi.org/10.1080/23311932.2020.1831124

3. Alewell, C., Ringeval, B., Ballabio, C., Robinson, D.A., Panagos, P., Borrelli, P. 2020. Global phosphorus shortage will be aggravated by soil erosion. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-18326-7
4. Alfaro, M.A., Alfaro, M.A., Jarvis, S.C., Gregory, P.J. 2004. Factors affecting potassium leaching in different soils. Soil Use and Management, 20(2). https://doi.org/10.1079/sum2004249
5. Batt, P.J., Parining, N. 2000. Price-quality relationships in the fresh produce industry in Bali. International Food and Agribusiness Management Review, 3(2). https://doi.org/10.1016/s1096-7508(00)00034-3
6. Bhayunagiri, I.B.P., Saifulloh, M. 2022. Mapping of subak area boundaries and soil fertility for agricultural land conservation. Geographia Technica, 17(2). https://doi.org/10.21163/GT_2022.172.17
7. Bremner, J.M. 1960. Determination of nitrogen in soil by the Kjeldahl method. The Journal of Agricultural Science, 55(1). https://doi.org/10.1017/S0021859600021572
8. Chaganti, V.N., Culman, S.W., Herms, C., Sprunger, C.D., Brock, C., Leiva Soto, A., Doohan, D. 2021. Base cation saturation ratios, soil health, and yield in organic field crops. Agronomy Journal, 113(5). https://doi.org/10.1002/agj2.20785
9. Chin, W.L., Haddock-Fraser, J., Hampton, M.P. 2017. Destination competitiveness: evidence from Bali. Current Issues in Tourism, 20(12). https://doi.org/10.1080/13683500.2015.1111315
10. Daba, N.A., Li, D., Huang, J., Han, T., Zhang, L., Ali, S., Khan, M.N., Du, J., Liu, S., Legesse, T.G., Liu, L., Xu, Y., Zhang, H., Wang, B. 2021. Long-term fertilization and lime-induced soil ph changes affect nitrogen use efficiency and grain yields in acidic soil under wheat-maize rotation. Agronomy, 11(10). https://doi.org/10.3390/agronomy11102069
11. Dămătîrcă, C., Moretti, B., Bertora, C., Ferrarini, A., Lerda, C., Mania, I., Celi, L., Gorra, R., Zavattaro, L. 2023. Residue incorporation and organic fertilisation improve carbon and nitrogen turnover and stabilisation in maize monocropping. Agriculture, Ecosystems and Environment, 342. https://doi.org/10.1016/j.agee.2022.108255
12. Das, D., Sahoo, J., Raza, M.B., Barman, M., Das, R. 2022. Ongoing soil potassium depletion under intensive cropping in India and probable mitigation strategies. A review. In Agronomy for Sustainable Development, 42(1). https://doi.org/10.1007/s13593-021-00728-6
13. Demir, Y., Demir, A.D., Meral, A., Yüksel, A. 2023. Determination of soil quality index in areas with high erosion risk and usability in watershed rehabilitation applications. Environmental Monitoring and Assessment, 195(5). https://doi.org/10.1007/s10661-023-11181-1
14. Eik, K., Hanway, J.J. 1986. Simultaneous extraction of P and K from Iowa soils with bray 1 solution containing NH4Cl. Communications in Soil Science and Plant Analysis, 17(11). https://doi.org/10.1080/00103628609367784
15. Finalis, E.R., Arfiana, Noor, I., Murti, S.D.S., Suratno, H., Rosyadi, E., Saputra, H., and Noda, R. 2021. Synthesis and characterization of NPK Slow Release Fertilizer for Red Onion by Using Empty Fruit Bunch (EFB) Char. Proceedings of the International Conference on Sustainable Biomass (ICSB 2019), 202. https://doi.org/10.2991/aer.k.210603.029
16. Hassink, J. 1994. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. Soil Biology and Biochemistry, 26(9). https://doi.org/10.1016/0038-0717(94)90147-3
17. Huang, L., Liu, X., Wang, Z., Liang, Z., Wang, M., Liu, M., Suarez, D.L. 2017. Interactive effects of pH, EC and nitrogen on yields and nutrient absorption of rice (*Oryza sativa* L.). Agricultural Water Management, 194. https://doi.org/10.1016/j.agwat.2017.08.012
18. Jiao, S., Peng, Z., Qi, J., Gao, J., and Wei, G. 2021. Linking bacterial-fungal relationships to microbial diversity and soil nutrient cycling. MSystems, 6(2). https://doi.org/10.1128/msystems.01052-20
19. Kartini, N.L., Saifulloh, M., Trigunasih, N.M., Narka, I.W. 2023. Assessment of soil degradation based on soil properties and spatial analysis in dryland farming. Journal of Ecological Engineering, 24(4). https://doi.org/10.12911/22998993/161080
20. Khaledian, Y., Brevik, E.C., Pereira, P., Cerdà, A., Fattah, M.A., Tazikeh, H. 2017. Modeling soil cation exchange capacity in multiple countries. Catena, 158. https://doi.org/10.1016/j.catena.2017.07.002
21. Lal, R. 1993. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. Soil and Tillage Research, 27(1–4). https://doi.org/10.1016/0167-1987(93)90059-X
22. Larson, W.E., Pierce, F.J. 1994. The dynamics of soil quality as a measure of sustainable management. Defining Soil Quality for a Sustainable Environment. Proc. Symposium, Minneapolis, MN, 1992.
23. Loke, P.F., Kotzé, E., Du Preez, C.C. 2014. Long-term effects of wheat production management practices on exchangeable base cations and cation exchange capacity of a plinthosol in semi-arid South Africa. Communications in Soil Science and Plant Analysis, 45(8). https://doi.org/10.1080/00103624.2013.867060
24. Mandal, D., Patra, S., Sharma, N.K., Alam, N.M., Jana, C., Lal, R. 2023. Impacts of soil erosion on soil quality and agricultural sustainability in the

north-western Himalayan Region of India. Sustainability (Switzerland), 15(6). https://doi.org/10.3390/su15065430

25. Mathers, N.J., Nash, D.M., Gangaiya, P. 2007. Nitrogen and Phosphorus Exports from High Rainfall Zone Cropping in Australia: Issues and Opportunities for Research. Journal of Environmental Quality, 36(6). https://doi.org/10.2134/jeq2006.0464
26. Mujiyo, M., Setyawan, Y.Y., Herawati, A., Widijanto, H. 2021. The effect of land use on soil quality in Giriwoyo Sub-district, Wonogiri Regency. Journal of Degraded and Mining Lands Management, 8(2). https://doi.org/10.15243/JDMLM.2021.082.2569
27. Mulyono, A., Suriadikusumah, A., Harriyanto, R., Djuwansah, M.R. 2019. Soil quality under agroforestry trees pattern in upper Citarum watershed, Indonesia. Journal of Ecological Engineering, 20(1). https://doi.org/10.12911/22998993/93942
28. Nguemezi, C., Tematio, P., Yemefack, M., Tsozue, D., Silatsa, T.B.F. 2020. Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon. Heliyon, 6(2). https://doi.org/10.1016/j.heliyon.2020.e03432
29. Ning, L., Cheng, C., Lu, X., Shen, S., Zhang, L., Mu, S., Song, Y. 2022. Improving the prediction of soil organic matter in arable land using human activity factors. Water (Switzerland), 14(10). https://doi.org/10.3390/w14101668
30. Ozores-Hampton, M., Stansly, P.A., Salame, T.P. 2011. Soil chemical, physical, and biological properties of a sandy soil subjected to long-term organic amendments. Journal of Sustainable Agriculture, 35(3). https://doi.org/10.1080/10440046.2011.554289
31. Page, K.L., Dang, Y.P., Dalal, R.C. 2020. The ability of conservation agriculture to conserve soil organic carbon and the subsequent impact on soil physical, chemical, and biological properties and yield. In Frontiers in Sustainable Food Systems, 4. https://doi.org/10.3389/fsufs.2020.00031
32. Penn, C.J., Camberato, J.J. 2019. A critical review on soil chemical processes that control how soil ph affects phosphorus availability to plants. Agriculture (Switzerland), 9(6). https://doi.org/10.3390/agriculture9060120
33. Pervaiz, Z.H., Iqbal, J., Zhang, Q., Chen, D., Wei, H., Saleem, M. 2020. continuous cropping alters multiple biotic and abiotic indicators of soil health. Soil Systems, 4(4). https://doi.org/10.3390/soilsystems4040059
34. Ribeiro, P.G., Martins, G.C., Gastauer, M., da Silva Junior, E.C., Santos, D.C., Caldeira Júnior, C.F., Cavalcante, R.B.L., Dos Santos, D.S., Carneiro, M.A.C., Valadares, R.B. da S., Nascimento Junior, W. da R., Oliveira, G., Filho, P.W.M.E.S., Ramos, S.J. 2022. Spectral and soil quality index for monitoring environmental rehabilitation and soil carbon stock in an amazonian sandstone mine. Sustainability (Switzerland), 14(2). https://doi.org/10.3390/su14020597
35. Romadhon, M.R., Mujiyo, M., Cahyono, O., Dewi, W.S., Hardian, T., Anggita, A., Hasanah, K., Irmawati, V., Istiqomah, N.M. 2024. Assessing the effect of rice management system on soil and rice quality index in Girimarto, Wonogiri, Indonesia. Journal of Ecological Engineering, 25(2). https://doi.org/10.12911/22998993/176772
36. Soumare, A., Sarr, D., Diedhiou, A.G. 2023. Potassium sources, microorganisms and plant nutrition: Challenges and future research directions. Pedosphere, 33(1). https://doi.org/10.1016/j.pedsph.2022.06.025
37. Spohn, M., Stendahl, J. 2024. Soil carbon and nitrogen contents in forest soils are related to soil texture in interaction with pH and metal cations. Geoderma, 441. https://doi.org/10.1016/j.geoderma.2023.116746
38. Sudarma, I.M., Saifulloh, M., Diara, I.W., As-syakur, A.R. 2024. Carbon stocks dynamics of urban green space ecosystems using time-series vegetation indices. Ecological Engineering & Environmental Technology, 25(9), 147–162.
39. Sumarniasih, M.S., Ginting, M.H., Bhayunagiri, I.B.P. 2022. Evaluation and improvement of rice field quality in Seririt District, Buleleng Regency, Bali Province, Indonesia. Journal of Degraded and Mining Lands Management, 10(1).
40. Susila, K.D., Trigunasih, N.M., Saifulloh, M. 2024. Monitoring agricultural drought in Savanna ecosystems using the vegetation health index – Implications of climate change. Ecological Engineering & Environmental Technology, 25(9), 54–67.
41. Tahir, S., Marschner, P. 2017. Clay addition to sandy soil reduces nutrient leaching—Effect of Clay concentration and ped size. Communications in Soil Science and Plant Analysis, 48(15). https://doi.org/10.1080/00103624.2017.1395454
42. Trigunasih, N.M., Saifulloh, M. 2022. Spatial distribution of landslide potential and soil fertility: A case study in Baturiti District, Tabanan, Bali, Indonesia. Journal of Hunan University Natural Sciences, 49(2). https://doi.org/10.55463/issn.1674-2974.49.2.23
43. Trigunasih, N.M., Narka, I.W., Saifulloh, M. 2023. Measurement of soil chemical properties for mapping soil fertility status. International Journal of Design and Nature and Ecodynamics, 18(6). https://doi.org/10.18280/ijdne.180611
44. Utama, I.M.S. 2021. Developing Agriculture Value Chain Inclusive for Small-Scale Vegetable Farmers in the Highland of Bedugul, Bali. IOP Conference Series: Earth and Environmental Science, 892(1). https://doi.org/10.1088/1755-1315/892/1/012103
45. Walkley, A., Black, I.A. 1934. An examination of

the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1). https://doi.org/10.1097/00010694-193401000-00003

46. Wang, X., He, C., Liu, B., Zhao, X., Liu, Y., Wang, Q., Zhang, H. 2020. Effects of residue returning on soil organic carbon storage and sequestration rate in China's croplands: A meta-analysis. Agronomy, 10(5). https://doi.org/10.3390/agronomy10050691
47. Wang, Y., Wu, P., Mei, F., Ling, Y., Qiao, Y., Liu, C., Leghari, S.J., Guan, X., and Wang, T. 2021. Does continuous straw returning keep China farmland soil organic carbon continued increase? A meta-analysis. Journal of Environmental Management, 288. https://doi.org/10.1016/j.jenvman.2021.112391
48. Wayan Budiasa, I., Ayu Ambarawati, I.G.A. 2014. Community based agro-tourism as an innovative integrated farming system development model towards sustainable agriculture and tourism in Bali. Journal of the International Society for Southeast Asian Agricultural Sciences, 20(1).
49. Wuepper, D., Borrelli, P., Finger, R. 2020. Countries and the global rate of soil erosion. Nature Sustainability, 3(1). https://doi.org/10.1038/s41893-019-0438-4