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Farmers' Crop Choice and Soil Sustainability: A Simulation Analysis Based on Perceived Profitability and Soil Load in Shan State, Myanmar

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Abstract

Cash crop expansion has contributed to income growth among smallholder farmers in developing countries, but its long-term implications for soil fertility remain insufficiently understood. In particular, few studies have incorporated farmers' perceptions of crop profitability and soil impacts into dynamic simulation models. This study examines the long-term effects of crop-choice behavior on soil fertility in Shan State, Myanmar, using a perception-based dynamic simulation model. Profit indices and soil-load indices for major cash crops were constructed from interviews with local farmers and applied to three crop-choice scenarios: profit maximization, continuous cropping restriction, and crop rotation. Soil fertility was simulated over a 50-year period under each scenario. Under the interview-derived parameter settings, the profit maximization scenario, corresponding to continuous cultivation of perilla, achieved both the highest cumulative profit and the highest level of soil fertility. In contrast, the continuous cropping restriction scenario resulted in the greatest decline in soil fertility because the replacement crop, peanut, was also perceived as imposing a relatively high soil load. Incorporating sweet potato into a four-year crop rotation substantially improved soil fertility compared with the continuous cropping restriction scenario, demonstrating that the effectiveness of crop rotation depends on the combination of crops included in the rotation. These findings suggest that farmers' perceptions of crop profitability and soil impacts can strongly influence long-term land-use outcomes and highlight the importance of considering local farming knowledge when designing sustainable agricultural management strategies.

Keywords: crop choice; soil fertility; natural capital; agricultural sustainability; environmental economics

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1. Introduction

The Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015. They have been guiding global sustainability efforts for more than a decade. Only a few years remain until the target year of 2030. Nevertheless, developing countries continue to face challenges such as poverty, hunger, and environmental degradation, highlighting the need for efforts toward sustainable development [1]. Food production is fundamental to human well-being, and the establishment of sustainable agricultural systems has become a critical global issue. At the same time, the world's population is projected to continue growing, resulting in increasing demand for food in the coming decades [2]. Under these circumstances, maintaining stable food production while making efficient use of limited land resources is essential. However, it is not sufficient to simply increase agricultural output; sustainable production must also be achieved while minimizing environmental impacts [3].

Agriculture remains a major economic sector in developing countries and is the primary source of income for many rural households [4]. In rural areas, farmers often depend heavily on agricultural income and must secure profits under conditions of limited land and resources. In recent years, the expansion of market economies and stronger integration into global markets have accelerated the production of cash crops. Although cash crop cultivation contributes to income generation, it may also encourage land-use practices that prioritize short-term profitability. Farmers generally tend to select crops with higher economic returns [5], which may lead to continuous cultivation of the same crop and reduced fallow periods. While such practices can increase income in the short term, they may also result in nutrient depletion and increased pest and disease pressure, ultimately reducing soil fertility [6]. Soil fertility is one of the most important forms of natural capital supporting agricultural production. Its degradation not only reduces crop yields and farm income but also threatens the long-term sustainability of regional agricultural systems and future food production. As these studies show, the expansion of cash crop cultivation has increased farmers' income in many developing countries. However, the long-term implications of crop-choice behavior for soil fertility remain insufficiently understood.

Agricultural intensification has accompanied the expansion of cash crop cultivation. Shan State in Myanmar, the study area of this research, is one of the country's major agricultural regions. The INGO Terra People Association (TPA), a collaborating organization in this study, has been promoting sustainable agricultural practices in Shan State [7,8]. Farmers in the region cultivate a variety of crops, including peanuts, maize, potatoes, soyabeans, sweet potatoes, and perilla, all of which provide important sources of household income. Through its field activities, TPA has realized that insufficient knowledge of agricultural practices and soil management may increase the risk of excessive land use and soil degradation. Furthermore, the authors believe that 'it is necessary to conduct a quantitative analysis to determine whether the crops chosen by farmers take long-term soil fertility into account'. Authors believe that this will lead to sustainable agriculture.

In environmental economics, such issues can be interpreted as a form of natural capital depletion. Although profit-maximizing behavior may be rational for individual farmers, the widespread adoption of such behavior can contribute to the degradation of soil resources and reduce agricultural productivity at the regional level. This situation shares important characteristics with the "tragedy of the commons," in which individually rational decisions lead to socially undesirable outcomes. Although research on soil health and agricultural sustainability has expanded in recent years, studies that dynamically analyze the relationship between farmers' crop choice behavior and long-term changes in soil fertility remain limited, particularly in the context of smallholder agriculture in Southeast Asia. Furthermore, the long-term implications of cash crop expansion for soil fertility and agricultural sustainability have not been sufficiently examined.

Consequently, this study utilizes a dynamic simulation approach to investigate how alternative crop-choice rules, derived from farmers' perceptions in Shan State, Myanmar, influence long-term soil fertility (Figure 1). Using interview data collected from local farmers, the study compares three crop-choice scenarios: profit maximization, continuous cropping restriction, and crop rotation. It then evaluates their long-term implications for soil fertility and agricultural sustainability. The novelty of this study lies in the development of profit and soil-load indices based on interviews with local farmers and their integration into a simulation framework linking crop-choice behavior with changes in soil fertility.

Furthermore, the study conceptualizes soil fertility as a form of natural capital and examines its long-term dynamics from the perspective of environmental economics.

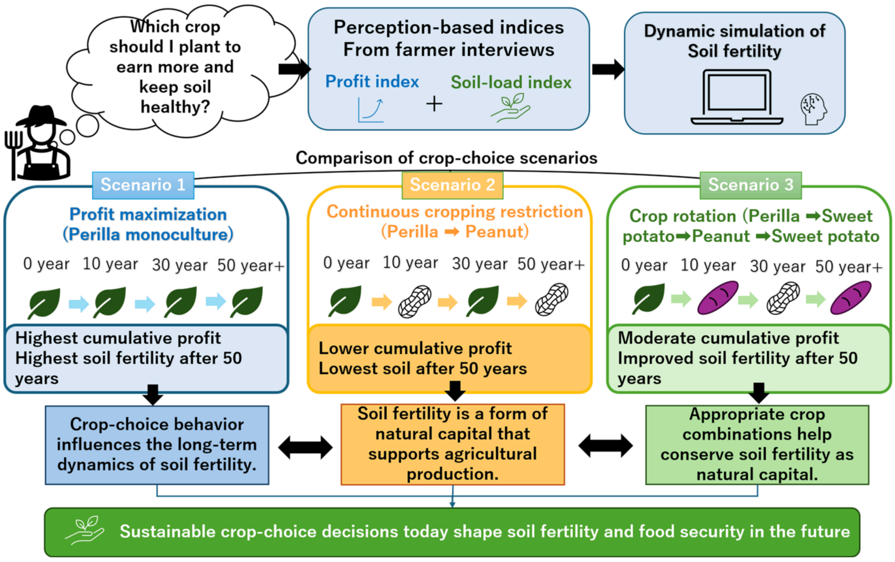

Figure 1. Overview of the study.

Environmental economics has long examined the use and management of natural resources. Gordon (1954) provided a theoretical framework for understanding the overexploitation of common resources, while Hardin (1968) conceptualized this phenomenon as the "tragedy of the commons" [9,10]. The tragedy of the commons refers to a situation in which individuals, acting in their own self-interest, overuse a shared resource, ultimately reducing collective welfare.

Subsequent studies have shown that resource degradation is not necessarily inevitable. Ostrom (1990) demonstrated that common resources can be managed sustainably when appropriate institutional arrangements and community-based governance systems are in place [11]. Furthermore, Ostrom (2009) emphasized the importance of institutions and governance for sustainable resource management from the perspective of social–ecological systems (SES) [12].

In the context of developing countries, Dasgupta (1993) argued that poverty and high discount rates may encourage short-term decision-making and contribute to the overuse of natural capital [13]. Similarly, Baland and Platteau (1996) showed that weak institutions and failures of collective action can lead to resource degradation in rural areas [14].

These studies suggest that individually rational decisions can contribute to long-term resource degradation under certain conditions and provide a useful theoretical framework for examining the management of soil resources that support agricultural production.

More recently, the concept of natural capital has become increasingly important in sustainability research. Natural capital refers to natural environments and ecosystem resources that provide benefits to human society, including soil, water, and biodiversity. The long-term maintenance of these resources is considered essential for sustainable development [15,16]. Soil fertility, which underpins agricultural production, is also a critical form of natural capital, and its depletion can undermine the sustainability of agriculture [17]. From this perspective, farmers' land-use and crop-choice decisions can be viewed as issues related to the management of natural capital.

Soil is one of the most important forms of natural capital supporting agricultural production, and its condition strongly influences agricultural sustainability. Declining soil fertility not only reduces crop yields but also affects farm income and food security, making soil degradation a major concern for sustainable agricultural development. As agricultural production has expanded, a substantial body of research has examined soil degradation. Tilman et al. (2002) argued that while intensive agricultural production can increase productivity in the short term, it may also generate environmental problems such as soil degradation and biodiversity loss in the long term [18]. Previous studies have estimated that approximately 24 billion tons of fertile soil are lost annually worldwide due to erosion, highlighting the severity of global soil degradation [19]. Likewise, Montgomery (2007) identified soil erosion and degradation as major threats to the long-term sustainability of agriculture [20]. Continuous cultivation of the same crop is known to cause nutrient imbalances and increase pest and disease pressure, thereby reducing soil fertility. Research on crop rotation has shown that the seed yield (47.7–68.0%) and nitrogen accumulation (45.1–61.7%) of oilseed flax increased significantly [21]. Consequently, crop rotation and fallowing have long been recognized as fundamental practices for maintaining soil functions. However, farmers' crop choices are influenced by a combination of economic returns, farming experience, and local production conditions. As a result, the long-term effects of crop choice on soil fertility may vary depending on the crops selected. Accordingly, many studies have examined the role of crop rotation in maintaining soil fertility and improving agricultural productivity.

Recent studies on soil health and agricultural sustainability have increasingly viewed soil not merely as a production input but as an important form of natural capital that provides ecosystem services. In particular, soil microbial communities and organic matter cycling have been identified as essential components of soil health and sustainable agricultural production [22]. Furthermore, recent studies have shown that practices such as crop rotation, cover cropping, and conservation tillage contribute to the accumulation of soil organic matter and improvements in soil structure, thereby supporting the long-term maintenance of soil fertility [23]. Review studies on conservation agriculture have also reported that crop diversification and rotational systems help reduce soil erosion and improve water retention, playing an important role in the development of sustainable agricultural systems [24]. Some studies suggest that conservation agriculture has led to a 19.94 percent increase in crop yields and a 19.48 percent increase in water use efficiency [25]. While these studies demonstrate the effectiveness of crop rotation and conservation agriculture in maintaining soil health, most focus primarily on agronomic or ecological aspects. Relatively few studies have dynamically examined how farmers' economic decision-making influences soil fertility through crop choice. In particular, the long-term effects of cash crop expansion on soil fertility and agricultural sustainability through farmers' crop-choice behavior remain insufficiently explored. This issue is also important from the perspective of natural capital management in environmental economics.

Previous studies in environmental economics have accumulated substantial knowledge regarding the overuse of common resources and the depletion of natural capital. Similarly, agricultural research has extensively examined the impacts of soil degradation and continuous cropping on agricultural sustainability. However, these two strands of literature have not been fully integrated. Environmental economics has primarily focused on theoretical analyses of resource use, whereas agricultural studies have mainly addressed technical issues related to soil and crop management. As a result, insufficient attention has been paid to how farmers' crop-choice decisions influence agricultural sustainability through changes in soil fertility. This gap is particularly evident in the context of smallholder agriculture in Southeast Asia, where few studies have jointly analyzed cash crop expansion, farmers' decision-making, and the dynamic evolution of soil fertility. In particular, studies examining farmers' perceptions of crop profitability and soil impacts, and incorporating these perceptions into dynamic simulation models of long-term soil fertility, remain limited, especially in Shan State, Myanmar.

This study makes three main contributions. First, it constructs profit indices and soil-load indices for major crops based on interviews with farmers in Shan State. Second, it develops a dynamic simulation model that integrates farmers' crop-choice behavior with changes in soil fertility. Third, it conceptualizes soil fertility as a form of natural capital and examines the implications of perception-based crop-choice behavior for long-term soil fertility from the perspective of environmental economics.

2. Research Methodology

2.1. Study Area and Data Collection

Interviews were conducted with local farmers in Shan State, Myanmar, to investigate cash crop cultivation and soil management practices. The survey was carried out with the cooperation of the TPA, a collaborating organization engaged in sustainable agricultural support activities in Shan State. Face-to-face semi-structured interviews were conducted in June 2026 using a convenience sampling method among farmers cultivating cash crops in fields supported by the TPA. A total of 8 farmers who agreed to participate were interviewed. Although the participants were not intended to be statistically representative of all farmers in Shan State, they were actively engaged in cash crop cultivation in the study area and provided practical information for parameterizing the simulation model. Information was collected on the selling prices of major cash crops and farmers' perceptions of crop profitability and soil degradation impacts. The surveyed crops included peanuts, maize, potatoes, soybeans, sweet potatoes, and perilla, all of which are widely cultivated in Shan State. Because detailed statistical data on crop yields and production costs were unavailable, the analysis relied on farmers' perceptions and experiences. Perceptions of crop profitability and soil degradation impacts were converted into ranking data and subsequently used as parameters in the simulation model described below. Crop selling prices are presented in Appendix A, Table A1.

2.2. Model and Equations

The purpose of the model is not to predict absolute soil fertility values but to examine the relative long-term effects of alternative crop management scenarios. Accordingly, the parameter values were selected to represent relative changes in soil fertility rather than site-specific agronomic thresholds. A dynamic simulation model was developed to analyze the impact of farmers' crop-choice behavior on soil fertility. The model assumes that farmers select crops according to predefined crop-choice rules. The crop selected in each period depends on the decision rule specified for each simulation scenario, whereas changes in soil fertility depend on the soil-load index of the cultivated crop. The three crop-choice rules are described in Section 2.5. Soil fertility at time (t) is denoted by S_t

$$0 \le S_t \le 1 \quad (1)$$

Here, S_t = 1 represents a fully fertile state, whereas S_t = 0 represents a severely degraded state. The model assumes smallholder agriculture in a developing-country context and does not incorporate fallow periods or natural soil recovery. Consequently, soil fertility is assumed to decline according to the soil load imposed by the cultivated crop.

Soil fertility is updated according to the following equation:

$$S_{(t+1)} = max(0,\ S_t - \alpha L_k) \quad (2)$$

where L_k denotes the soil-load index of crop k, and α is a scaling coefficient that converts soil load into changes in soil fertility.

When soil fertility falls below a specified threshold, agricultural sustainability is considered to be significantly compromised. The model is used to evaluate the effects of alternative crop-choice rules on long-term soil fertility and agricultural sustainability. Accordingly, the simulation model is intended to compare the relative long-term effects of alternative crop-choice rules rather than to predict absolute soil fertility under actual farming conditions.

2.3. Simulation Conditions

The main variables and parameters used in the simulation model are presented in Table 1.

Table 1. Variables and parameters used in the simulation model.

Symbol	Definition
S_t	Soil fertility at time (t)
R_k	Profit index for crop (k)
L_k	Soil-load index for crop (k)
α	Soil degradation coefficient
b	Soil fertility threshold

The profit index R_k was derived from farmers' perceptions of crop profitability obtained through interviews. A higher profit index indicates greater economic attractiveness to farmers. The soil-load index L_k was derived from farmers' perceptions of the degree of soil degradation associated with each crop. Higher values of the soil-load index indicate a greater negative impact on soil fertility. Accordingly, both indices represent farmers' relative perceptions rather than objective agronomic measurements.

A threshold value b was introduced to represent a substantial decline in agricultural sustainability. When soil fertility falls below this threshold,

$$S_t \leq b \tag{3}$$

the agricultural land is considered to be in a state of significantly reduced sustainability. This threshold enables an assessment of how different crop-choice rules affect long-term soil fertility.

The initial soil fertility was set as

$$S_0 = 1 \tag{4}$$

representing a fully fertile state at the beginning of the simulation.

The soil fertility threshold was defined as

$$b = 0.3 \tag{5}$$

This threshold represents the minimum soil condition required to sustain agricultural production. In this study, soil fertility at or below 30% of its normalized initial value was regarded as a state of low sustainability. Because no established threshold value is available for the study area, 0.3 was adopted as a simplified assumption for the simulation. The threshold is intended to illustrate the relative behavior of the model rather than to represent a universal agronomic criterion and should be adjusted according to local conditions when the model is applied elsewhere.

The soil degradation coefficient (α) is a scaling parameter that converts the soil-load index into changes in soil fertility. Because empirical estimates of soil degradation rates

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were unavailable for the study area, α = 0.005 was adopted as a baseline value representing a moderate rate of soil fertility decline under continuous cultivation. This value was used as a simplified model assumption rather than an empirically derived parameter. Accordingly, the simulation focuses on comparing the relative effects of alternative crop management scenarios rather than predicting absolute soil fertility values. To examine the robustness of the results, a sensitivity analysis was conducted using three alternative values of the soil degradation coefficient:

$$\alpha = 0.003,\ \alpha = 0.005,\ \alpha = 0.007 \tag{6}$$

These values represent low, moderate, and high rates of soil degradation, respectively.

The simulation period was set to 50 years in order to capture long-term changes in soil fertility. Based on these assumptions and parameter settings, the simulation model was used to compare the long-term trajectories of soil fertility under the three crop-choice scenarios.

2.4. Parameter Settings

Farmers were asked to rank the six major cash crops according to their perceived profitability and perceived impact on soil fertility based on their farming experience. In the questionnaire, Rank 1 represented the highest perceived profitability (or the greatest perceived soil impact), whereas Rank 6 represented the lowest. These rankings were converted into numerical scores (Rank 1 = 6 points, . . ., Rank 6 = 1 point). For each crop, the scores were averaged across respondents after excluding missing responses. The average score was then normalized by assigning the highest average score an index value of 6.0, and the indices for the remaining crops were calculated proportionally according to

$$Index_k = 6 \times \frac{\overline{Score_k}}{\max\left(\overline{Score}\right)} \tag{7}$$

where $\overline{\text{Score}_k}$ is the mean score of crop k, and $\max\left(\overline{\text{Score}}\right)$ is the highest mean score among all crops. The normalized values were used as the profit index (R_k) and soil-load index (L_k) in the simulation model.

Based on the interview results, perilla was ranked as the most profitable crop, followed by peanut, soybean, maize and potato (tied), and sweet potato. In contrast, potato was perceived as imposing the greatest soil load, followed by maize, peanut, soybean, perilla, and sweet potato.

These findings indicate that crop profitability and perceived soil impacts did not necessarily correspond. For example, perilla was perceived as both the most profitable crop and a crop with only a moderate soil load, whereas potato was perceived as imposing the greatest soil load despite its relatively low profitability ranking. Based on these rankings, profit indices and soil-load indices were assigned to each crop and subsequently used in the simulation analysis. The resulting parameter values are presented in Table 2, whereas the detailed interview rankings and the calculation of the normalized indices are provided in Appendix B (Tables A2–A4).

Table 2. Profit index and soil-load index.

Crop	Profit Index (R_k)	Soil Load Index (L_k)
Perilla	6.000	2.336
Sweet potato	3.800	1.605
Peanut	5.600	4.085
Soyabean	5.250	3.191
Potato	4.725	6.000
Maize	4.725	4.723

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2.5. Scenario Settings

Three scenarios were developed to examine how different crop-choice rules affect long-term soil fertility.

(1) Profit Maximization Scenario

Farmers cultivate the crop with the highest profit index throughout the simulation period. Based on the interview-derived profit index, perilla was selected every year. Soil impacts are not considered, and the sole objective is to maximize short-term profitability.

(2) Continuous Cropping Restriction Scenario

Continuous cultivation of the same crop is prohibited. Farmers therefore alternate between the two crops with the highest profit indices, perilla and peanut, throughout the simulation period. This scenario examines whether restricting continuous cultivation alone is sufficient to conserve soil fertility.

(3) Crop Rotation Scenario

A four-year crop rotation consisting of perilla → sweet potato → peanut → sweet potato was introduced. This rotation combines highly profitable crops with a low-soil-load crop to reduce the cumulative impact of cultivation on soil fertility. The objective is to evaluate whether incorporating low-soil-load crops into the rotation can improve the long-term sustainability of agricultural land use.

3. Analysis Results

3.1. Profit Maximization

The profit maximization scenario was first examined. Under this scenario, farmers were assumed to select the crop with the highest profit index in each period. Perilla has the highest profit index and was therefore cultivated throughout the simulation period.

Perilla has a soil-load index of 2.334. Using the baseline soil degradation coefficient ($\alpha = 0.005$), soil fertility declined by approximately 0.0117 per year. Given an initial soil fertility of 1.0, the simulated soil fertility after 50 years was 0.416. Soil fertility declined continuously throughout the simulation period and fell below the sustainability threshold of 0.3 after approximately 60 years. These results suggest that crop-choice behavior aimed at maximizing short-term profitability may reduce agricultural sustainability over the long term through the gradual depletion of soil fertility as a form of natural capital. In particular, the repeated cultivation of a highly profitable crop may generate cumulative adverse effects on soil fertility, thereby undermining the long-term sustainability of agricultural production.

3.2. Continuous Cropping Restriction

The continuous cropping restriction scenario was next examined. Under this scenario, farmers were not allowed to cultivate the same crop in consecutive periods. Among the remaining available crops, the crop with the highest profit index was selected. As a result, farmers alternated between perilla and peanut cultivation throughout the simulation period. Although perilla has the highest profit index, it cannot be selected in the following year because of the continuous cropping restriction. Consequently, peanut, which has the second-highest profit index, was selected.

Perilla and peanut have soil-load indices of 2.334 and 4.085, respectively, giving an average soil-load index of 3.210 over the two-year rotation. Under the baseline parameter setting ($\alpha = 0.005$), soil fertility was updated annually according to the soil-load index of the crop cultivated in each year. After 50 years, the simulated soil fertility was 0.198, which is substantially lower than that observed under the profit maximization scenario.

These results suggest that, under the parameter settings used in this study, restricting continuous cropping alone was insufficient to maintain soil fertility. Because peanut also has a relatively high soil-load index, alternating between perilla and peanut accelerated the long-term decline in soil fertility. This finding indicates that the effectiveness of continuous cropping restrictions depends not only on avoiding repeated cultivation of the same crop but also on the soil-load characteristics of the replacement crop.

3.3. Crop Rotation

Finally, the crop rotation scenario was examined. Under this scenario, crops with relatively high soil loads were followed by crops with lower soil loads. Specifically, a four-year rotation consisting of perilla, sweet potato, peanut, and sweet potato was adopted. The corresponding soil-load indices were 2.334, 1.605, 4.085, and 1.605, respectively. The average soil-load index over one rotation cycle was therefore 2.407. Soil fertility was updated annually according to the soil-load index of the crop cultivated in each year. The simulation results are presented in Table 3.

Table 3. Comparison of different patterns in 4-year crop rotations.

Compare Contents	**4-Year Crop Rotation System Maize Version**
Pattern	Perilla → Sweet potato → Peanut → Sweet potato
Total profit over four years	19.20 (Average of 4.8)
Total load over four years	9.63 (Average of 2.41)
Soil fertility after 50 years	0.403
Total cumulative profit after 50 years	240.0

Compared with the continuous cropping restriction scenario, the decline in soil fertility was slower because the inclusion of sweet potato, which had the lowest soil-load index among the major cash crops, reduced the cumulative soil burden over the rotation cycle. However, soil fertility still declined gradually throughout the simulation period because the model did not incorporate fallow periods or natural soil recovery.

Although the crop rotation scenario improved soil fertility relative to the continuous cropping restriction scenario, it did not outperform the profit maximization scenario under the interview-derived parameter settings. This result reflects the relatively moderate soil-load index assigned to perilla by the interviewed farmers. The findings suggest that the effectiveness of crop rotation depends not only on alternating crops but also on the soil-load characteristics of the crops included in the rotation. Under the farmers' perceptions represented in this study, perilla was regarded as both highly profitable and only moderately burdensome to soil fertility, indicating that farmers may already incorporate experiential knowledge of soil conditions into their crop-choice decisions.

3.4. Comparison of the Three Scenarios

Table 4 summarizes the simulation results obtained under the three scenarios and illustrates the trajectories of soil fertility over time.

Under the baseline parameter setting ($\alpha = 0.005$), the simulated soil fertility after 50 years was 0.416 in the profit maximization scenario, 0.198 in the continuous cropping restriction scenario, and 0.403 in the crop rotation scenario. Among the three scenarios, the profit maximization scenario maintained the highest soil fertility, whereas the continuous cropping restriction scenario resulted in the most rapid decline. The crop rotation scenario

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substantially improved soil fertility compared with the continuous cropping restriction scenario but did not outperform the profit maximization scenario.

Table 4. Comparison of simulation results under the three crop-choice scenarios.

Scenario	Pattern	Cumulative Profit	Soil Fertility (50 Years)
Profit maximization	Perilla	300.0	0.416
Continuous cropping restriction	Perilla → Peanut	290.0	0.198
Crop rotation	Perilla → Sweet potato → Peanut → Sweet potato	240.2	0.403

Overall, these results demonstrate that different crop-choice rules can have substantial long-term effects on soil fertility. In particular, restricting continuous cultivation alone was insufficient to conserve soil fertility when the replacement crop also had a relatively high soil-load index. Introducing a low-soil-load crop into the rotation reduced the cumulative soil burden and improved long-term soil fertility. However, under the interview-derived parameter settings used in this study, the profit maximization scenario corresponded to continuous cultivation of perilla, which achieved the highest cumulative profit while also maintaining the highest level of soil fertility. This result reflects the interview findings, in which farmers perceived perilla as both highly profitable and only moderately burdensome to soil fertility. It therefore suggests that farmers' crop-choice decisions may reflect their perceptions of both profitability and soil impacts acquired through farming experience.

A sensitivity analysis was conducted to examine the effects of the soil degradation coefficient (α) on the simulation results. Three values were considered: $\alpha = 0.003$, $\alpha = 0.005$, and $\alpha = 0.007$. The results are presented in Table 5. As expected, larger values of α resulted in greater declines in soil fertility across all scenarios. However, the relative ranking of the scenarios remained unchanged. The profit maximization scenario consistently maintained the highest level of soil fertility, followed by the crop rotation scenario, whereas the continuous cropping restriction scenario produced the lowest soil fertility. These findings indicate that the relative performance of the three crop-choice scenarios is robust to variations in the soil degradation coefficient.

Table 5. Results of sensitivity analysis for soil fertility after 50 years under each scenario.

Scenario	$\alpha = 0.003$	$\alpha = 0.005$	$\alpha = 0.007$
Profit maximization	0.650	0.416	0.183
Continuous cropping restriction	0.519	0.198	0.000
Crop rotation	0.642	0.403	0.164

Overall, the results demonstrate that crop-choice rules have a substantial influence on long-term soil fertility. Under the interview-derived parameter settings used in this study, the profit maximization scenario, in which perilla was cultivated continuously, maintained the highest level of soil fertility throughout the simulation period. In contrast, the continuous cropping restriction scenario resulted in the greatest decline in soil fertility because the replacement crop, peanut, was also perceived by farmers as imposing a relatively high soil load. The crop rotation scenario, which incorporated sweet potato as a low-soil-load crop, substantially improved soil fertility relative to the continuous cropping restriction scenario, although it did not outperform the profit maximization scenario.

These findings indicate that the effectiveness of crop-choice rules depends not only on avoiding continuous cultivation but also on the soil-load characteristics of the crops included in the cropping system. Under the farmers' perceptions represented in this study, perilla was regarded as both highly profitable and only moderately burdensome to soil fertility. This suggests that farmers' crop-choice decisions may reflect their perceptions of both profitability and soil impacts acquired through farming experience. Nevertheless, because the model did not incorporate fallow periods or natural soil recovery, soil fertility declined gradually in all scenarios, indicating that additional soil conservation practices would be required to maintain soil fertility over the long term.

4. Discussion

The simulation results indicate that the relationship between crop profitability and long-term soil fertility is more complex than a simple trade-off between economic returns and environmental conservation. Under the interview-derived parameter settings used in this study, the profit maximization scenario corresponded to continuous cultivation of perilla and achieved both the highest cumulative profit and the highest level of soil fertility. This outcome reflects the interviewed farmers' perception that perilla is not only the most profitable crop but also imposes only a moderate soil load. These findings suggest that farmers' crop-choice decisions may be influenced by their perceptions of both profitability and soil impacts acquired through farming experience. The following sections discuss the implications of these findings in relation to farmers' decision-making, crop rotation, previous studies, environmental economics, and the limitations of the present study.

4.1. Farmers' Perceptions and Crop-Choice Behavior

The simulation results showed that, under the interview-derived parameter settings, continuous cultivation of perilla produced both the highest cumulative profit and the highest level of soil fertility among the three scenarios. This finding contrasts with the commonly assumed trade-off between short-term economic gains and long-term environmental conservation. Rather than indicating that profit maximization necessarily accelerates soil degradation, the results suggest that the relationship between profitability and soil sustainability depends on how farmers perceive the characteristics of individual crops.

In the interviews, farmers consistently ranked perilla as the most profitable crop while assigning it only a moderate soil-load score. Consequently, the profit maximization scenario corresponded to continuous cultivation of perilla, which also maintained relatively high soil fertility throughout the simulation period. This result suggests that farmers' crop-choice decisions may reflect not only economic considerations but also their accumulated experience regarding the effects of different crops on soil conditions.

At the same time, these findings should be interpreted with caution. The profit and soil-load indices used in the simulation were derived from farmers' perceptions rather than direct agronomic measurements. Therefore, the results represent the consequences of farmers' perceived relationships between crop profitability and soil impacts, rather than objective measurements of soil degradation. Nevertheless, because crop-choice decisions in practice are often based on farmers' own knowledge and experience, the perception-based approach adopted in this study provides valuable insights into farmers' actual crop-choice decision-making in smallholder agriculture.

4.2. Implications for Crop Rotation

The comparison between the continuous cropping restriction scenario and the crop rotation scenario highlights the importance of crop selection within rotation systems. Simply prohibiting the continuous cultivation of the same crop did not improve long-term soil fertility in the present simulation. Instead, alternating perilla with peanut resulted in the greatest decline in soil fertility because peanut was also perceived by the interviewed farmers as imposing a relatively high soil load.

In contrast, introducing sweet potato into the rotation substantially improved soil fertility compared with the continuous cropping restriction scenario. Sweet potato received the lowest soil-load score in the interviews and therefore reduced the cumulative soil burden when included between the cultivation of perilla and peanut. These results indicate that the effectiveness of crop rotation depends not only on the practice of rotation itself but also on the combination of crops included in the rotation.

From a practical perspective, the findings suggest that crop rotation strategies should consider farmers' knowledge of crop-specific soil impacts when designing sustainable cropping systems. Replacing one crop with another without considering its perceived effects on soil fertility may not necessarily contribute to the long-term conservation of natural capital.

4.3. Comparison with Previous Studies

The findings of the present study differ in some respects from previous agronomic studies on the effects of individual crops on soil fertility. Leguminous crops such as peanut are generally considered to improve soil fertility through biological nitrogen fixation and are often recommended as components of sustainable crop rotation systems. However, the interviewed farmers in Shan State perceived peanut as imposing a relatively high soil load, resulting in a higher soil-load index in the simulation model.

This discrepancy does not necessarily indicate that the farmers' perceptions are incorrect. Rather, it may reflect local cultivation practices, environmental conditions, or accumulated farming experience under the specific agricultural conditions of Shan State. Farmers' evaluations may also incorporate factors beyond soil nutrient dynamics, such as cultivation intensity, labor requirements, or other practical considerations associated with peanut production.

It should therefore be emphasized that the soil-load index used in this study is a perception-based indicator derived from farmers' interview responses rather than an objective agronomic measure of soil degradation. Consequently, the simulation results should be interpreted as illustrating the long-term implications of farmers' perceptions and decision-making rather than the direct effects of individual crops on soil properties.

4.4. Environmental Economics

The present findings provide an interesting perspective on environmental economics and the concept of natural capital. Conventional discussions of environmental degradation often assume a trade-off between short-term economic benefits and the long-term conservation of natural resources. In particular, the tragedy of the commons [10] suggests that individually rational decisions may collectively lead to the depletion of shared natural resources.

The results of the present study, however, indicate that this relationship is not necessarily universal. Under the interview-derived parameter settings, the crop with the highest perceived profitability, perilla, was also perceived as imposing only a moderate soil load. Consequently, the profit maximization scenario maintained both the highest cumulative profit and the highest level of soil fertility. This finding suggests that economic incentives and environmental conservation do not necessarily conflict when farmers' perceptions of profitability are aligned with relatively low perceived soil impacts.

At the same time, the simulation demonstrated that inappropriate crop combinations can accelerate the depletion of soil fertility. The continuous cropping restriction scenario, in which perilla and peanut were cultivated alternately, produced the lowest level of soil fertility because both crops were perceived as imposing relatively high soil loads. These results indicate that the sustainability of agricultural systems depends not only on farmers' economic decisions but also on the environmental characteristics of the crops they choose. From this perspective, soil fertility can be regarded as a form of natural capital that requires appropriate long-term management. The present findings therefore suggest that farmers' perceptions should also be considered when designing policies for sustainable natural capital management.

4.5. Limitations

This study has several limitations. First, the profit index and soil-load index were derived from farmers' interview responses rather than direct agronomic measurements. Consequently, the simulation reflects farmers' perceptions of crop profitability and soil impacts, which may differ from the actual effects of individual crops on soil properties. Although this perception-based approach provides valuable insights into farmers' decision-making, the results should not be interpreted as direct measurements of soil degradation.

Second, the simulation model was intentionally simplified. Factors such as fertilizer application, organic amendments (e.g., compost or green manure), fallow periods, natural soil regeneration, climate variability, pest and disease incidence, and market price fluctuations were not incorporated into the model. These factors may influence both crop profitability and long-term soil fertility under actual farming conditions.

Finally, the simulation was based on interview data collected from farmers in Shan State, Myanmar. The findings therefore reflect local farming experience and may not be directly applicable to other regions with different environmental conditions or cropping systems. Future research should validate the model using long-term field observations and refine the model parameters by integrating empirical agronomic data with farmers' experiential knowledge.

5. Conclusions

This study examined the long-term effects of crop-choice behavior on soil fertility using a simulation model based on farmers' perceptions in Shan State, Myanmar. Profit and soil-load indices were constructed from interview data and applied to three crop-choice scenarios: profit maximization, continuous cropping restriction, and crop rotation.

The simulation results showed that, under the interview-derived parameter settings, the profit maximization scenario, corresponding to continuous cultivation of perilla, achieved both the highest cumulative profit and the highest level of soil fertility. In contrast, the continuous cropping restriction scenario resulted in the greatest decline in soil fertility because the replacement crop, peanut, was also perceived as imposing a relatively high soil load. Introducing sweet potato into the crop rotation substantially improved soil fertility compared with the continuous cropping restriction scenario. These results indicate that the effectiveness of crop rotation depends on the combination of crops included in the rotation rather than on rotation alone.

These findings suggest that farmers' perceptions of crop profitability and soil impacts can strongly influence long-term land-use outcomes. The results also indicate that locally accumulated farming experience may play an important role in crop-choice decisions and should be considered when designing sustainable agricultural management strategies. Because the simulation was based on farmers' perceptions rather than direct agronomic measurements, future research should integrate empirical agronomic data with farmers' perception-based information to develop more comprehensive models of agricultural sustainability.

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Abbreviations

The following abbreviations are used in this manuscript:

INGO	International non-governmental organization
SES	Social–ecological system
TPA	Terra People Association

Appendix A

Table A1 presents the selling prices of major cash crops reported by farmers interviewed in Shan State, Myanmar. These price data are provided as contextual information on the relative profitability of the major cash crops cultivated in the study area.

Because reliable statistical data on production costs and yields were not available, the simulation model did not directly use market prices. Instead, farmers' perceptions of crop profitability were used to construct the profit rankings and profit indices employed in the analysis. The price information presented in this appendix therefore serves as supplementary evidence supporting the relative profitability assessments reported by the interviewed farmers.

Table A1. Selling prices of major crops reported by farmers in Shan State, Myanmar.

Crop	Selling Price
Perilla	8000–14,000 MMK/viss
Sweet potato	2000 MMK/viss
Peanut	8000 MMK/viss
Soyabean	5000 MMK/viss
Potato	4000 MMK/viss
Maize	1300 MMK/viss

Source: Authors' field interviews conducted in Shan State, Myanmar (June 2026). Note: 1000 MMK = 0.48 USD (exchange rate based on 15 June 2026). Viss is a traditional Myanmar unit of weight equivalent to approximately 1.63 kg.

Appendix B

The profit index and soil-load index used in the simulation model were derived from farmers' interview responses. Farmers were asked to rank the six major cash crops according to their perceived profitability and perceived impact on soil fertility based on their farming experience. In the questionnaire, Rank 1 represented the highest perceived profitability (or the greatest perceived soil impact), whereas Rank 6 represented the lowest. These rankings were converted into numerical scores (Rank 1 = 6 points, . . ., Rank 6 = 1 point), averaged across respondents after excluding missing responses, and normalized to construct the profit and soil-load indices used in the simulation model. The detailed rankings, mean scores, and normalized indices are presented in Tables A2–A4.

Table A2. Farmers' rankings of crop profitability (in descending order).

Farmer	Maize	Peanut	Perilla	Soyabean	Sweet Potato	Potato
1	6	3	1	4	2	5
2	1	2	3	4	5	6
3	4	5	2	6	3	1
4	5	1	4	2	3	6
5	5	4	3	1	6	2
6	4	2	-	3	-	1
7	3	4	1	2	5	6
8	1	3	5	4	6	2

Note: Rank 1 = highest; Rank 6 = lowest.

Table A3. Farmers' rankings of perceived impacts on soil fertility.

Farmer	Maize	Peanut	Perilla	Soyabean	Sweet Potato	Potato
1	5	2	4	3	6	1
2	2	3	5	4	6	1
3	3	2	5	4	6	1
4	2	4	5	3	6	1
5	2	3	5	6	4	1
6	2	3	-	4	-	1
7	1	4	4	3	4	2
8	2	3	5	4	6	1

Note: Rank 1 = highest; Rank 6 = lowest.

Table A4. Calculation of normalized profit and soil-load indices.

Crop	Mean Profit Score	Profit Index (Rk)	Mean Soil-Load Score	Soil-Load Index (Lk)
Perilla	4.286	6	2.286	2.336
Sweet potato	2.714	3.8	1.571	1.605
Peanut	4	5.6	4	4.085
Soyabean	3.75	5.25	3.125	3.191
Potato	3.375	4.725	5.875	6
Maize	3.375	4.725	4.625	4.723

Note: Rankings were converted into scores (Rank 1 = 6 points, . . ., Rank 6 = 1 point). Mean scores were calculated for each crop after excluding missing responses. The highest mean score was assigned an index value of 6.0, and the remaining indices were calculated proportionally according to Equation (7).

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