



Evaluation of Land Suitability for Teak (*Tectona grandis* L.) and Peanut (*Arachis hypogaea* L.) Agroforestry Development in the Upper Solo Sub-watershed

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ABSTRACT

Purpose of the study: This study aims to determine the land suitability class for teak (*Tectona grandis* L.) and peanut (*Arachis hypogaea* L.) plants in the agroforestry area in the Solo Hulu Sub-DAS, and to assess the economic feasibility of the cultivation system in supporting sustainable land use.

Methodology: The descriptive-exploratory survey method with stratified random sampling, field soil survey, pedon observation, analysis of physical and chemical properties of soil in the laboratory, GIS-based spatial analysis using ArcView 3.3, GPS tools, altimeters, clinometers, Munsell Soil Color Charts, pH meters, soil drills, land suitability matching methods, R/C ratio farming analysis, and in-depth interviews with farmers.

Main Findings: Land suitability for teak plantations is generally classified as unsuitable (N), with limiting factors including dry season duration, soil depth, drainage, slope gradient, and erosion hazard. Peanuts are also predominantly unsuitable due to high rainfall and steep slopes. Nevertheless, both agroforestry systems remain economically viable, with a R/C ratio of 20.22 for teak and 2.02 for peanuts.

Novelty/Originality of this study: This research integrates biophysical land suitability evaluation with economic feasibility analysis of a teak-peanut agroforestry system in the Upper Solo Sub-watershed. This study provides specific recommendations related to land-limiting factors and improvement strategies, thereby enriching scientific information for sustainable agroforestry planning in marginal sub-watershed areas.

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1. INTRODUCTION

Agroforestry is a land management system that integrates forestry plants with agricultural crops within a single sustainable management unit [1], [2]. This system plays a crucial role in increasing land productivity, maintaining ecological balance, and providing economic benefits to communities. The application of agroforestry is increasingly relevant in areas facing land use pressures and environmental degradation [3], [4]. The combination of woody plants and annual crops can improve soil structure, reduce erosion, and increase the efficiency of land resource utilization [5], [6]. Therefore, agroforestry is a strategic approach to sustainable agricultural landscape management.

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The Upper Solo River Sub-Watershed is an area characterized by diverse land characteristics, varying topography, soil texture, and hydrological conditions [7], [8]. This area has significant potential for the development of agroforestry systems due to its ample land area and intensive community agricultural activities [9], [10]. However, differences in biophysical conditions between regions mean that not all plant species can grow optimally in every location. This situation necessitates land suitability evaluations to ensure appropriate land use [11], [12]. These evaluations serve as an important basis for determining plant species appropriate to local land characteristics.

Teak (*Tectona grandis* L.) is a forestry commodity with high economic value and is widely cultivated in agroforestry systems [13], [14]. Teak is known for its high adaptability to various environmental conditions, but its optimal productivity is strongly influenced by factors such as soil depth, drainage, rainfall, and slope. Selecting a suitable planting site significantly determines the growth and quality of the wood produced. In agroforestry systems, teak is often combined with annual crops to optimize space utilization [15], [16]. Therefore, analyzing land suitability for teak is a crucial step in agroforestry planning [17], [18].

Peanuts (*Arachis hypogaea* L.) are a strategic food crop with high economic value and are often grown as an intercrop in agroforestry systems [19], [20]. This crop is relatively fast-growing and can provide short-term income for farmers. Peanut growth is strongly influenced by soil physical and chemical conditions, particularly texture, pH, drainage, and nutrient availability [21], [22]. Appropriate land suitability will significantly increase yield and quality [23], [24]. Therefore, evaluating land suitability for peanuts is essential as part of efficient agroforestry management.

Land suitability assessment is a crucial process for determining the suitability of a plot of land for the growing requirements of specific crops [25], [26]. This analysis considers various environmental parameters such as soil characteristics, climate, topography, and other limiting factors. The results of the land suitability evaluation can be used as a basis for decision-making in sustainable land-use planning [27], [28]. In the context of agroforestry, this information is crucial for ensuring that the selected crop combinations can grow optimally, both ecologically and economically. Thus, land suitability evaluation contributes to improving the effectiveness of land management.

Various previous studies have addressed land suitability for forestry crops and food crops separately, but studies specifically analyzing land suitability for teak and peanuts simultaneously in agroforestry areas in the Upper Solo Sub-watershed are still very limited [29], [30]. Most studies focus on evaluating a single commodity or solely reviewing productivity aspects without considering the integration of crop types within the agroforestry system. This situation indicates a research gap that needs to be filled. The novelty of this research lies in its approach to evaluating land suitability for two different commodities within a single integrated land-use system. The results are expected to provide new information for developing land suitability-based agroforestry models.

The urgency of this research is heightened given the increasing pressure on land use in the Solo Hulu Sub-watershed, which can lead to environmental degradation and reduced land productivity. Land use without considering its suitability has the potential to cause economic losses and damage natural resources. Therefore, accurate scientific information regarding land suitability classes is needed as a basis for sustainable agroforestry management. This research has strategic value in supporting adaptive and productive land use planning. The main objective of this study is to determine the land suitability classes for teak and peanut crops in the agroforestry area of the Solo Hulu Sub-watershed.

2. RESEARCH METHOD

2.1. Place and Time of Research

This research was conducted in the Solo Hulu Sub-watershed area, geographically located at coordinates 7°58'–8°6' South Latitude and 110°53'–111°5' East Longitude. Administratively, the research area is mostly located in Wonogiri Regency, Central Java Province, while the rest is located in Pacitan Regency, East Java Province. Soil sample analysis was conducted at the Soil Chemistry and Fertility Laboratory. Meanwhile, data processing and analysis based on Geographic Information Systems were carried out at the Pedology and Soil Survey Laboratory, Faculty of Agriculture, Sebelas Maret University, Surakarta.

2.2. Research Materials and Tools

The materials used in this study consisted of primary data, secondary data, and chemical analysis support materials. Primary data included qualitative information on the physical and chemical properties of the soil and land morphology, quantitative data from measurements of physical and chemical properties of the soil, and socioeconomic data from the local community [31], [32]. Secondary data utilized included administrative maps of the Solo Hulu Sub-watershed, topographic maps, geological maps, and other supporting data such as climate data, crop production data, village monographs, and interview results. Chemicals used for field analysis included solutions for measuring soil pH, organic matter analysis, aeration and drainage, and lime content

testing. Meanwhile, laboratory analysis used various reagents to determine cation exchange capacity, base saturation, organic matter content, organic carbon, and soil texture.

Research equipment included field measurement instruments, documentation tools, and laboratory analysis equipment. Field instruments used included a pocket tape measure, Munsell Soil Color Chart, altimeter, clinometer, GPS, compass, magnifying glass, hoe, soil auger, and knife for sampling and soil profile observation. Soil chemical parameter measurements were supported by the use of pH meters, pipettes, flasks, and other analytical equipment [33], [34]. Field documentation was conducted using cameras, while data recording was carried out using writing instruments and transparent plastic for sample storage. Furthermore, this study utilized Geographic Information System devices, such as computers with ArcView 3.3 software, for spatial data processing. Various physical and chemical soil analysis tools were also used to support sample testing in the laboratory.

2.3. Research Design and Sampling Techniques

This research employed a descriptive exploratory approach, conducted through field surveys supported by laboratory analysis. Stratified random sampling was used to collect soil samples, dividing the study area into several strata based on variations in geology, land physiography, topography, and climate. Sampling points were determined by overlaying several relevant thematic maps. Next, a regional delineation process was conducted to identify representative land units as the basis for determining sampling locations. The selected points were deemed representative of the characteristics of the entire study area.

Land suitability classes were determined through direct field evaluations, observing land use productivity at each sample location. The data obtained were then analyzed by matching land characteristics and quality with land suitability class criteria based on plant growth requirements [25], [35]. This approach allows for more accurate identification of the level of land suitability for the studied commodities. In addition to the biophysical evaluation, this study also analyzed aspects of farming feasibility using the R/C ratio approach. Data collection for the economic analysis was conducted through in-depth interviews with respondents involved in agroforestry land management.

2.4. Research Procedures

The research was conducted through three main stages: preparation before fieldwork, field survey implementation, and analysis after fieldwork was completed. The preparation phase began with a literature review to establish a theoretical basis relevant to the research. Secondary data, including spatial data and other supporting information, were then collected to support the analysis. The administrative boundaries of the research area were determined to ensure a clear scope of the study area [36], [37]. Sample points were then determined using a stratified random sampling method, taking into account land use maps, topographic maps, geological maps, and satellite imagery as the basis for determining strata.

The fieldwork phase began with a soil survey, which involved sampling using soil drilling techniques at predetermined points. Each sample location was designated as a representative pedon based on the Soil Map Unit, thus accurately depicting land conditions within a specific area. Soil samples were then collected for further analysis, along with a description of the soil profile at each representative pedon. Field observations also included qualitative identification of soil physical and chemical properties and documentation of general environmental conditions. In addition, random sampling was conducted to support laboratory analysis, while interviews with relevant parties were conducted to obtain data needed for the farming analysis.

The final stage of the research involved laboratory analysis of the collected soil samples. This analysis included testing various physical and chemical parameters of the soil to obtain quantitative information regarding land characteristics. The resulting data were then interpreted using a matching method, which involves matching land characteristics with plant growth requirements to determine land suitability classes [38], [39]. The evaluation results were then presented in the form of an actual land suitability map using Geographic Information System technology. This spatial data presentation aims to facilitate visualization of the distribution of land suitability levels in the research area.

3. RESULTS AND DISCUSSION

3.1. Land Suitability for Teak Plants

The results of matching land characteristics with teak growth requirements indicate that all soil map units in the study area are classified as unsuitable (N). In some land units, the main limiting factors include water availability, effective soil depth, drainage, erosion hazard, and slope gradient. This condition indicates that most land in the agroforestry area of the Upper Solo Sub-watershed has biophysical limitations to support optimal teak growth. These limiting factors vary in each soil map unit, resulting in different combinations of constraints across locations. Nevertheless, all land units remain classified as unsuitable for teak cultivation.

Water availability is the dominant limiting factor found in almost all study locations. This is related to the length of the dry season, which can reach six months, making it unsuitable for the ideal growth requirements of teak. Furthermore, some locations also exhibit limited effective soil depth, which can hinder the development of the plant's root system. In certain land units, slow soil drainage also exacerbates growing conditions. Topographic factors such as slope gradient and potential erosion hazards also exacerbate the level of land suitability limitations.

Although the evaluation results indicated an unsuitable class, field conditions show that teak remains widely cultivated and even dominates the vegetation across all soil map units. This dominance demonstrates teak's adaptability to less-than-ideal environmental conditions. Furthermore, local communities maintain teak cultivation due to its high long-term economic value. Teak, harvested at a productive age, can generate substantial financial returns. This situation highlights the discrepancy between the results of the biophysical land evaluation and community land use practices.

Vegetation analysis shows that teak is the dominant component in almost all observation locations, accompanied by the presence of other plants such as mahogany, acacia, coconut, bamboo, cloves, petai, and peanuts. The presence of these diverse plant species reflects a fairly complex agroforestry pattern. This system allows for more efficient land use through a combination of annual and seasonal crops. In addition to providing economic benefits, vegetation diversity also contributes to the stability of the land ecosystem. Thus, even if the land is low in suitability, the agroforestry system can still operate productively.

Several improvement efforts can be implemented to increase the level of land suitability for teak. To address limited water availability, adjusting planting times to the beginning of the rainy season is a viable alternative. Drainage problems can be addressed through the use of organic mulch or litter, which can improve soil aggregate structure. Erosion and slope hazards can be minimized through the application of soil conservation techniques such as terracing. These measures have the potential to gradually improve land conditions.

However, not all limiting factors can be addressed through technical interventions. Effective soil depth is a factor heavily influenced by long-term natural soil formation processes. Therefore, this limitation is difficult to modify quickly. This condition is one of the main causes of the low land suitability for teak in the study area. Therefore, land management strategies need to focus on limiting factors that can be manipulated.

Overall, the study results indicate that agroforestry areas in the Upper Solo Subwatershed have a low level of land suitability for teak cultivation based on biophysical parameters. Despite this, cultivation practices continue due to teak's high economic value and relatively good adaptability. Addressing certain limiting factors can gradually increase land productivity. These results underscore the importance of integrating land suitability assessments and socioeconomic considerations in agroforestry management. This approach is necessary for sustainable land use.

3.2. Land Suitability for Peanut Plants

The results of the land suitability evaluation for peanuts in the study area show a relatively uniform pattern across almost all Soil Map Units (SPT). Based on the matching of land characteristics with peanut growing requirements, most locations fall into the N;wa; land suitability class, while SPT1K4, SPT2K4, SPT4K4, and SPT6K4 fall into the N;wa;eh; land suitability class. This class indicates that the main limiting factors for peanut cultivation are water availability in the form of high rainfall and steep slopes in some land units. These conditions indicate that the land in the Upper Solo Subwatershed is not yet suitable for optimal peanut growth.

Rainfall is the dominant limiting factor in determining land suitability across all SPTs. Based on analysis of climate data over ten years, the average annual rainfall at the study site reached 2,045 mm per year. This value far exceeds the optimal requirements for peanut plants, which generally require rainfall ranging from 400–1,100 mm per year during their growing season. High rainfall intensity causes excessive soil moisture, potentially disrupting root growth, increasing the risk of disease, and reducing plant productivity. Therefore, high rainfall is categorized as a severe limitation, placing the entire study site in the unsuitable category.

In addition to rainfall, slope gradient also poses an additional limitation in certain land units. Moderately steep to steep slopes increase the potential for surface erosion, reduce soil stability, and complicate intensive land management. This problem is particularly evident in land units classified as K4, directly increasing the level of land unsuitability for peanut cultivation. Without conservation efforts, the risk of losing nutrient-rich topsoil will increase. This situation ultimately impacts the land's low production capacity.

In general, the N land suitability class indicates that the land's optimal production capacity is estimated to be below 40% of the FAO production index reference. This indicates that the Upper Solo Sub-watershed area has significant limitations for conventional peanut cultivation. Low land suitability will result in less than optimal harvest quality and low production quantity. This condition certainly impacts the efficiency of farming operations and the economic benefits that farmers can obtain. Therefore, appropriate management strategies are needed to minimize the impact of these limiting factors.

One alternative improvement that can be implemented is adjusting cropping patterns by selecting planting times that align with local rainfall distribution. Peanuts should be planted during periods with lower rainfall, namely between November and January, so that the plants' water needs can be optimally met without causing excessive waterlogging. This planting time adjustment allows the plants to pass through critical growth phases under more suitable environmental conditions. Thus, growth potential and yields can be increased even when regional climate factors are less than ideal.

This approach to adjusting cropping patterns aligns with the concept of agroclimate adaptation, which adapts plant water needs to local seasonal characteristics. Adjusting the planting season has been proven to increase water use efficiency and reduce the risk of crop failure due to unfavorable climatic conditions. Furthermore, this strategy is relatively easy for farmers to implement because it does not require significant technological investment. Implementing a planting calendar based on local rainfall data can be a practical solution to increase peanut productivity in the study area.

To address the limiting factor of slope gradient, the application of soil conservation techniques such as terracing is highly recommended. Terracing can reduce surface runoff, reduce erosion, and increase water infiltration into the soil. Improving the physical condition of the land through conservation will help create a more stable growing environment for peanut plants. In the context of agroforestry, increasing peanut productivity is crucial because this commodity serves as a source of short-term income for the community. Therefore, optimizing land management through a combination of adjusting planting times and land conservation is a strategic step to increase the economic value of agroforestry systems in the Upper Solo Sub-watershed.

3.3. Farming Business Analysis

The Solo Hulu Sub-watershed is dominated by agricultural land use using agroforestry patterns. The cultivation system employed by the community generally combines perennial and seasonal crops, particularly teak and peanuts, through intercropping. Farmers choose this system because it is considered to provide better economic returns than monoculture cultivation. The combination of the two commodities allows for more optimal land use and provides flexibility in generating income over different periods.

In agroforestry land suitability studies, teak is positioned as the primary crop. This is based on the genetic characteristics of teak, which are relatively resilient to varying environmental conditions compared to annual crops. Determining the primary crop in an intercropping system is crucial for determining the direction of land suitability evaluation and the overall productivity of the system. Therefore, the success of teak cultivation is a key indicator in assessing the effectiveness of agroforestry in the study area. The presence of peanuts serves as a supporting component, providing additional economic benefits.

Farmers' motivation for cultivating peanuts is based on sound economic considerations. Peanuts have a relatively short harvest period, enabling them to generate income more quickly. Furthermore, the relatively high yields and relatively stable selling prices make this commodity attractive for cultivation. Meanwhile, teak, although requiring a long harvest period, has a high timber value. The combination of the two creates a balance between short-term and long-term profits for farmers.

The land management system implemented by communities in the Solo Hulu Sub-watershed has adopted soil conservation principles. This is demonstrated through the use of organic fertilizers and pesticides in cultivation activities. Irrigation is still largely dependent on rainfall or a rain-fed system. This condition requires farmers to adapt their cropping patterns to seasonal dynamics. Given that agriculture is the primary source of livelihood for the community, the success of agroforestry systems has a significant impact on local economic stability.

To assess the profitability of teak and peanut farming, an economic analysis was conducted using the revenue-to-cost ratio (R/C) approach. This analysis considers both tangible and intangible costs as a basis for evaluating farming efficiency. The analysis showed that peanut cultivation has an average R/C ratio of 2.02, with a harvest yield ranging from 1,000 to 1,500 kg. Meanwhile, teak cultivation yielded an average R/C ratio of 20.22, with a production of approximately 300–400 trees at a harvest age of 15–20 years. This value indicates that both commodities are economically viable.

An R/C ratio greater than one indicates that the farming business is able to generate profits and capital efficiency. This condition indicates that the teak and peanut agroforestry system in the study area has good economic prospects. Capital efficiency is an important indicator in assessing the feasibility of agricultural investments. With this level of profitability, farmers have the opportunity to improve their welfare through optimized land management. This system can also serve as a model for developing sustainable farming businesses in similar areas.

The development of teak and peanut-based agroforestry in the Solo Hulu Sub-watershed offers benefits not only economic but also ecological and social. This system allows farmers to generate short-term income from peanuts while awaiting long-term yields from teak. Thus, economic risk can be minimized due to the diversification of income sources [40], [41]. In addition to improving farmer welfare, agroforestry patterns also

contribute to land resource conservation. Therefore, the implementation of this integrated planting system can be an effective strategy in supporting sustainable agricultural development in the Solo Hulu Sub-DAS area.

Land suitability evaluation in agroforestry areas plays a strategic role in supporting sustainable land resource management. In the context of the Solo Hulu Sub-watershed, land suitability analysis is a crucial approach for understanding the relationship between the biophysical characteristics of the land and the growing needs of cultivated crops. Agroforestry systems that combine forestry crops like teak with annual crops like peanuts require good ecological compatibility for optimal productivity [42], [43]. This compatibility relates not only to crop productivity but also to soil and water conservation functions. Therefore, land suitability evaluation is a crucial basis for land-use planning that adapts to local environmental conditions.

Theoretically, land suitability is influenced by complex interactions between climate, topography, soil physical properties, and chemical characteristics. In agroforestry systems, this complexity is further enhanced by the interactions between plant species in utilizing growing space, water, and nutrients [44], [45]. Teak, as an annual crop, has a high degree of adaptability to various marginal land conditions, while peanuts require more specific environmental conditions to support optimal generative growth. These differing ecological needs require a land management strategy that considers the ecological trade-offs between the two commodities. Therefore, a land evaluation approach based on specific plant characteristics is highly relevant.

The implementation of an agroforestry system in the Upper Solo Sub-watershed also plays a crucial role in supporting watershed conservation. Agroforestry has been shown to improve slope stability by strengthening soil structure with the root systems of perennial plants [46], [47]. Furthermore, the presence of cover vegetation helps suppress surface runoff and reduces the risk of erosion, a major problem in sloping areas. The integration of teak and peanut plantations creates a dual function: an ecological function through land protection and an economic function through diversified production. This approach aligns with the principles of sustainable agricultural development, which emphasize a balance between productivity, conservation, and community well-being.

From a socio-economic perspective, agroforestry systems offer opportunities to increase farmers' incomes through diversified income sources. Combining annual and seasonal crops allows farmers to reap both short- and long-term economic benefits. Peanuts can yield a harvest in a relatively short time, while teak serves as a long-term investment with high economic value. This pattern is especially important for rural communities that depend on agriculture for their livelihoods. With accurate land suitability information, farmers can develop more efficient cultivation strategies, thereby minimizing the risk of farm failure.

The impact of this research is significant, both scientifically and practically. Scientifically, this research enriches the study of land suitability evaluation in agroforestry systems by providing an overview of the relationship between land characteristics and the potential for developing specific commodities in the sub-watershed. Practically, the study results can serve as a basis for local governments, agricultural extension workers, and communities in formulating land management policies based on local potential. This information can also be used to design more targeted land conservation strategies to maintain the sustainability of the ecological function of the Upper Solo Sub-watershed. In the long term, implementing land suitability-based recommendations can contribute to increased food security and environmental rehabilitation.

However, this research has several limitations. Current land suitability analyses still focus on biophysical parameters and have not fully integrated socio-economic aspects, such as market access, farmer technological capacity, and local institutional dynamics. Furthermore, the data used represents conditions at a specific time period, thus not fully capturing the dynamics of environmental change due to climate change or land-use changes. Another limitation lies in the limited spatial coverage of the study area, requiring caution in generalizing the results to other regions.

These limitations open up opportunities for further research to develop a more comprehensive approach to land suitability evaluation. Integrating spatial data based on remote sensing technology, long-term climate analysis, and a participatory approach with direct farmer involvement can yield more applicable recommendations. Furthermore, further studies on land management scenario simulations are needed to predict the response of agroforestry systems to future environmental changes. This will enable agroforestry development in the Upper Solo Sub-watershed to be more adaptive, efficient, and sustainable.

4. CONCLUSION

Based on the results of the land suitability evaluation in the agroforestry area of the Solo Hulu Sub-watershed, teak plantations show variations in land suitability classes in each Soil Map Unit (SPT). However, generally, all locations fall into the unsuitable (N) category, with the main limiting factors being water availability, effective soil depth, drainage conditions, and erosion hazard. In some land units, an additional limiting factor, slope gradient, also worsens the land suitability level. However, the presence of teak plantations growing predominantly in the study area indicates that this crop can still be cultivated with proper land management. This condition indicates that these limiting factors can be minimized through the application of

conservation techniques and appropriate cultivation management. For peanuts, the evaluation results indicate that almost all land units fall into the N₂w₁ class, with the main limiting factor being excessively high rainfall. In certain land units, slope gradient is an additional limiting factor, further reducing the land suitability level. This condition indicates that the study area is actually unsuitable for peanut cultivation without special management efforts. High rainfall is a major constraint because it does not meet the optimal growth requirements of peanuts. Therefore, adjusting planting times and water management are crucial aspects in developing this commodity.

The results of the farming analysis indicate that the teak and peanut agroforestry system remains economically viable. Teak has an average R/C ratio of 20.22, while peanuts have a R/C ratio of 2.02. An R/C ratio greater than one indicates that both commodities provide economic benefits to farmers. This agroforestry system can provide both short-term income through peanuts and long-term income through teak. Therefore, the combination of these two commodities represents a financially viable and strategic farming model for implementation in the Solo Hulu Sub-watershed. Further research is recommended to integrate land suitability analysis with socioeconomic aspects, climate change, and the use of remote sensing technology to obtain more comprehensive and applicable results. Furthermore, experimental studies are needed on the application of land conservation techniques and adaptive agroforestry management to sustainably increase teak and peanut productivity in the Upper Solo Sub-watershed.

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AUTHOR CONTRIBUTIONS

Conceptualization, B.W. and I.K.I.; Methodology, B.W.; Software, I.K.I.; Validation, B.W. and I.K.I.; Formal Analysis, B.W.; Investigation, B.W.; Resources, B.W.; Data Curation, I.K.I.; Writing – Original Draft Preparation, B.W.; Writing – Review & Editing, I.K.I.; Visualization, I.K.I.; Supervision, B.W.; Project Administration, B.W.; Funding Acquisition, I.K.I.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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