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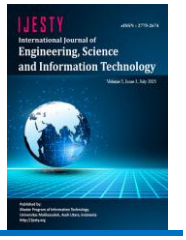

Optimizing Annual Cropping Patterns Using A multi-objective Approach to Maximize Income and Minimize Soil Erosion

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Abstract

This research investigates planting strategies to optimize productivity and conserve soil, focusing on potatoes and onions grown on erosion-prone land. Cross planting versus perpendicular plantings is evaluated using the MOORA (Multi-Objective Optimization Based on Ratio Analysis) method based on erosion rates, crop productivity, and economic outcomes. Meanwhile, data from six experimental contour and perpendicular planting plots are analyzed. The measurements for sediment and runoff are carried out using a dual-bucket system. After erosion calculations, the highest erosion rate was found in the contour planting of shallots at 385,65 tons/ha/year. At the same time, Potatoes planted perpendicular to the contour lines resulted in the lowest erosion rate, at only 114.51 tons/ha/year. Economic analysis, considering crop productivity and financial outcomes, revealed the highest productivity for potatoes planted perpendicular to the contour at Rp. 26.891 kg/ha, and the highest Income for the contour planting of potatoes at Rp. 215.133.360/ha. Optimization using the MOORA method, which calculates minimal erosion (cost) and maximal Income (benefit), yielded the highest value for potatoes planted along the contour at 0.409963. This was followed by perpendicular planting (0.075816) and shallots along the contour (0.067163). The MOORA method can provide optimal planting pattern recommendations by analyzing multiple criteria, including soil erosion and productivity, thereby offering practical guidance to farmers and policymakers in making more economically viable and sustainable planting decisions.

Keywords: *Soil Erosion, Multi-Objective Optimization, Contour Planting, Sustainable Agriculture.*

1. Introduction

The Dieng Plateau in Indonesia is a crucial upstream watershed, facing severe environmental challenges due to steep slopes and intensive agricultural activity [1]. Initially, a conservation zone supporting water retention and soil fertility [2], as well as increasing demand for high-value crops such as potatoes (Solanum tuberosum) and onions (Allium cepa) [3], has transformed the landscape. This leads to deforestation, soil degradation[4], and sedimentation in local rivers and reservoirs [5]. Farming on steep terrain increases soil erosion[6], particularly with inadequate conservation practices [7]. Traditional methods, such as contour planting and buffer strips, are underused due to labor demands and misconceptions about yield impacts [8]. Furthermore, high seasonal rainfall [9] aggravates erosion, decreasing soil fertility and agricultural productivity [10].
Based on the description above, this research uses MOORA (Multi-Objective Optimization Based on Ratio Analysis) method to identify optimal planting strategies, comparing contour planting vs. cross-contour planting[11]. Data from experimental [12] plots show that contour planting significantly reduces erosion and maintains yields to achieve a balanced solution for sustainable highland agriculture [13] [14]. Despite labor demands, terracing and vegetative barriers effectively mitigate erosion [15]. Adopting the practices supports economic productivity and preserves ecological integrity [16], contributing to sustainable development in highland areas [17]. By integrating soil conservation and financial analysis, this research offers a model for addressing environmental challenges in similar regions, advancing sustainable highland agriculture [18].

2. Materials and Methods

Potato and shallot farming was optimized in Wonosobo using the MOORA method [19] [20] to (1) maximize crop yield income and (2) minimize soil erosion. Data on land characteristics, rainfall, planting patterns, and sediment/runoff levels were gathered. Subsequently, the MOORA method was used to analyze and balance the objectives of maximizing Income and minimizing soil erosion.

This research was conducted in the Dieng Plateau, Wonosobo Regency, with annual rainfall of 2,500–3,500 mm and steep slopes (15% to over 40%) [21]. Data collection (**Figure 1**) from January to March 2024 focused on soil erosion rates, crop yield, and planting configurations across six plots, namely three with contour to reduce runoff and three control plots for perpendicular planting. Rainfall data recorded 1,821 mm during the Period, contributing to 3,466 mm annually. Meanwhile, high-intensity rainfall from February 5–11 (357 mm) correlated with significant erosion. Economic impacts were analyzed using production costs and revenues for each configuration. The results emphasize the effectiveness of contour planting in reducing soil erosion under rainfall conditions and the economic advantages, reinforcing the role in sustainable highland agriculture.

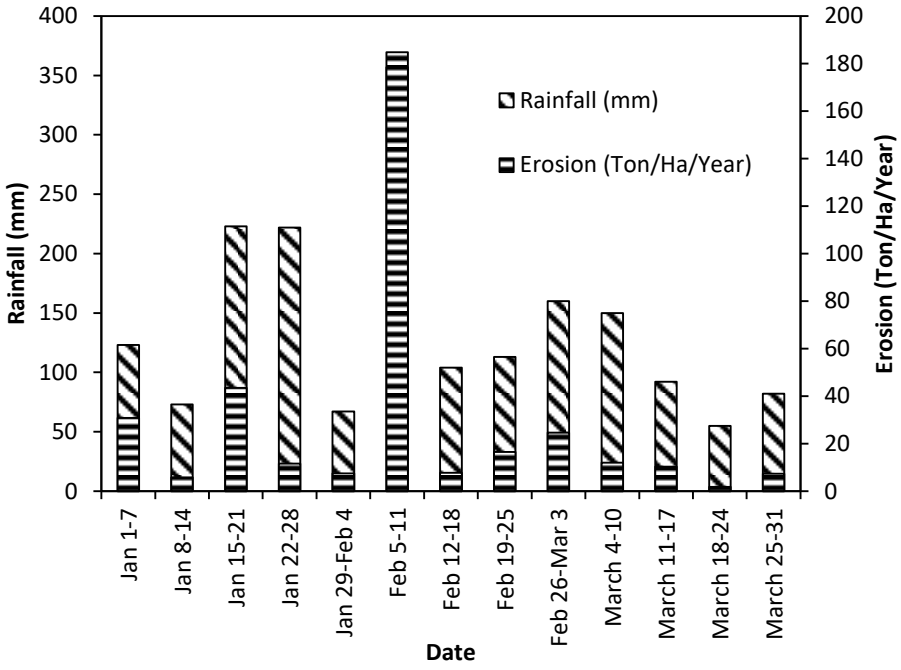

Fig. 1. Weekly rainfall in research area

This research uses essential materials for precise erosion measurement and planting pattern evaluation. Wooden plot boundaries prevent external water intrusion [22] and maintain stability, while stakes and bolts reinforce the setup. Runoff water and sediment are collected in a dual-bucket system, where the first and second capture heavier sediment and retain finer particles, respectively. Plots, sized 7x1 meters, include planting patterns (potato, onion, and fallow) perpendicular to contour to assess erosion. Data collection tools, comprising GPS, compasses, cameras, and a two-basin system, ensure accurate measurements. The first and second basin settles heavier sediment and capture finer particles, respectively. PVC gutters direct runoff and sediment to the basins [23] [24], minimizing loss and allowing precise assessment of rainfall, runoff volume, and levels. **Figure 2** shows the sediment catchment basins and PVC gutters, reporting their role in supporting controlled and reliable erosion and productivity analysis.

The experimental setup analyzes soil erosion under different planting conditions, including sections for potatoes, shallots, and bare soil, connected to sediment traps to measure erosion. This setup enables direct comparison of rates, supporting sustainable agricultural practices on sloped land. The 80 cm wide bed accommodates two rows of shallots planted 15 cm apart, while potatoes are spaced 35 cm. Gutters measuring 12 cm in length and 10 cm in height and 2-inch diameter pipes ensure adequate irrigation. Sediment collection uses buckets with top and bottom diameters of 30.8 cm and 27.2 cm and a height of 33 cm to optimize space and resources for crop growth.

Erosion Measurement Method and Sediment Processing

This research measures erosion using plots with boundaries to prevent external interference. Each plot, sized 1 x 7 meters with four berms, is positioned along the slope. Runoff water [9] and sediment are collected in a dual-bucket system, where the first and second capture heavier sediment and retain finer particles, respectively. The dual-bucket sediment trap system separates heavier particles in the first bucket and finer sediment in the second, ensuring precise sediment and erosion rate measurements. Overflowed sediment is calculated by measuring both buckets [25], while runoff volume is recorded from the second. In the lab, sediment samples are separated, dried, and weighed to calculate erosion rates in kilograms per square meter (kg/m²). This data enables comparative analysis of planting patterns to identify the most effective arrangement for minimizing erosion.

Fig. 2. Field Site Conditions for Rainfall, Runoff, and Sediment Measurement

Multi-Objective Optimization in Agriculture
MOORA method facilitates the simultaneous evaluation of multiple criteria for assessing and selecting optimal planting patterns[26] that balance crop yield with soil conservation efforts [27]. In this context, decision-making includes several steps, beginning with constructing a matrix X_ij where each entry represents the performance of an alternative i against criterion j.

3. Results and Discussion

This research shows that parallel-to-contour planting significantly reduces soil erosion compared to perpendicular-to-contour, particularly on steep slopes. Erosion measurements, sediment collection, and rainfall data analysis show the effectiveness of contour planting in preserving soil and improving crop yields. These results support contour planting as a sustainable practice for environmental and economic benefits in highland agriculture.
Erosion measurement in the Dieng Plateau evaluated soil conservation practices for potato and onion crops on steep slopes. **Figure 3** reports weekly rainfall trends, showing fluctuations and correlation with erosion levels.
Figure 4 shows the effectiveness of planting configurations in controlling soil erosion, with contour planting significantly outperforming the perpendicular method. Contour planting reduced soil erosion rates for potatoes (364.37 tons/ha/year) and onions (325.65 tons/ha/year), while perpendicular resulted in higher losses, averaging 114.51 tons/ha/year and 315.26 tons/ha/year. Even though contour-planted potatoes experienced higher erosion rates (364.37 tons/ha/year), the results are improved by combining the method with sediment traps.

Optimization Outcomes (MOORA Analysis).
The decision matrix consists of alternatives representing different planting patterns and criteria such as Net Profit, Yield, Production Cost, Soil Erosion, Growing Period, Demand, and Productivity. The values in the matrix reflect the actual measurements or estimated values of each criterion for each alternative. **Table** 1 shows that potatoes planted along the contour achieved the highest net profit (Rp 26,892) and productivity (76,8 %). Onions planted against contour recorded the lowest net profit (Rp 8,150) and productivity (65,2%a). Therefore, contour planting offers superior economic and productivity benefits compared to planting against contour.

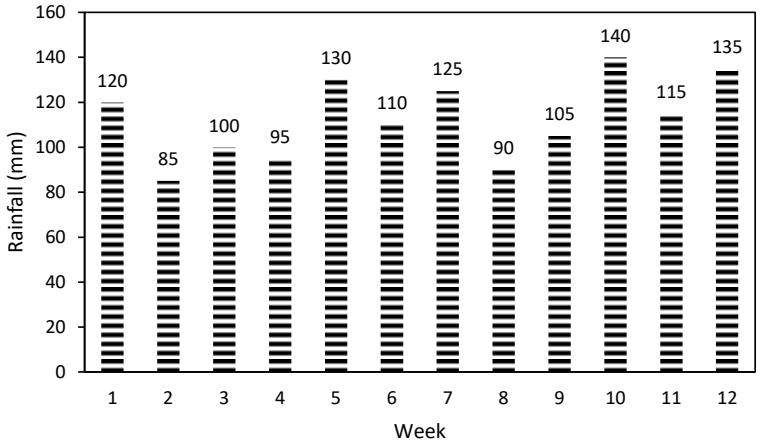

Fig. 3. Three (3) month rainfall measurements

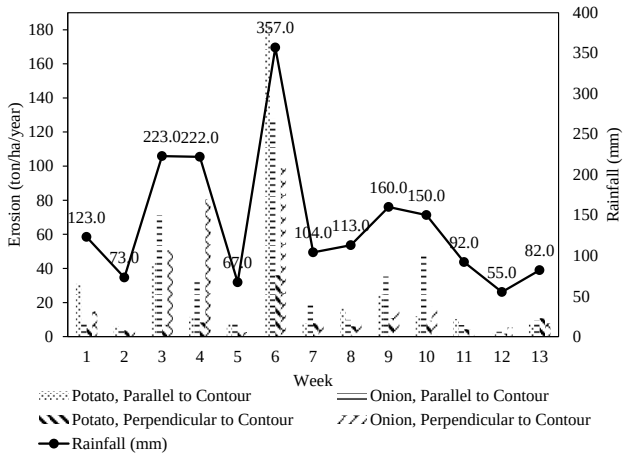

Fig. 4. Soil Erosion by planting pattern

MOORA score for each planting pattern is calculated using the normalized values and weights. Beneficial criteria, such as Net Profit and Yield, are maximized, while non-beneficial criteria, including Production Cost and Soil Erosion, are minimized. **Table 2**. shows MOORA scores for planting patterns, and the highest score is "Potato Along Contour" (MOORA Score: 0.410), the optimal choice for balancing productivity and environmental sustainability. Therefore, planting potatoes along a contour is the most effective method for minimizing soil erosion and maximizing yield and profitability.

Table 1. Decision matrix

Planting Pattern	Yields (ton/ha)	Erosion (ton/ha/ year)	Growing Period (days)	Productivity (%)
Potato Along Contour	26.892	364	120	76,8
Potato Perpendicular to Contour	21.921	115	120	62,6
Onion Along Contour	8.325	326	65	66,6
Onion Against Contour	8.150	315	65	65,2
Vacant Land Along the Contour	-	248	-	-
Vacant Land Perpendicular to the Contour	-	317	-	-

Table 2. MOORA Scores for Planting Patterns

Alternatives	Total Benefit	Total Cost	MOORA score
Potato Along Contour	0.633	0.224	0.410
Potato Perpendicular to Contour	0.506	0.163	0.344
Onion Along Contour	0.485	0.187	0.299
Onion Against Contour	0.477	0.186	0.292
Vacant Land Along the Contour	0.000	0.011	-0.011
Vacant Land Perpendicular to the Contour	0.000	0.071	-0.071

4. Conclusion

In conclusion, three-month research (January–March 2024) using the MOORA method showed that Potatoes Along contour achieved the highest score (0.409963), serving as the best planting pattern for balancing economic and environmental benefits. This pattern offered optimal results at lower costs. Other alternatives, such as potatoes perpendicular to the contour (0.075816) and shallots along the contour (0.067163), also performed well but were less effective. Shallots against contour showed the lowest MOORA score (0.065601), showing limited effectiveness and potential use in specific scenarios. These results showed the importance of sustainable agricultural practices, particularly contour planting, to optimize productivity, mitigate environmental degradation, and ensure long-term economic gains.

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