Multi-criteria Decision Analysis (MCDA) and GIS-assisted Suitability Evaluation for Corn (Zea mays L.) Production in Negros Oriental, Philippines

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Multi-criteria Decision Analysis (MCDA) and GIS-assisted Suitability Evaluation for Corn (*Zea mays* L.) Production in Negros Oriental, Philippines

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Abstract. *The application of Multi-Criteria Decision Analysis (MCDA) integrated with Geographic Information Systems (GIS) was used to assess and map land suitability for corn (Zea mays L.) production in Negros Oriental, Philippines. Key environmental criteria, including climate (annual rainfall and temperature), topography (slope), soil (erosion hazard, slope, and pH), and land cover, was evaluated to optimize agricultural productivity. The weighted overlay, weighted sum, and raster calculator analyses were used in the study to generate the suitability map. The results showed that 24.42% of the land is highly suitable for corn cultivation, 74.66% is moderately suitable, and less than 1% is marginally suitable. The study recommends interventions such as organic matter additions, cover cropping, mulching, and balanced fertilization to improve soil fertility and plant growth to enhance suitability and agricultural sustainability. This study provides valuable insights for improving corn productivity in Negros Oriental, addressing environmental challenges, and promoting resilient agricultural practices.*

Keywords: *suitability; corn production; GIS; MCDA; AHP;*

1. INTRODUCTION

The multi-criteria decision analysis (MCDA) is a method that helps decision-makers evaluate, prioritize, and select between many conflicting alternatives and criteria [1]. It serves as an essential framework for determining the suitability of crops by integrating various decision-making techniques and criteria. This approach not only aids in optimizing crop selection but also enhances sustainability in agricultural practices by comprehensively considering environmental and socio-economic factors. Integrating Geographic Information Systems (GIS) further enriches the analysis, enabling precise mapping and visualization of crop suitability across the study area [1]. The MCDA is increasingly utilized in land suitability assessments to evaluate various land use options based on multiple criteria. This approach integrates different factors affecting land use, such as environmental, economic, and social dimensions, to determine the most suitable areas for specific purposes like agriculture or urban development [2]. Analytic Hierarchy Process (AHP) is widely used in MCDA to establish priorities among different criteria through pairwise comparisons. Each criterion is assigned a weight based on importance, allowing for a structured decision-making process [2]. The GIS-assisted suitability evaluation for corn (*Zea mays* L.) production involves the integration of GIS with various analytical techniques to assess and map areas suitable for maize cultivation. This approach is increasingly important in optimizing agricultural productivity, particularly in regions facing environmental challenges. GIS-assisted suitability evaluations provide essential insights into optimizing corn production by identifying areas where environmental conditions align favorably with maize cultivation needs. By leveraging advanced analytical techniques and comprehensive data collection, these assessments support sustainable agricultural practices and informed land-use planning across diverse ecosystems [3]. The current agricultural landscape in Negros Oriental shows a mix of traditional and modern farming methods. The province has approximately 27,103 ha. of land dedicated to white corn production as of the second quarter of 2023, with a total production of around 24,930 metric tons (MT) during that period. Despite this, challenges such as soil erosion and inadequate water management practices hinder productivity [4]. The status of corn production in Negros Oriental, Philippines, is currently challenging due to a combination of climatic factors and land suitability issues. As of April 2024, agricultural losses in the province reached over PHP 229 million, affecting various crops, including corn [5]. This decline is reflected in a reported 20.35% decrease in corn production from the second quarter of 2023 to the same period in 2024, dropping from 1.47 to 1.17 million MT [6]. In this connection, the suitability evaluation for corn production in Negros Oriental, Philippines, can be approached using GIS and multi-criteria decision-making techniques to improve its current situation. Studies in this region are limited, but methodologies applied in similar contexts can provide valuable insights. A GIS-assisted suitability evaluation for corn production in Negros Oriental can help reveal critical insights into optimal farming locations based on environmental conditions. The objectives of this study were to utilize AHP-MCDA integrated GIS to assess and map land suitability for corn production in Negros Oriental, Philippines. The AHP was used to evaluate multiple criteria and determine their respective weights and priorities. The criteria included climate (annual rainfall and temperature), soil properties (soil erosion hazard, slope, and soil pH), and land cover. The integration of these criteria was carried out using GIS analyses—specifically, weighted overlay, weighted sum, and raster calculator tools—to determine overall land suitability and generate suitability maps to identify optimal areas for sustainable corn cultivation in the province through GIS-assisted MCDA, focusing on improving agricultural productivity and resilience against climatic challenges and informing land-use planning for enhanced production and environmental sustainability.

2. MATERIALS AND METHODS

GIS-based suitability assessment for corn production across Negros Oriental involves evaluating the land suitability for corn cultivation using GIS and MCDA, particularly AHP. This involved analyzing the Land Mapping Units (LMUs) in the province based on a defined set of criteria. This approach considered various factors affecting corn production, such as climate (annual rainfall and temperature), soil properties (soil erosion hazard, slope, and soil pH), and land cover, respectively.

2.1 Study Area

Negros Oriental has a total land area of 5,402.30 km^2 with 19 municipalities, six cities, and 557 barangays (villages or districts) [7]. The province of Negros Oriental is part of the Visayas Region, which is in the middle of the Philippine Archipelago [8].

2.2 Data Sources

Different secondary data sources were used to analyze the land suitability of corn production. Rainfall and temperature data were obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) [9]. Slope data were derived from SRTM 30-meter resolution Digital Elevation Model (DEM) sourced from USGS EarthExplorer [10]. Both erosion and soil pH (derived from soil type) data were obtained from the Bureau of Soils and Water Management (BSWM) and the land cover data was obtained from the National Mapping and Resource Information Authority (NAMRIA) through the Geoportal website [11].

2.3 Identifying Weights using the Analytic Hierarchy Process (AHP)

AHP was used to assign weights to each parameter based on its perceived importance on corn production by a total of ten experts from the academe, attached bureaus and agencies of agriculture, and farm associations. Pairwise comparisons were performed to determine the relative weights of each parameter. The weights of these criteria were determined through expert opinions and pairwise comparison matrices. The ten experts were from the academe, attached bureaus and agencies of agriculture, and farm associations. An AHP software (Super Decisions v3.2) was used to analyze the data from the ten experts and ensure that the AHP matrix was consistent. For the consistency of the matrix to be considered acceptable, the Consistency Ratio (CR) must be less than 10%.

2.4 GIS Data Processing

The precipitation and temperature data from nearby PAGASA weather stations were interpolated using Inverse Distance Weighting (IDW) to create raster layers representing the spatial distribution of annual precipitation and mean annual temperature in Negros Oriental province. These interpolated raster layers were then integrated into the Geographic Information System (GIS) and overlaid with other relevant raster layers to assess landscape suitability. An SRTM 30m DEM was used to derive slope data. Moreover, soil pH and erosion hazard were incorporated in the GIS map layer for suitability analysis. After the raster layers were produced, they were reclassified according to corn suitability. The basis for raster preparation and reclassification is shown in Table 1. Each parameter's raster layer was reclassified based on its suitability for corn cultivation. In accordance with the FAO Land Evaluation framework, the layers were reclassified into "highly suitable (S1)", "moderately suitable (S2)", "marginally suitable (S3)", "currently not suitable (N1)", and "permanently not suitable (N2)" based on corn's suitability [12].

2.5 Generating the Suitability Map

Using ArcGIS Pro 3.0, the initial step in creating the corn suitability map was to ensure spatial accuracy and consistency during analysis, it was crucial to align all datasets to a common coordinate system. This involved verifying the coordinate system of each dataset and, if necessary, reprojecting them to ensure uniformity across all spatial data layers. The second step involved converting the features to raster format using the "Feature to Raster" tool. This step transformed the vector datasets into raster layers suitable for spatial analysis. Subsequently, the raster layers were reclassified using the "Reclassify" tool to standardize the datasets to a common suitability scale (1 to 5), with 1 denoting N2 to 5 denoting S1 based on corn suitability requirements. To generate the final corn suitability map, three overlay tools were utilized to combine the reclassified raster layers: Weighted Overlay, Weighted Sum, and Raster Calculator. In the Weighted Overlay approach, each reclassified raster was assigned a percentage influence in integer type (whole numbers) as its weights, reflecting its importance in corn suitability. The tool then combined these layers by multiplying each cell value by its assigned weight and summing the results to produce a suitability map. In the Weighted Sum method, each layer was assigned a specific weight as positive decimal values based on the AHP results. The tool then calculated a weighted sum for each cell by multiplying the cell values by their respective weights and summing them, resulting in a suitability map. Lastly, the Raster Calculator allowed for the construction of a custom formula within the GIS software to compute a suitability index directly. By inputting a mathematical expression that incorporated the reclassified layers and their corresponding weights, the Raster Calculator computed the suitability index for each cell, offering flexibility in the analysis. Each of these tools provided a method to integrate multiple factors into a comprehensive suitability map, facilitating informed decision-making for corn cultivation planning. A model was created in the ArcGIS Pro ModelBuilder toolbox to automate the analyses to produce the suitability maps (Figure 1). The resulting composite raster had each cell that represented the overall suitability for corn cultivation and displayed suitability levels across the study area, represented by values and a gradient color scheme (Figure 2).

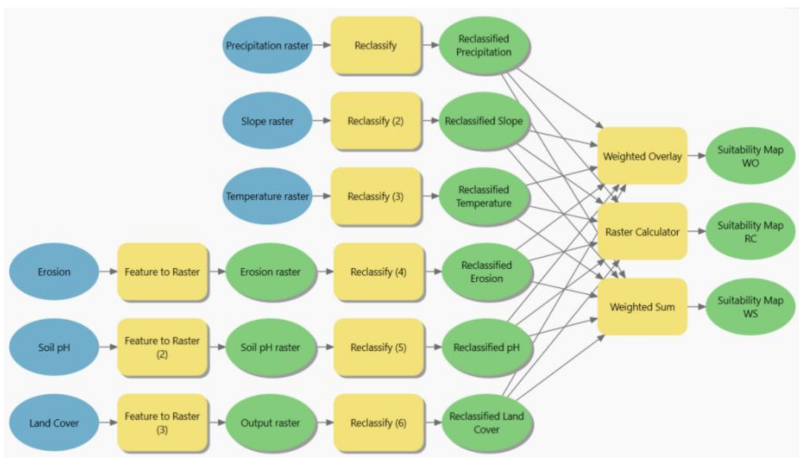

Figure 1. Corn Suitability model using ArcGIS Pro ModelBuilder.

Table 1. Climatic and Land Requirements of Corn and Suitability Classification [12]

LAND AND CLIMATIC CHARACTERISTICS						
Class	S1		S2	S3	N1	N2
Rating Scale	5		4	3	2	1
Rating Scale	95-100	85-95	60-85	40-60	25-40	0-25
Annual Precipitation (mm)	> 2000	2000-1000	1000-500	500-250	-	< 250
Mean Annual Temperature (^{0}C)	29-26	26-24	24-22	22-20	-	< 20
Slope (%)	0-4	4-8	8-16	16-30	30-50	> 50
pH (H_2O)	6.4-6.8	6.8-7.8	7.8-8.0	8.0-8.2	< 4.5	> 8.2
Erosion Hazard	None	None	Slight	Moderate	-	Severe, Unclassified
Land Cover	-	-	-	-	-	-

3. RESULTS AND DISCUSSION

3.1 Criteria Ranking

Table 2 shows the expert-elicited weights for parameters deemed important for corn suitability in Negros Oriental. The AHP results quantify the relative importance of these six criteria before generating the corn suitability model. The experts agree that precipitation (0.33) is the most critical factor, reflecting corn's dependence on sufficient rainfall for optimal growth and development. In Negros Oriental, where climatic patterns may vary across the area. Corn production in the province is substantially affected by climatic conditions, particularly the reliance on rainfed systems. Recent reports have noted that rainfed areas contribute significantly to the overall corn yield, although the specific percentages vary by year and environmental conditions. The reliance on rainfed agriculture makes corn production in Negros Oriental particularly vulnerable to weather fluctuations and events like El Niño. For instance, recent agricultural losses due to El Niño have been reported to reach PHP 229 million, affecting various crops in the province [5]. This highlighted the challenges faced by farmers who depend heavily on rainfall for their crop yields.

Slope (0.22) is the second-highest criterion, which highlights concerns about terrain suitability. Steeper slopes can lead to challenges like erosion and water runoff, impacting the feasibility of cultivation. This is particularly relevant in the hilly and mountainous areas of Negros Oriental. Steep slopes are highly susceptible to soil erosion, especially during heavy rainfall. The loss of topsoil can significantly reduce soil fertility, making it difficult for crops to thrive. This can also lead to sedimentation in nearby water bodies, impacting local ecosystems and water quality. A geohazard assessment study was previously carried out in the province by the Department of Environment and Natural Resources (DENR) have classified as many as 76 barangays as highly vulnerable, including those with ongoing or recent landslides, huge and many tension cracks, steep slopes, unstable geology, and proximity to fault lines, among other characteristics [13]. The annual temperature (0.20) is ranked third, followed by land cover (0.1), erosion (0.09), and soil pH (0.06). The erosion's lower weight indicates that while it is a concern, it may not be immediately impactful in decision-making compared to precipitation and slope. Soil pH is deemed the least critical, according to experts. This suggests that most soils in Negros Oriental fall within a suitable pH range, or its impact is perceived as manageable with interventions like liming or fertilization [14].Table 2. The AHP results for GIS-based corn suitability analysis.

Criteria	Weights
1. Annual Precipitation	0.33130
2. Annual Temperature	0.20184
3. Land Cover	0.09771
4. Slope	0.21960
5. Erosion	0.08545
6. Soil pH	0.06411
Consistency Ratio (CR)	0.09549

3.2 Mean Annual Precipitation

Precipitation plays a central role in defining the world's agro-climatic zones, each characterized by unique land-use patterns and influencing the length of the growing season for crops. In Negros Oriental, the annual precipitation interpolated using IDW ranges from 1,322-2,178 mm, which indicates that the entire province is suitable for corn farming due to its adequate moisture supply. Precipitation serves as a vital source of moisture, essential for sustaining corn growth and enhancing productivity. The climate and precipitation patterns in Negros Oriental create an ideal setting for crops like corn that require consistent moisture throughout their growing season. In well-watered settings, corn typically requires 650 mm of water overall, with a range of 500–800 mm [15]. The distribution of rainfall in Negros Oriental, Philippines, is characterized by a tropical climate with distinct wet and dry seasons. Negros Oriental experiences a tropical monsoon climate, characterized by significant rainfall throughout the year, around 245 rainy days per year, which constitutes about 67.25% of the time [9].

3.3 Mean Annual Temperature

The mean annual temperature of Negros Oriental is 27.74-27.97 °C interpolated using IDW [9]. This temperature range is optimal for corn, which thrives in warm climates. Corn typically grows best at temperatures between 20°C and 30°C, in which the mean annual temperature in Negros Oriental falls comfortably within this range, promoting healthy growth and high yields. Warm temperatures significantly enhance corn growth, particularly during its vegetative and reproductive stages. This temperature effect is crucial as it directly influences photosynthesis and overall productivity. Corn utilizes the C4 photosynthetic pathway, which allows it to convert sunlight into energy efficiently. Warmer temperatures can increase the rate of photosynthesis, leading to greater biomass accumulation and yields [16]. During the vegetative stage, warm temperatures promote leaf development and overall plant vigor. This stage is critical for establishing a robust canopy that maximizes light capture [17, 18, 19].

3.4 Land Cover

Cultivated areas mixed with brushland/grassland dominate at 76.63%. This suggests that the primary use of land is for agricultural purposes despite some limitations. Arable land (crops, mainly cereals and sugar, accounts for 6.09% of the total area. Despite its relatively small share, this is the most fertile and productive category, while open canopy areas and cropland mixed with plantations (either other types or coconuts) together constitute around 11.11% of the land, indicating some agricultural viability with constraints. Various land types, including grasslands, mangroves, coral reefs, lakes, and coconut plantations, are categorized as unsuitable for the given purpose, comprising a significant portion of the remaining land. At 0.04%, built-up areas indicate minimal urban or infrastructure development in the province. The vast extent of moderately suitable land (76.63%) underscores its potential for targeted improvements, such as enhancing irrigation or adopting better farming practices to improve productivity [11]. The major crops of the province include sugarcane, rice, corn, and various fruits. The significant area devoted to these crops suggests that agricultural practices have expanded over the years, reflecting an increase in cultivated land. In addition to palay and corn, Negros Oriental also produces other important crops, including cassava, sugarcane, bananas, banana saba, and coconut (with husk). Based on the 2018 output volume reported by the Philippine Statistics Authority (PSA), these are the province's top five other crops [4].

3.5 Slope

Among the slope classes, the rolling to moderately steep (22.07%) is the largest proportion, covering about 154,341 ha. This suggests a significant portion of the landscape has gentle to moderate gradients, which may influence land use, such as agriculture or settlements, depending on soil conditions and accessibility. Coming in second is the undulating to rolling (20.73%), covering nearly 145,000 ha. This category represents transitional zones where topography varies, often suited for mixed land use like agroforestry or moderate farming. Level to nearly level (16.20%) represents flat or near-flat areas, encompassing 113,238 ha. These areas are typically ideal for intensive agriculture, urban development, or industrial purposes due to ease of construction and farming [10]. Very steep terrains (16.08%) cover 112,448 ha, presenting challenges for development but potentially suitable for forestry, watershed management, or conservation areas. Gently sloping to undulating (12.83%) is about 89,701 ha, these areas provide a balance between accessibility and suitability for diverse uses, such as grazing or low-intensity farming. While steep (12.09%), comprising 84,510 ha, may pose challenges for mechanized farming but can support reforestation or niche farming techniques, depending on soil type and rainfall. After reclassification for corn suitability, the highly suitable area for corn is 16.20%. The moderately suitable area is 12.83%, currently not suitable is 58.89%, and permanently not suitable is 12.09%. Most of the area (58.89%) is currently not suitable for corn farming, indicating significant challenges for expansion without intensive interventions. Highly suitable and moderately suitable areas collectively account for 29.03%, offering clear opportunities for focused corn production.

3.6 Soil Erosion

Slight erosion (35.66%) is the most common category, covering over a third of the total area in Negros Oriental, indicating mild soil displacement and is likely manageable through sustainable land management practices. Moderate erosion (32.40%) is nearly a third of the area, which can reduce agricultural productivity and compromise ecosystem health. A significant portion of the land is severely eroded, which could render areas unsuitable for agriculture or other uses accounting for 18.27%. Meanwhile, 12.69% of the area has no apparent erosion. A minimal area which accounts for miscellaneous and unclassified erosion is only <1% [11]. After reclassification for corn suitability, highly suitable areas for corn cultivation correspond to 48.35% which is nearly half of the total land area. Moderately suitable areas are about 32.41%, currently not suitable areas are 18.27% and permanently not suitable areas are 0.97%, respectively.

3.7 Soil pH

The different soil series in Negros Oriental are the following: Batuan, Bolinao, Dauin, Faraon, Guimbalaon, Isabela, La Castellana, Lugo, Mandawe, San Manuel, Siaton, Taal, Tupi, and Zamboanguita, respectively. The Faraon series dominates with the largest area of 120,604.66 ha (53.52%). Its high pH range (7.0–8.0) indicates alkalinity, which could significantly influence the types of crops that can be grown. Other notable contributors include Tupi (13.48%) and La Castellana (8.05%), which together cover a substantial portion of the area. Several soil series, such as Dauin (0.18%) and Siaton (0.10%), represent much smaller areas. The soil pH ranges from 4.5 (acidic) to 8.0 (alkaline) across the series, impacting soil fertility and crop suitability. Negros Oriental has approximately 55,000 hectares planted with corn, with significant portions dedicated to both white and yellow corn varieties. The province's agricultural profile indicates that corn is among the major crops produced, alongside sugarcane and rice [4]. Bayawan City is highlighted for its model corn farm initiatives, where a 50-hectare farm is projected to yield between seven to eight metric tons per hectare using hybrid corn seeds [4].

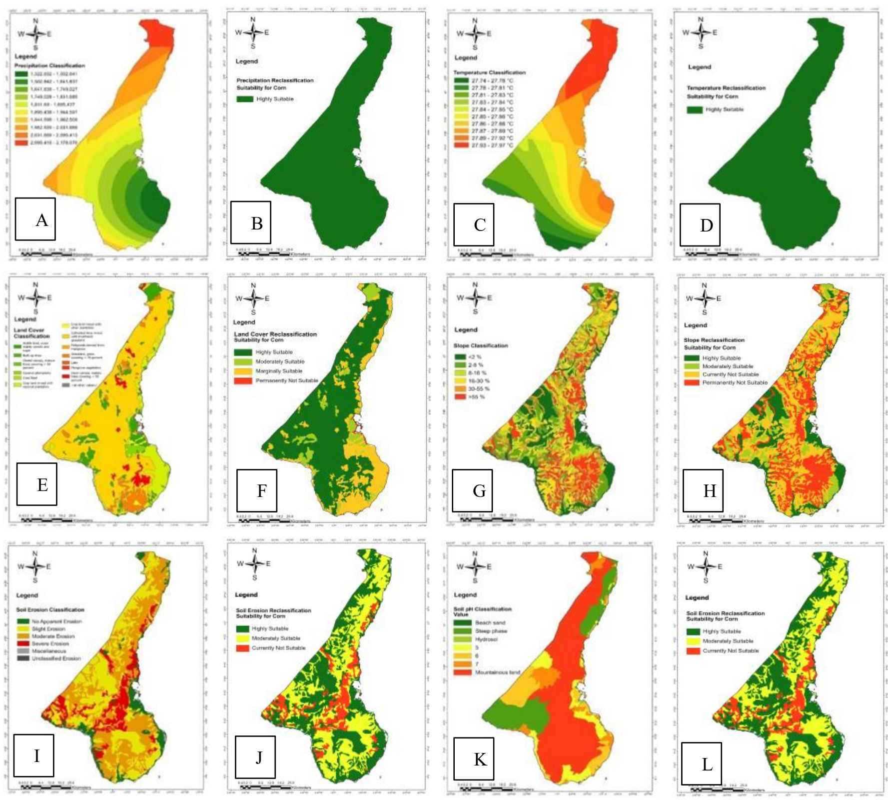

Figure 2. Annual Precipitation of Negros Oriental using Inverse Distance Weighting (IDW) (A) and Annual Precipitation Reclassification for Corn Suitability (B); Mean Annual Temperature using Inverse Distance Weighting (IDW) (C) and Mean Annual Temperature Reclassification for Corn Suitability (D) [10]; Land Cover Classification (E) and Land Cover Reclassification for Corn Suitability (F); Slope Classification of Negros Oriental (G) and Slope Reclassification for Corn Suitability (H); Soil Erosion Classification (I) and Soil Erosion Reclassification for Corn Suitability (J); Soil pH Classification (K) and Soil pH Reclassification for Corn Suitability (L).

3.8 Corn Suitability Map

The corn suitability maps after the overlaying of raster layers were categorized into three classes: highly suitable, moderately suitable, and marginally suitable. The highly suitable areas cover 118,861.88 ha, accounting for 24.42% of the total area. This indicates that about one-fourth of the land is optimal for corn cultivation, where the environmental and soil conditions are most favorable. Moderately suitable areas constitute most of the land, with 363,485.93 ha or 74.66% of the total area. This suggests that most of the land has adequate but not ideal conditions for the cultivation of corn due to limiting factors such as suboptimal soil properties. Marginally suitable areas represent the smallest portion, covering only 4,476.78 ha, which is less than 1% of the total area. This reflects areas where conditions for corn cultivation are significantly limited due to steep slopes, poor soil, and other unfavorable factors. To upgrade moderately suitable land to highly suitable for corn cultivation, several effective soil amendments can be utilized. These amendments focus on improving soil fertility, structure, and moisture retention, which are crucial for enhancing corn yields. Soil conservation strategies such as organic matter additions and incorporating compost improve soil structure, enhance nutrient availability, and increase water retention. It also promotes beneficial microbial activity in the soil [20]. Planting cover crops such as legumes can enhance soil fertility through nitrogen fixation and reduce erosion. They also improve soil structure and moisture retention when tilled back into the soil [21, 22]. Applying organic mulches helps retain soil moisture, suppress weeds, and gradually adds organic matter to the soil as it decomposes [23]. Adding organic fertilizer and biochar will help improve both soil health and plant growth [24, 25].

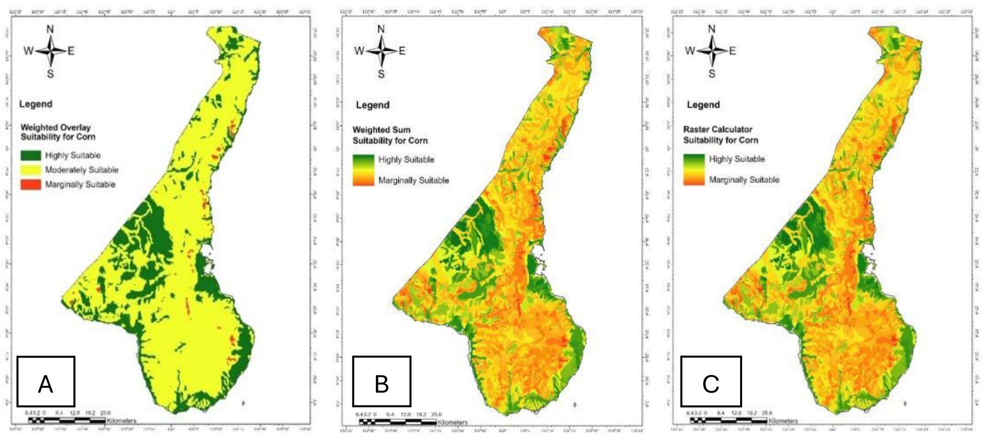

Figure 3. Corn Suitability Map Model created using Weighed Overlay (A), Weighted Sum (B), and Raster Calculator (C).

4. CONCLUSION

This study evaluated multiple criteria, including climate (annual rainfall and temperature), topography (slope), soil (soil erosion hazard and soil pH), and land cover, to determine the suitability of land for corn production in Negros Oriental. It utilized GIS-assisted MCDA to determine the suitable areas in the province for corn production, with an emphasis on enhancing agricultural resilience and productivity in the face of climate change and guiding land-use planning for increased output and environmental sustainability. Results showed that highly suitable areas cover 24.42% of the total area, indicating that one-fourth of the land is optimal for corn cultivation. Moderately suitable areas constitute most of the land, which is about 74.66%, while marginally suitable areas represent the smallest portion, covering less than 1% of the total area. Soil amendments can be applied to improve land that is currently moderately suitable for corn production. Soil amendments and soil conservation techniques like adding compost and organic matter can alleviate soil problems and increase corn yields.

5. ACKNOWLEDGEMENT

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