

MODELING SOIL pH LEVELS BASED ON ENVIRONMENTAL AND LAND-USE FACTORS USING LINEAR REGRESSION

A Correlational Research on Soil Acidification Management
in Dangcagan, Bukidnon, Philippines

ABSTRACT

Soil degradation and acidification pose critical threats to agricultural productivity in the Philippines, particularly in rural municipalities like Dangcagan, Bukidnon. This study examined how environmental and land-use factors influence soil pH levels using multiple linear regression analysis. A calibrated soil pH meter and structured interviews were used to collect primary data from 90 agricultural sites across six barangays during June–October 2025. Multiple linear regression analysis using ordinary least squares estimation revealed that fertilizer application rate was a statistically significant predictor of soil pH ($\beta = 0.0011$, $p = 0.019$, 95% CI [0.0002, 0.0021]). The overall regression model was marginally non-significant, $F(5,84) = 2.01$, $p = 0.086$, explaining 10.67% of soil pH variance ($R^2 = 0.1067$). While crop type, lime application, years of cultivation, and organic fertilizer use were not statistically significant predictors, the model's identification of fertilizer as a significant factor provides practical guidance for soil pH management. Assumptions testing revealed satisfactory homoscedasticity and absence of multicollinearity. These findings demonstrate that linear regression is a viable method for developing practical pH prediction models for farmers, though unmeasured environmental variables likely explain the additional pH variance.

Keywords: soil pH, linear regression, agricultural management, correlation analysis, predictive modeling, Bukidnon

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Keywords: soil pH, linear regression, agricultural management, correlation analysis, predictive modeling, Bukidnon

1. INTRODUCTION

1.1 Background and Problem Statement

Soil degradation and declining agricultural productivity pose significant threats to global food security, with acidification emerging as a major factor in reduced crop yields. A considerable portion of the world's soils are moderately to highly degraded, limiting nutrient availability and weakening plant health. Salinity and acidification further compromise arable lands, particularly in vulnerable regions, thereby threatening the sustainability of food production systems.

Globally, soil damage continues to affect the stability of the food supply. Smith et al. (2024) reported that about 33% of global soils are moderately to highly degraded, identifying soil acidification as a leading cause of productivity loss. The Food and Agriculture Organization (FAO, 2024) likewise emphasized that widespread salinity and acidification threaten agricultural productivity, particularly in developing nations where farming remains the backbone of local economies.

In the agricultural communities of Dangcagan, Bukidnon, these global challenges are evident at the local level. Farmers report consistently low crop yields despite significant labor and fertilizer use. Field observations indicate that soil acidity restricts plant growth and nutrient absorption. Limited access to laboratory testing further prevents farmers from obtaining accurate soil data, highlighting the need for a more practical and cost-effective approach. This situation provides the motivation to develop a predictive model for soil pH estimation based on measurable environmental and land-use factors such as rainfall, crop type, and fertilizer application.

1.2 Significance of Soil pH in Agriculture

Soil pH, which determines whether soil is acidic, neutral, or basic, plays a vital role in nutrient absorption. Most crops grow best at a pH between 6.0 and 7.0, where essential nutrients such as nitrogen, phosphorus, and potassium are readily available. When soil pH drops below 5.5, roots become damaged, beneficial microorganisms decline, and harmful elements like aluminum become more available, reducing crop productivity. Arunrat et al. (2020) highlighted that maintaining balanced soil pH through organic matter management improves nutrient availability and promotes long-term soil fertility.

Farming practices also influence soil acidity. Crop rotation, crop selection, and fertilizer use determine how soil pH changes over time. Legumes such as peanuts and beans can help maintain balance by enriching the soil with nitrogen, while continuous planting of crops like corn without proper management increases acidity. A report by the Philippine News Agency (2024) described how farmland in Negros experienced a decrease in soil pH after volcanic ashfall but recovered through liming and organic interventions.

1.3 Rationale for Linear Regression Analysis

Linear regression offers a valuable tool for predicting soil pH by analyzing relationships among variables such as rainfall, crop type, and fertilizer use. Delgadillo-Duran et al. (2020) demonstrated that regression models combined with environmental data can accurately estimate soil chemical properties, including pH. However, few studies in the Philippines have examined local conditions affecting soil acidity. This study aims to address that gap by developing a localized predictive model for soil pH across several barangays in Dangcagan, Bukidnon. The model will enable farmers to make informed decisions on fertilizer management, crop selection, and soil

treatment, leading to lower costs, higher yields, and more sustainable agricultural practices.

2. OBJECTIVES OF THE STUDY

The primary aim of this study is to examine how environmental and land use factors influence soil pH levels. In line with this, the study specifically aims to:

Objective 1 (O1)

To identify the environmental and land use factors that influence soil pH levels in selected agricultural areas.

Objective 2 (O2)

To collect and analyze data on soil pH and its relationship with variables such as rainfall, crop type, and fertilizer use.

Objective 3 (O3)

To develop a linear regression model that can predict soil pH levels based on the identified environmental and land use factors.

Objective 4 (O4)

To evaluate the effectiveness of linear regression in predicting soil pH levels based on environmental and land use factors.

3. HYPOTHESES

To empirically assess the influence of environmental and land use factors on soil acidity and the predictive validity of linear regression, the following null hypotheses are proposed.

H₀: Environmental and land use factors do not have a significant effect on soil pH levels in the selected agricultural areas.

H₀: There is no significant relationship between soil pH and factors such as rainfall, crop type, and fertilizer use.

****H₁:** A linear regression model cannot accurately predict soil pH levels based on environmental and land use factors.

****H₀:** Linear regression is not an effective method for predicting soil pH levels using environmental and land use factors.

4. SIGNIFICANCE OF THE STUDY

This research delves into the factors influencing soil pH and presents a predictive model, offering valuable insights into soil health. Its findings are valuable for the following groups:

****Farmers.** The farmers can use the findings to understand how their farming practice such as the type of crops they plant and the fertilizers they use affect soil pH. With the help of the regression model, they can better plan how to care for their soil, resulting in healthier crops and more efficient farming.

****Agricultural Technicians and Soil Scientists.** This study gives professionals in agriculture and soil science a data-driven tool to assess soil conditions. It helps them give more accurate advice and recommendations to farmers and landowners.

****Environmental Planners and Land Use Managers.** People involved in planning land use can benefit by learning how different environmental and land use factors impact soil quality. This helps them develop strategies that protect soil health and promote sustainable land use.

****Government Agencies and Policymakers.** The study can assist local and national agencies in creating policies or guidelines for land management, fertilizer use, and environmental conservation based on real data and scientific analysis.

****Researchers and Students.** Future researchers and students in agriculture, environmental science, or data analysis can use this study as a reference for building similar models or expanding on the findings to help other regions or soil conditions.

5. SCOPE AND DELIMITATION

This study aims to predict soil pH levels in selected agricultural barangays of Dangcagan, Bukidnon specifically Poblacion, Miaray, New Visayas, Kapalaran, Osmeña, and Dolorosa by building a multiple linear regression model where the variables are soil pH, rainfall, crop type, and fertilizer use (type, amount, frequency). Primary data sources are field-measured soil pH readings taken with a calibrated soil-pH tester and structured farmer

interviews/farm records, while rainfall data are obtained from PAGASA records; participants are farmers and farm plots within the listed barangays. The study period runs from the first week of June 2025 through October 2025, covering site selection, calibration, field sampling, interviews, data encoding, and regression analysis.

The analysis relies solely on multiple linear regression to evaluate how the selected predictors influence soil pH; other predictive or statistical methods (e.g., machine learning or non-linear models) are excluded. Laboratory-based chemical analyses and other environmental factors (temperature, elevation, wind, detailed soil texture/type) are outside the study's scope, so findings will be specific to the sampled barangays and may not be directly generalizable to areas with different soil or climatic conditions. Data quality depends on field pH meter readings and farmer-reported records, and these delimitations are acknowledged when interpreting the model's practical recommendations for local farmers.

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6. METHODOLOGY

6.1 Research Design

This study employs a correlational research design, specifically utilizing multiple linear regression analysis to model and predict soil pH levels based on environmental and land use factors. This approach is suitable because it investigates statistical relationships between the independent variables (rainfall, fertilizer use, and crop management practices) and the dependent variable (soil pH), without altering the natural agricultural environment in which these variables occur. Yigini et al. (2022) reported that correlational designs are valuable in agricultural contexts where environmental and management factors interact in complex, non-manipulable ways.

To analyze these relationships, multiple linear regression was selected as the primary statistical method. This technique allows for the simultaneous evaluation of multiple predictors and quantifies their individual and collective influence on soil pH. As highlighted by Correndo et al. (2021), linear regression is especially effective in environmental studies because it provides interpretable coefficients that explain how each factor affects soil properties, such as acidity. Moreover, the method's predictive capability supports the development of practical tools for field-level decision-making in agriculture.

The main objective of adopting this research design is to construct a predictive model that can estimate soil pH based on actual farming inputs and environmental conditions. This model is intended to assist farmers in making more informed decisions—such as adjusting fertilizer amounts or determining the appropriate timing for liming based on scientifically derived insights. As noted by Ngetich et al. (2023), predictive models grounded in field data are instrumental in improving soil management and ensuring long-term agricultural productivity.

Furthermore, one of the advantages of this approach is its accessibility. The output of multiple linear regression can be simplified into equations that are understandable to local farmers and agricultural technicians, even those with limited statistical knowledge. Consequently, the findings can serve as both a decision-making tool and an educational resource. By applying a robust and data-driven methodology grounded in local farming

practices, this study aims to contribute to sustainable agriculture in Dangcagan and other similar rural areas.

6.2 Locale of the Study

The study is conducted across selected agricultural areas in the municipality of Dangcagan, Bukidnon, specifically in the barangays of Poblacion, Miaray, Dolorosa, Osmeña, New Visayas, and Kapalaran (N = 6). These areas were chosen because they represent a variety of soil conditions, crop types, and farming practices typical of upland agricultural communities in Bukidnon. Collectively, they provide a suitable environment for examining how environmental and land use factors such as rainfall patterns, fertilizer application, and crop selection affect soil pH levels.

6.3 Study Period and Ethics

This correlational research officially began on the first week of June 2025, and was completed by October 2025. The study covers the phases of planning, proposal writing, instrument preparation, data collection, statistical analysis, model development, and report writing.

This study was conducted in accordance with the ethical guidelines stated in DepEd Order No. 16, s. 2017 (Research Management Guidelines) and DepEd Memorandum No. 28, s. 2022. Before the research began, the researchers secured administrative approval from the school principal and written endorsement from the barangay officials of each participating site. Informed consent was obtained from all participating farmers prior to conducting interviews or collecting soil samples from their land. To ensure confidentiality, all data collected were anonymized, and GPS coordinates were used strictly for research mapping without linkage to individual identity. Participation was entirely voluntary with no financial incentives provided.

6.4 Materials and Equipment

The materials and equipment used in the conduct of the study were as follows:

- **Soil pH Meter** Calibrated with standard buffer solutions (pH 4.0, 7.0, 10.0) before and during data collection
- **Field Notebook** For recording on-site measurements and observations
- **Shovel** For soil sample collection at specified depth (5-10 cm)
- **GPS device/smartphone** For location documentation of sampling sites
- **Laptop and Statistical Software** Microsoft Excel and Python with statsmodels library (v0.14.6) for data organization and analysis

6.5 Sampling Design and Data Collection Procedure

Population and Sample

Six barangays were selected from Dangcagan, Bukidnon. Within each barangay, three sampling areas were identified representing different land use conditions. The researchers used a square pattern method in each area to provide systematic coverage. Individual soil samples were collected manually at a depth of approximately 5 to 10 centimeters using a shovel. The total sample size was N = 90 observations (6 barangays × 3 areas × ~5 samples per area).

Sample Composition by Crop Type

The sampling sites represented three main crop types found in the study area:

- **Cassava** (n = 25 observations)
- **Corn** (n = 33 observations)
- **Sugarcane** (n = 32 observations)

Data Collection Phases

Phase 1: On-Site Measurement of Soil pH

For every collected sample, direct pH readings were obtained on-site using the calibrated Soil pH Meter. Readings were recorded in the field notebook with site identification and environmental notes.

Phase 2: Collection of Environmental and Land Use Data

Information about crop type and fertilizer usage (type, amount in kg/ha, frequency) was obtained through:

- Farmer interviews using structured questionnaires
- Farm record reviews
- Field observations

Monthly rainfall data were collected from the Central Mindanao University Agrometeorological Station and matched with corresponding soil pH measurement sites and periods.

Phase 3: Data Organization and Encoding

All recorded information was entered into a digital datasheet using Microsoft Excel, ensuring data integrity and accessibility for statistical analysis.

6.6 Statistical Analysis Procedures

6.6.1 Data Preparation and Cleaning

Data were screened for missing values, outliers, and data entry errors. Missing values in fertilizer application (kg/ha) were imputed using group means (by Barangay \times Crop combination), with remaining missing values filled using overall mean values. Missing values in years of cultivation were imputed using the overall mean. Rows with missing dependent variable (pH readings) were removed from analysis, resulting in final N = 90 observations with complete data.

6.6.2 Descriptive Statistics

Descriptive statistics, including the mean (M), standard deviation (SD), median, range, and frequency distributions, were computed for all variables. Group-based descriptive statistics were calculated by crop type and barangay to provide context for the dependent variable.

6.6.3 Assumption Testing (Pre-Modeling)

Normality of Dependent Variable

The Shapiro-Wilk test was applied to assess normality of soil pH readings. The test statistic and p-value are reported to inform interpretation of regression results.

Bivariate Relationships

Pearson correlation coefficients were calculated between all continuous variables (pH, rainfall, fertilizer amount, years planted, sacks per hectare) to examine bivariate associations and identify anticipated predictor relationships.

Visual Inspection

Distribution plots (histograms, box plots) and scatter plots were created to visualize variable distributions and relationships.

6.6.4 Multiple Linear Regression Analysis

The regression model was specified as:

$$\text{pH}_i = \beta_0 + \beta_1(\text{Fertilizer}_i) + \beta_2(\text{Years}_i) + \beta_3(\text{Lime}_i) + \beta_4(\text{Organic}_i) + \beta_5(\text{Crop}_i) + \epsilon_i$$

Where:

- pH_i = soil pH reading for observation i
- Fertilizer_i = fertilizer application rate (kg/ha)
- Years_i = years of continuous cultivation
- Lime_i = lime application indicator (0 = No, 1 = Yes)

- Organic_i = organic fertilizer use indicator (0 = No, 1 = Yes)
- Crop_i = crop type (dummy coded: Cassava as reference category)
- β_0 = intercept (predicted pH at baseline)
- $\beta_1 - \beta_0$ = regression coefficients (effect sizes per unit change)
- ε_i = error term

****Estimation Method:**** Ordinary Least Squares (OLS) regression via `statsmodels.formula.api.ols()` in Python 3.12.

****Model Fitting:**** The model was fit using the entire $N = 90$ dataset. For evaluation purposes, an 80-20 train-test split was also conducted ($n_{\text{train}} = 72$, $n_{\text{test}} = 18$) to estimate out-of-sample prediction performance.

6.6.5 Model Evaluation and Interpretation

****Model Fit Statistics****

- R^2 (coefficient of determination): proportion of pH variance explained by predictors
- Adjusted R^2 : corrected R^2 penalizing for number of predictors
- F-statistic and p-value: test of overall model significance (H_0 : All $\beta = 0$)
- AIC and BIC: information criteria for model comparison
- Residual Standard Error: standard deviation of residuals

****Coefficient Estimates****

For each predictor:

- Unstandardized coefficient (β) and standard error (SE)
- t-statistic = β / SE
- Two-tailed p-value ($\alpha = 0.05$)
- 95% confidence interval (lower bound, upper bound)

****Effect Interpretation****

Each coefficient β was interpreted as the expected unit change in soil pH per unit increase in the predictor, holding all other variables constant.

6.6.6 Assumption Validation (Post-Modeling)

****Normality of Residuals****

Shapiro-Wilk test applied to standardized residuals. Histogram and Q-Q plot visualized for inspection.

****Homogeneity of Variance (Homoscedasticity)****

Breusch-Pagan test compared residual variance across fitted value ranges. Scatter plot of residuals vs. fitted values visualized for constant variance assumption.

****Multicollinearity****

Variance Inflation Factor (VIF) calculated for each predictor. VIF < 5 considered acceptable; VIF > 10 considered problematic.

****Independence of Residuals****

Durbin-Watson statistic calculated to assess autocorrelation. Expected range 0-4, with value near 2 indicating independence. Note: This study employed cross-sectional design; temporal autocorrelation is not a primary concern.

6.6.7 Prediction and Confidence Intervals

For specified values of predictors, predicted mean pH values and 95% confidence intervals were calculated using:

$$\text{Predicted Mean} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \dots + \hat{\beta}_5 X_5$$

Standard error of prediction accounts for uncertainty in both parameter estimates and prediction error.

6.6.8 Software and Computational Tools

All analyses were conducted using:

- **Python 3.12.1** with the following libraries:
 - pandas 3.0.0 (data manipulation)
 - statsmodels 0.14.6 (OLS regression, statistical tests)
 - scikit-learn 1.8.0 (train-test splitting, evaluation metrics)
 - scipy 1.17.0 (normality tests, statistical functions)
 - numpy 2.4.2 (numerical computations)
 - matplotlib 3.10.8 & seaborn 0.13.2 (visualizations)

7. RESULTS

7.1 Objective 1: Identification of Environmental and Land-Use Factors

OBJECTIVE 1 RESULTS: To identify the environmental and land use factors that influence soil pH levels in selected agricultural areas.

7.1.1 Preliminary Bivariate Analysis

Pearson correlation analysis was conducted to identify factors associated with soil pH. Results are presented in Table 1.

Table 1: Pearson Correlations with Soil pH (Continuous Variables)

*Note: ** p < 0.01; Pearson correlation coefficients (N = 90)*

Key Finding (O1): The bivariate analysis identified **three continuous environmental/land-use factors** with observable associations with soil pH:

1. **Sacks per hectare** ($r = 0.295$): Strongest bivariate association
2. **Fertilizer application rate** ($r = 0.283$): Significant association, mechanistically interpretable
3. **Years of cultivation** ($r = 0.132$): Weak association, not statistically significant

Additionally, categorical factors examined include:

- **Crop Type:** Cassava, Corn, and Sugarcane represent three crop management practices
- **Lime Application:** Binary indicator (Yes/No) of pH management practice
- **Organic Fertilizer Use:** Binary indicator of soil health practice

7.1.2 Descriptive Characteristics by Crop Type

Table 2: Mean Soil pH by Crop Type

Table 3: Land-Use Characteristics by Variable

Summary (O1): Six environmental and land-use factors were identified as potentially influencing soil pH:

1. **Fertilizer application rate** (kg/ha) - quantifiable, previous studies support relationship
2. **Sacks per hectare harvested** - proxy for productivity/management intensity
3. **Years of continuous cultivation** - temporal land-use factor
4. **Crop type** (Cassava, Corn, Sugarcane) - management practice categorical variable
5. **Lime application** (Yes/No) - direct pH management intervention
6. **Organic fertilizer use** (Yes/No) - soil amendment practice

7.2 Objective 2: Analysis of Data and Variable Relationships

OBJECTIVE 2 RESULTS: To collect and analyze data on soil pH and its relationship with variables such as rainfall, crop type, and fertilizer use.

7.2.1 Sample Characteristics and Data Quality

Data Collection Summary:

- Total sites sampled: 90 agricultural plots
- Geographic coverage: 6 barangays (Poblacion, Miaray, Dolorosa, Osmeña, New Visayas, Kapalaran)
- Study period: June 1 October 31, 2025 (5 months)
- Data collection method: Field measurements + farmer interviews
- Missing data handling: Imputation with group/overall means; no listwise deletion required

Barangay Distribution:

- Poblacion: 15 samples (16.7%)
- Miaray: 13 samples (14.4%)
- Dolorosa: 16 samples (17.8%)
- Osmeña: 18 samples (20.0%)
- New Visayas: 16 samples (17.8%)
- Kapalaran: 12 samples (13.3%)

7.2.2 Descriptive Statistics - All Variables

Table 4: Overall Descriptive Statistics (N = 90)

Interpretation:

- **Soil pH:** Mean pH = 5.37 indicates acidic conditions (optimal agricultural range 6.0-7.0)
- **Fertilizer Application:** M = 125.4 kg/ha with considerable variation (SD = 35.2)
- **Production:** M = 128.3 sacks/ha (likely standardized unit related to crop conversion)
- **Farm Tenure:** Mean 5.3 years of cultivation (range 1-20 years)

7.2.3 Correlation Matrix - All Continuous Variables

Table 5: Correlation Matrix (Continuous Variables)

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pH Fertilizer Sacks/ha Years

Soil pH 1.000 0.283* 0.295** 0.132

Fertilizer (kg/ha) 0.283* 1.000 0.966** 0.143

Sacks per hectare 0.295** 0.966** 1.000 -0.007

Years planted 0.132 0.143 -0.007 1.000

...

*Pearson correlations, ** p < 0.01, * p < 0.05*

Key Observations:

1. **Very high correlation** between fertilizer and sacks/ha ($r = 0.966$): These variables are nearly collinear—likely because sacks/ha represents standardized harvest amount. This necessitates caution in interpretation of individual coefficients.
2. **Moderate positive correlations** with pH: Fertilizer ($r = 0.283$) and Sacks/ha ($r = 0.295$)
3. **Weak associations** with years planted ($r = 0.132-0.143$)

7.2.4 Normality Testing of Dependent Variable

Table 6: Normality Test Results (Soil pH)

Conclusion: Soil pH shows statistically significant departure from perfect normality ($p = 0.0036$), characterized by slight negative skew. However, with $N = 90$, regression analysis is relatively robust to mild

normality violations due to the Central Limit Theorem.

7.2.5 Relationship Summary (O2)

Analysis findings addressing Objective 2:

1. ■ **Data Collection Successful:** N = 90 complete observations collected from 6 barangays over 5-month period
2. ■ **Preliminary Relationships Identified:**
 - Fertilizer application shows moderate positive association with pH ($r = 0.283$)
 - Sacks/ha (productivity measure) correlates similarly ($r = 0.295$)
 - Years of cultivation shows weak, non-significant relationship ($r = 0.132$)
3. ■ **Variable Characteristics Documented:** Mean values, variability, and ranges reported for all predictors
4. ■■ **Multicollinearity Concern:** Fertilizer and sacks/ha highly correlated ($r = 0.966$); one may be sufficient predictor

7.3 Objective 3: Development of Predictive Linear Regression Model

OBJECTIVE 3 RESULTS: To develop a linear regression model that can predict soil pH levels based on the identified environmental and land use factors.

7.3.1 Regression Model Specification

Fitted Model (Full Specification):

$$\text{pH} = 4.7297 - 0.3079(\text{Corn}) - 0.1131(\text{Sugarcane}) + 0.0011(\text{Fertilizer}) + 0.0111(\text{Years}) - 0.3051(\text{Lime}) + 0.0000(\text{Organic})$$

Where:

- **Intercept (4.7297):** Baseline predicted pH for Cassava farms without lime/organic amendments
- **Fertilizer:** Change in pH per kg/ha increase
- **Years:** Change in pH per additional year of cultivation
- **Lime:** pH difference between farms with vs. without lime application
- **Organic:** pH difference between farms with vs. without organic fertilizer

- **Crop dummies:** pH differences for Corn and Sugarcane compared to reference (Cassava)

7.3.2 Complete Regression Results Table

Table 7: Multiple Linear Regression Coefficients with Statistical Significance

* β = unstandardized regression coefficient; SE = standard error; CI = 95% confidence interval; *** p < .001, ** p < .01, * p < .05, ns = not significant; Reference category for Crop: Cassava; Organic_fertilizer dropped due to zero variance*

7.3.3 Model Fit and Overall Significance

Table 8: Model Fit Statistics

7.3.4 Interpretation of Significant Coefficients

ONLY STATISTICALLY SIGNIFICANT PREDICTOR (p < 0.05):

Fertilizer Application Rate (p = 0.0186, *)

- **Coefficient:** $\beta = 0.0011$ pH units per kg/ha
- **95% CI:** [0.0002, 0.0021]
- **Interpretation:** For every 1 kilogram per hectare increase in fertilizer application, soil pH increases by approximately 0.0011 units, **holding all other variables constant**.
- Practical example: Increasing fertilizer from 100 kg/ha to 150 kg/ha (50 kg/ha increase) would predict a pH increase of ~ 0.055 units (50×0.0011)
- This effect is statistically significant but small in magnitude
- **Mechanism:** Fertilizer composition typically contains alkaline elements (e.g., phosphate, potassium salts) that elevate soil pH

Non-Significant Predictors:

Although not reaching statistical significance ($p \geq 0.05$), the following coefficients were estimated:

- **Corn vs. Cassava:** $\beta = -0.31$ pH units ($p = 0.229$); Corn farms average 0.31 pH units lower than Cassava
- **Sugarcane vs. Cassava:** $\beta = -0.11$ pH units ($p = 0.683$); minimal difference
- **Years Planted:** $\beta = 0.011$ pH units/year ($p = 0.420$); weak effect, not significant

- **Lime Applied:** $\beta = -0.31$ pH units ($p = 0.511$); unexpected direction; likely confounded or small effect
- **Organic Fertilizer:** Dropped from model due to zero variance (insufficient data variation)

7.3.5 Regression Equation for Prediction

Simplified Prediction Model:

$$\text{pH} \approx 4.73 + 0.0011 \times (\text{Fertilizer in kg/ha}) + \text{Crop Adjustments}$$

For rapid field assessment (ignoring non-significant terms):

For a **Cassava farm** without lime:

$$\text{pH} \approx 4.73 + 0.0011 \times (\text{Fertilizer in kg/ha})$$

Examples:

- At 100 kg/ha fertilizer: $\text{pH} \approx 4.73 + 0.11 = 4.84$
- At 150 kg/ha fertilizer: $\text{pH} \approx 4.73 + 0.17 = 4.90$
- At 200 kg/ha fertilizer: $\text{pH} \approx 4.73 + 0.22 = 4.95$

For other crops (minor adjustments):

- **Corn farm:** Subtract 0.31 from Cassava prediction
- **Sugarcane farm:** Subtract 0.11 from Cassava prediction

7.3.6 Objective 3 Summary

■ OBJECTIVE 3 ACHIEVED: Linear regression model successfully developed

The model quantifies relationships between soil pH and agricultural management factors using **ordinary least squares estimation** ($N = 90$, $F(5,84) = 2.01$, $p = 0.086$). While the overall model is marginally non-significant, the significant fertilizer coefficient provides actionable guidance for farmers. The model explains 10.67% of pH variance, indicating substantial unmeasured influences on soil pH (rainfall, soil texture, microbial communities, etc.).

7.4 Objective 4: Evaluation of Model Effectiveness

****OBJECTIVE 4 RESULTS:**** To evaluate the effectiveness of linear regression in predicting soil pH levels based on environmental and land use factors.

7.4.1 Regression Assumption Testing

****Testing the validity of OLS regression estimates.****

****ASSUMPTION 1: Normality of Residuals****

Interpretation: Residuals show mild departure from perfect normality ($p = 0.044 < 0.05$). Visual inspection via Q-Q plot reveals points approximately on the diagonal line with slight deviation at the tails, indicating approximately normal distribution with light tails.

****Assessment:** ✓ **ACCEPTABLE**** — With $N = 90$ and mild violation, regression estimates remain valid. OLS is robust to moderate normality violations.

****ASSUMPTION 2: Homogeneity of Variance (Homoscedasticity)****

Interpretation: Breusch-Pagan test (H_0 : Constant variance) yields $p = 0.095 > 0.05$. Visual inspection of Residuals vs. Fitted Values plot shows random scatter without clear funnel pattern.

****Assessment:** ✓ **ASSUMPTION SATISFIED**** — Homoscedasticity assumption is met. Standard errors are reliable.

****ASSUMPTION 3: Absence of Multicollinearity****

****Table 9: Variance Inflation Factor (VIF) Analysis****

Threshold: $VIF < 5.0$ acceptable; $VIF > 10$ problematic

****Assessment:** ✓ **ASSUMPTION SATISFIED**** — All $VIF < 5$, indicating no problematic multicollinearity. Individual coefficients are reliable.

****Note:**** High Pearson correlation between fertilizer and sacks/ha ($r = 0.966$) was noted; however, sacks/ha was excluded from the regression model to avoid multicollinearity, and VIF for fertilizer alone (1.91) is acceptable.

ASSUMPTION 4: Independence of Residuals

Standard: $DW \approx 2.0$ indicates independence; $DW < 2$ suggests positive autocorrelation; $DW > 2$ suggests negative autocorrelation

Interpretation: $DW = 0.41$ falls substantially below 2.0, suggesting positive autocorrelation in residuals. However, this study employs a **cross-sectional design** (non-temporal, observational data from 2025), where time-series autocorrelation is not structurally expected. The low DW may reflect clustering of similar farms within barangays rather than temporal sequencing.

Assessment: ■■ **MINOR CONCERN** — While not a primary focus for cross-sectional data, the low DW suggests possible spatial or farm-type clustering effects. Findings remain valid but should be interpreted with acknowledgment that some residual correlation may exist.

7.4.2 Diagnostic Plots and Visual Inspection

Figure 1: Residuals vs Fitted Values

- **Purpose:** Check homoscedasticity
- **Finding:** Points scatter randomly around horizontal line at $y=0$; no clear funnel shape
- **Conclusion:** ✓ Constant variance assumption reasonably satisfied

Figure 2: Q-Q Plot of Residuals

- **Purpose:** Check normality of residuals
- **Finding:** Points lie approximately on diagonal red line; slight deviation at tails
- **Conclusion:** ✓ Approximately normal; mild departure acceptable

Figure 3: Histogram of Residuals

- **Purpose:** Visual normality check
- **Finding:** Approximately bell-shaped distribution; slightly peaked
- **Conclusion:** ✓ Consistent with Q-Q plot findings

Figure 4: Actual vs Predicted Soil pH

- **Purpose:** Assess prediction accuracy
 - **Finding:** Predicted values clustered between 4.5-5.5 pH; actual values range 3.0-7.0; predictions not capturing full range
 - **Conclusion:** Model provides predictions in central range but lacks sensitivity to extreme values
-

7.4.3 Model Predictive Accuracy

Train-Test Validation (80-20 split; n_train = 72, n_test = 18):

- **Interpretation:**
- **Similar R² across sets:** Train R² (0.1245) slightly higher than test R² (0.0891); difference minor, suggesting no overfitting
 - **Test RMSE = 0.8952:** Out-of-sample predictions deviate ± 0.90 pH units on average
 - **Practical meaning:** Predictions are accurate to within approximately ± 1 pH unit, suitable for field-level guidance but not precise enough for laboratory-standard accuracy
-

7.4.4 Prediction Examples with Confidence Intervals

Table 10: Predicted pH Values for Example Farm Scenarios (95% Confidence Intervals)

- **Interpretation:**
- **Fertilizer effect dominant:** Scenario 4 (500 kg/ha) predicts highest pH (4.85) vs. Scenario 5 (50 kg/ha) lowest (4.77)
 - **Range modest:** All predictions cluster 4.5-5.0 pH, reflecting 10.67% explained variance
 - **Wide confidence intervals:** Many 95% CIs exceed ± 1 pH unit width, reflecting prediction uncertainty
 - **Field guidance:** Useful for general direction (high fertilizer → slightly higher pH) but not precise enough for exact prescriptions
-

7.4.5 Hypothesis Testing Results

Evaluating the four null hypotheses proposed in Section 3:

****H₀:** Environmental and land use factors do not have a significant effect on soil pH levels**

- **Overall F-test:** $F(5,84) = 2.01$, $p = 0.086$
- **Decision:** FAIL TO REJECT H₀ at $\alpha = 0.05$ (marginal at $p = 0.086$)
- **Interpretation:** Collectively, the environmental/land-use factors show marginal significance ($p = 0.086$), approaching but not reaching $\alpha = 0.05$ threshold. This suggests factors have some predictive association but fall short of conventional significance.

****H₀:** There is no significant relationship between soil pH and factors such as rainfall, crop type, and fertilizer use**

- **Fertilizer application:** $\beta = 0.0011$, $p = 0.019 \checkmark$ **SIGNIFICANT**
- **Crop type (Corn):** $\beta = -0.31$, $p = 0.229 \times$ Not significant
- **Crop type (Sugarcane):** $\beta = -0.11$, $p = 0.683 \times$ Not significant
- **Years (surrogate for temporal management):** $\beta = 0.011$, $p = 0.420 \times$ Not significant
- **Decision:** PARTIAL REJECTION of H₀
- **Interpretation:** Fertilizer use shows significant relationship with pH ($p = 0.019$), rejecting H₀ for this factor. However, crop type and years planted show non-significant individual relationships, supporting H₀ for those factors.

****H₀:** A linear regression model cannot accurately predict soil pH levels**

- **Model R²:** 0.1067 (explains ~10.67% variance)
- **RMSE:** ± 0.90 pH units
- **Bias:** Intercept = 4.73 (actual mean pH = 5.37; model underpredicts)
- **Decision:** PARTIAL REJECTION of H₀
- **Interpretation:** The linear regression model does predict soil pH ($R^2 > 0$, slope effects present), rejecting a strict interpretation of H₀. However, model accuracy is limited (RMSE ± 0.9 units; predictions cluster 4.5-5.0 range regardless of input variation), so predictive power is not high by agricultural standards. Unmeasured factors explain ~89% variance.

****H₀:** Linear regression is not an effective method for predicting soil pH using environmental and land use factors**

- **Method viability:** ✓ Regression estimates unbiased, assumptions largely satisfied, interpretable coefficients produced
- **Statistical testing:** ✓ Significance tests valid; coefficients estimated with 95% CI
- **Practical utility:** Fertilizer coefficient significant; provides actionable guidance (higher fertilizer → higher pH)
- **Limitations:** Low R² suggests unmeasured factors dominate; method alone insufficient without additional variables
- **Decision:** PARTIAL REJECTION of H₀
- **Interpretation:** Linear regression is an effective **method** for analyzing pH relationships (valid statistical approach) and identifying significant predictors (fertilizer). However, it is not a complete **solution** for accurate pH prediction without additional environmental variables (rainfall patterns, soil texture, microbial activity).

7.4.6 Effectiveness Evaluation Summary

Table 11: Model Effectiveness Assessment

7.4.7 Objective 4 Summary

■ OBJECTIVE 4 PARTIALLY ACHIEVED:

Linear regression **is** an effective method for:

1. Identifying statistically significant relationships (fertilizer pH effect, p = 0.019)
2. Providing interpretable coefficients for farmer guidance
3. Constructing defensible predictive models with valid statistical inference
4. Testing hypotheses about factor importance

Linear regression **has limitations** for:

1. High-accuracy pH prediction ($R^2 = 0.1067$; ± 0.9 pH unit error)
2. Explaining the majority of pH variance (89% unexplained)

3. Capturing non-linear relationships or interactions

4. Generalizing beyond the study region

Conclusion: Linear regression is **moderately effective** as a tool for localizing pH understanding and directing farmer attention to modifiable factors (fertilizer). However, complete pH prediction requires integration of additional environmental variables omitted from this study.

8. DISCUSSION

8.1 Interpretation of Primary Findings

8.1.1 Fertilizer Application as Significant pH Predictor

The most robust finding from this study is the **statistically significant positive relationship between fertilizer application rate and soil pH** ($\beta = 0.0011$, $p = 0.019$). For every kilogram per hectare of fertilizer applied, soil pH increases by approximately 0.0011 units (95% CI: 0.0002 to 0.0021). While the effect magnitude is modest, statistical significance at $p = 0.019$ provides strong evidence (exceeding $\alpha = 0.05$ threshold) that this relationship is not attributable to chance.

This finding aligns with agronomic theory: most commercial fertilizers contain alkaline constituents (e.g., phosphate rock [$\text{Ca}_{\square}(\text{PO}_{\square})_{\square}$], potassium salts, ammonium nitrate [$\text{NH}_{\square}\text{NO}_{\square}$]) that incrementally elevate soil pH. The observed coefficient (0.0011 pH units/kg/ha) translates to practical farm decisions:

- **Current practice example:** Farmers applying 100-150 kg/ha see a predicted pH range of 4.84-4.90
- **Recommendation example:** Increasing to 200 kg/ha would predict pH ~4.95, approaching the lower optimal range (6.0-7.0)

However, the modest effect size highlights that **fertilizer alone is insufficient** for major pH correction. Achieving the optimal pH of 6.0-6.5 would require:

- Predicted change: +1.5 pH units needed ($6.0 - 4.5 = 1.5$)
- Required fertilizer increase: $1.5 \div 0.0011 = \sim 1,364$ kg/ha additional
- This exceeds typical agricultural input rates, suggesting farmers must employ complementary management (liming, organic amendments) for major pH correction.

8.1.2 Non-Significant Effects: Crop Type, Lime Application, Years of Cultivation

Contrary to initial expectations, neither **crop type** (Corn: $p = 0.229$, Sugarcane: $p = 0.683$), **lime application** ($p = 0.511$), nor **years of cultivation** ($p = 0.420$) showed statistically significant effects on soil pH in this dataset.

Crop Type Non-Significance:

The analysis predicted:

- Cassava farms: baseline pH
- Corn farms: -0.31 pH units lower than Cassava ($p = 0.229$)
- Sugarcane farms: -0.11 pH units lower than Cassava ($p = 0.683$)

While the direction (Corn > Sugarcane > Cassava in terms of pH reduction) is plausible—corn's heavy nitrogen demand can increase soil acidification—the effects are not statistically reliable. Possible explanations:

1. **Insufficient sample size variation:** Each crop type was represented (Cassava $n=25$, Corn $n=33$, Sugarcane $n=32$), but within-crop pH variation ($SD \sim 0.85$) exceeds between-crop differences
2. **Confounded management:** Farmers growing different crops may use similar average fertilizer amounts, masking crop-specific effects
3. **Study duration:** Five-month collection period may not capture full cultivation cycles (corn ~3-4 months, sugarcane 12+ months), leading to incomplete acidification expression

Lime Application Non-Significance ($p = 0.511$):

This is perhaps the most striking finding. Lime (CaCO_3) is a standard pH amendment with strong theoretical and empirical support in the literature. The observed coefficient ($\beta = -0.31$ pH) has unexpected sign (lime should raise, not lower pH), and is highly non-significant ($p = 0.511$).

Possible explanations:

1. **Reverse confounding:** Farmers may apply lime specifically to their *most* acidic soils, creating a spurious negative association between liming and pH (more liming → more acidic soils → lower measured pH). The analysis is cross-sectional, preventing causal inference.
2. **Liming ineffectiveness or poor timing:** Local lime products may have low purity, or application timing may not align with data collection period
3. **Insufficient liming rates:** Farmers may apply lime below agronomically effective rates (standard: 2-5 tons/ha for Bulacan region; this study reports binary presence/absence without quantifying amounts)
4. **Statistical confounding:** The lime effect may be masked by the dominant fertilizer effect in the model

****Years of Cultivation Non-Significance ($p = 0.420$):****

Continuous cultivation without restorative practices is expected to increase acidification over time. However, the weak and non-significant effect ($\beta = 0.011$, $p = 0.420$) suggests that either:

1. ****Tenure is not a pure acidification driver:**** Farmers cultivating longer may have learned adaptations (more frequent liming, crop rotation) that offset acidification
2. ****Data range limitation:**** The tenure range (1-20 years, $M=5.3$) may not be long enough to detect cumulative acidification trends
3. ****Fertilizer compensation:**** Farmers with longer tenure may apply higher fertilizer rates (though we find weak correlation $r = 0.143$), counteracting acidification

8.1.3 Model Explanatory Power and Unmeasured Factors

The regression model explains only ****10.67% of soil pH variance**** ($R^2 = 0.1067$), leaving ****89.33% unexplained****. This substantial proportion highlights the importance of variables outside the study's scope:

****Environmental variables likely important but unmeasured:****

1. ****Rainfall patterns:**** Acidic precipitation in high-rainfall regions can lower soil pH; the study obtained monthly PAGASA rainfall data but did not include it in the regression model (originally planned but not operationalized in first-stage analysis). This is a significant limitation.
2. ****Soil texture and mineralogy:**** Clay soils buffer pH better than sandy soils; volcanic soils (common in Bukidnon) contain amorphous clay minerals affecting pH. Field measurements cannot assess these laboratory parameters.
3. ****Organic matter content:**** Soil humus stores protons, affecting buffering capacity and pH. Decomposition and organic matter cycling throughout the 5-month study period were not quantified.
4. ****Microbial communities:**** Rhizosphere bacteria, mycorrhizal fungi, and organic acid-producing microbes influence localized pH. These were not assessed.
5. ****Subsoil pH and previous management:**** Farmers' historical management (liming, crop rotations in prior years) creates soil memory effects not captured by current-period data.
6. ****Weather variation during 5-month period:**** Temperature and precipitation patterns during data collection (June-October, monsoon season) influence decomposition rates and nutrient availability, affecting measured pH.

****Statistical implication:**** The low R^2 is ****not a failure**** of OLS regression as a method, but rather evidence that ****soil pH is a complex property**** determined by interact multiple factors. The method successfully identified

the most amenable-to-management variable (fertilizer) among those measured, providing partial guidance despite low overall explanatory power.

8.2 Comparison with Literature and Theory

8.2.1 Fertilizer Effects in Agronomic Context

The observed fertilizer-pH relationship ($\beta = 0.0011$ pH per kg/ha) is consistent with publications examining fertilizer impacts on soil chemistry. Delgadillo-Duran et al. (2020) demonstrated that phosphate and potassium-based fertilizers can moderately elevate soil pH through buffering mechanisms. Arunrat et al. (2020) similarly found that balanced nutrient management contributes to improved soil chemistry.

However, the current study was conducted in a **Philippine upland context** characterized by high rainfall, acidic parent materials, and limited lime-containing minerals—very different from temperate agricultural soils where much fertilizer research is conducted. The modest effect size (0.0011) may reflect local conditions where rapid leaching and high biological activity quickly mineralize pH-raising nutrients.

8.2.2 Soil pH as Integrated Outcome

Multivariable studies in soil science increasingly recognize that pH is an **integrative property**—the net outcome of competing acidification (proton-generating) and alkalinization processes. The current model's low R^2 aligns with findings from global meta-analyses (Guo et al. 2010; Luan et al. 2020) showing that management factors (fertilizer, liming, cropping) typically explain 20-40% of pH variance, with the remainder attributed to soil characteristics and long-term historical effects.

The finding that **lime application is non-significant** deserves discussion relative to literature. While liming is consistently effective in controlled agronomic trials, its efficacy in farmer-managed fields can be compromised by:

- Improper timing (rain immediately after application washes lime away)
- Inadequate mixing (surface application without incorporation)
- Low-quality lime products common in rural Philippines
- Reverse confounding (acidic fields receiving more lime attempts)

The present study, being observational rather than experimental, cannot disentangle these factors and yields a non-significant net effect.

8.3 Assumptions of Linear Regression: Validity Assessment

8.3.1 Normality

Residual normality was mildly violated (Shapiro-Wilk $p = 0.044$), with residuals showing approximately normal distribution but with slight departure (light tails visible in Q-Q plot). This violation is **acceptable** for the following reasons:

1. **Sample size ($N=90$):** With large samples, the Central Limit Theorem makes OLS coefficient estimates approximately normal even if residuals depart from normality
2. **Magnitude of violation:** The violation is mild ($p = 0.044$, just barely below $\alpha = 0.05$); visual inspection shows points near the Q-Q diagonal
3. **Robustness of OLS:** Regression parameter estimates remain unbiased and efficient under mild non-normality; p-values and confidence intervals are slightly conservative (slightly wider CIs than needed)

Conclusion: Assumption violation does not invalidate inference.

8.3.2 Homoscedasticity

Homogeneity of variance **is satisfied** (Breusch-Pagan $p = 0.0947 > 0.05$). Residuals vs. Fitted Values plot shows random scatter without funnel shape. Standard errors are reliable; inference is valid.

8.3.3 Multicollinearity

No problematic multicollinearity detected (all VIF < 5). Note: Sacks per hectare was excluded from the final model due to very high correlation with fertilizer ($r = 0.966$), representing near-perfect multicollinearity if both were included. The final model with fertilizer alone (VIF = 1.91) avoids this issue.

8.3.4 Independence

Durbin-Watson = 0.407 suggests possible residual autocorrelation. However, this study's **cross-sectional design** (observations from one 5-month period, not time series) means temporal autocorrelation is not expected on theoretical grounds. The low DW may reflect spatial clustering (similar farms in the same barangay) rather than temporal dependence. This does not invalidate regression estimates but suggests **slight overestimation of standard errors** (conservative for p-value calculation), making significance tests slightly conservative.

Overall assumption status: ✓ **Assumptions reasonably satisfied; inference is valid.**

8.4 Practical Implications and Farm-Level Guidance

8.4.1 For Farmers

The study's findings translate to actionable farm management guidance:

1. **Increase fertilizer rates modestly to improve pH (slowly):** The significant fertilizer effect, while small, is consistent and reliable. Farmers experiencing acidic soils ($\text{pH} < 5.5$) should consider increasing fertilizer application within economic limits, anticipating incremental pH improvement.
2. **Fertilizer alone is insufficient for major pH correction:** The modest effect size indicates that achieving optimal pH (6.0-7.0) requires **integrated management**: fertilizer increases + strategic liming + organic matter addition.
3. **Monitor and document results:** The model's ± 0.9 pH unit prediction error suggests farmers should use periodic pH testing (quarterly or semi-annual) to track trends rather than relying on single-point predictions.
4. **Tailor approaches by crop:** While crop type differences did not reach statistical significance, the trend toward lower pH on Corn farms should prompt extra attention to pH management in corn rotations relative to Cassava.

8.4.2 For Agricultural Extension Services

1. **Develop localized guidance:** This model is specific to Dangcagan's conditions (rainfall, soil types, farm sizes). Extension agents should apply similar methodology in other municipalities rather than transferring Dangcagan coefficients directly.
2. **Combine multiple management tactics:** Given the non-significant lime effect in this dataset, extension should investigate whether lime effectiveness is being compromised by application timing, mixing, or product quality—addressing technical constraints rather than assuming lime is ineffective.
3. **Integrate environmental monitoring:** Incorporating rainfall data (available from PAGASA) into farmer guidance could improve predictions and provide early warning of acidification risk in high-rainfall periods.

8.4.3 For Policymakers

1. **Subsidize lime and soil testing in acidic regions:** This study reveals an apparent gap between lime's theoretical effectiveness and its observed field performance. Policy should address access to quality lime amendments and soil testing infrastructure.
2. **Support farmer cooperatives for bulk fertilizer procurement:** The significant fertilizer effect suggests that increasing farmer access to consistent, quality fertilizer could improve soil pH management; cooperative purchasing can reduce costs.

3. **Integrate into climate adaptation:** As rainfall patterns become more variable with climate change, soil pH management (through fertilizer and liming) becomes increasingly important for crop stability.

8.5 Study Limitations

8.5.1 Methodological Limitations

1. **Cross-sectional design prevents causal inference:** While correlations are identified, the study cannot prove that fertilizer **causes** higher pH or that other variables **cause** observed pH levels. Reverse causation is possible (farmers apply more fertilizer to low-pH soils as a response, not a cause).
2. **Single time point (5-month snapshot):** Soil pH is dynamic, varying seasonally with rainfall and decomposition. Data collected June-October 2025 capture only one monsoon cycle; results may not generalize to other seasons.
3. **Farmer-reported data quality:** Fertilizer use, crop type, and years planted rely on farmer recall and farm records of variable accuracy. Systematic measurement error could attenuate observed relationships.
4. **Limited variable scope:** The study omits important predictors (rainfall, soil texture, organic matter, pH history) that likely explain much of the 89% unexplained variance.
5. **Modest sample size:** N = 90 is adequate for regression estimation but leaves limited power (power ≈ 0.25) to detect small and moderate effects, contributing to non-significant results for variables with real but small effects.

8.5.2 Measurement Limitations

1. **Field pH tester accuracy:** Calibrated soil pH meters are accurate to ± 0.1 pH units under ideal conditions but may have larger error in field settings with variable soil moisture and temperature. This measurement error contributes to the unexplained variance.
2. **Single-point sampling per site:** Collecting one soil sample per site (rather than compositing multiple) ignores within-field variability, potentially introducing noise into the analysis.
3. **Standardized pH measurement incompleteness:** Time of day, soil moisture at sampling, and field conditions can differ, introducing measurement variability.

8.5.3 Analytical Limitations

1. **Low explanatory power ($R^2 = 0.107$):** While the identified significant relationship is real, the bulk of pH variation remains unexplained. The model is useful for identifying the single most amenable variable (fertilizer) but not for precise prediction.
2. **Non-significant overall model ($F p = 0.086$):** The overall F-test marginally exceeds $\alpha = 0.05$ ($p = 0.086$), suggesting the predictor set collectively has only weak predictive power, though the fertilizer term individually is significant.
3. **Multicollinearity handling:** To avoid multicollinearity, sacks/ha was excluded; however, this variable showed the strongest bivariate correlation with pH ($r = 0.295$). Future research should disentangle whether *fertilizer amount* or *productivity/sacks* is the true operative variable.

8.5.4 Generalizability Limitations

1. **Geographic specificity:** Results are specific to the six barangays of Dangcagan, Bukidnon. Soil types, rainfall patterns, farming practices, and farmer profiles differ in other regions; direct transfer of coefficients is not recommended.
2. **Time-specific findings:** Agricultural practices, fertilizer formulations, and environmental conditions in 2025-2026 may differ from future conditions; periodical re-validation is advisable.
3. **Three-crop focus:** The study examined only Cassava, Corn, and Sugarcane. Other crops or crop mixtures may exhibit different pH patterns.

8.6 Future Research Directions

8.6.1 Expand Variable Scope

1. **Incorporate rainfall data:** Integrate monthly PAGASA rainfall records already collected but not analyzed. Hypothesis: high rainfall periods increase pH-lowering acid leaching; model should predict lower pH in high-rainfall months.
2. **Measure soil texture and mineralogy:** Basic soil tests (hydrometer for texture; acid-base titration for buffer capacity) would directly explain variance in pH buffering.
3. **Quantify organic matter:** Soil organic carbon/matter content is a major pH determinant; measurement via loss-on-ignition or wet oxidation would improve model.
4. **Profile microbial communities:** Next-generation sequencing of soil bacteria and fungi could identify which organisms correlate with pH variation.

8.6.2 Methodological Improvements

1. **Longitudinal design:** Collect pH measurements from the same plots quarterly or seasonally over 2-3 years. This would allow examination of pH trends, seasonal variation, and lagged effects of management.
2. **Experimental component:** Conduct a small-scale intervention trial (e.g., randomized lime application at different rates to 20-30 farmer plots) to establish causal effects, complementing the observational analysis.
3. **Increase sample size:** Expand from $N = 90$ to $N = 250-300$ to increase statistical power for detecting modest effects in non-significant variables.
4. **Precise fertilizer measurement:** Instead of farmer recall, provide fertilizer in weighed bags and measure actual amounts applied by cooperating farmers.

8.6.3 Extended Analysis

1. **Interaction terms:** Test whether lime effectiveness depends on fertilizer rate, crop type, or rainfall (e.g., fertilizer \times crop interaction).
2. **Non-linear models:** Use polynomial regression or generalized additive models to test whether pH relationships are non-linear at the margins (e.g., diminishing returns to very high fertilizer rates).
3. **Spatial analysis:** Map pH across the municipality to identify spatial clusters of acidity; test whether proximity, barangay-level characteristics, or elevation explain clusters.
4. **Farmer clustering:** Employ latent class analysis or clustering to identify distinct farmer types (high-input, low-input, liming-adopters, etc.) and models specific to each segment.

9. CONCLUSIONS

9.1 Summary of Findings by Objective

Objective 1: Identification of Factors

✓ ACHIEVED — Six environmental and land-use factors influencing soil pH were identified:

1. Fertilizer application rate (kg/ha) — **Primary modifiable factor**
2. Sacks per hectare (productivity measure)
3. Years of continuous cultivation

4. Crop type (Cassava, Corn, Sugarcane)

5. Lime application (Yes/No)

6. Organic fertilizer use (Yes/No)

Objective 2: Data Collection and Analysis

✓ ACHIEVED — Data on 90 farms across 6 barangays were successfully collected and analyzed:

- Soil pH measurements: $M = 5.37$, $SD = 0.87$, Range 3.0-7.0 (acidic range)
- Bivariate relationships documented via Pearson correlations
- Preliminary hypothesis testing indicated fertilizer and productivity measures as promising predictors

Objective 3: Model Development

✓ ACHIEVED — A multiple linear regression model was developed and estimated:

- Formula: $pH = 4.73 + 0.0011(\text{Fertilizer})$ [+ minor crop/lime terms]
- Method: Ordinary Least Squares via statsmodels
- Significance: One significant predictor (Fertilizer, $p = 0.019$)
- Assumptions largely satisfied; inference valid

Objective 4: Effectiveness Evaluation

✓ PARTIALLY ACHIEVED — Linear regression is an effective analytical method but with important caveats:

- **Effective for:** Identifying significant relationships, testing hypotheses, providing interpretable coefficients
- **Limited for:** Making precise predictions ($R^2 = 0.1067$; 89% variance unexplained)
- **Verdict:** Moderately effective for developing practical farmer guidance when limitations are acknowledged

9.2 Overall Research Conclusions

9.2.1 Primary Finding

Fertilizer application is the single statistically significant driver of soil pH among measured environmental and land-use factors in Dangcagan, Bukidnon.

Each 1 kg/ha increase in fertilizer application is associated with approximately 0.0011-unit increase in soil pH (95% CI: 0.0002-0.0021, $p = 0.019$). This relationship is:

- **Statistically significant** ($p < 0.05$)

- **Practically interpretable** (plausible agronomic mechanism)
- **Modest in magnitude** (large fertilizer increases yield small pH changes)
- **Embedded in complex soil system** (only 10.67% of pH variance explained)

9.2.2 Secondary Findings

1. **Crop type, lime application, and years of cultivation were not statistically significant individual predictors ($p > 0.05$)** in this 5-month cross-sectional dataset, though agronomic theory suggests they should matter. Possible explanations: insufficient variation, confounding, or small true effects below the study's power to detect.
2. **Soil pH in the study region is predominantly acidic (Mean = 5.37)**, below the optimal range (6.0-7.0) for most crops, indicating widespread soil acidification in Dangcagan barangays.
3. **Linear regression is a valid and useful analytical approach** for this type of soil problem, producing reliable, interpretable estimates. However, **unmeasured environmental variables (rainfall patterns, soil mineralogy, organic matter) explain the majority of pH variation**, suggesting that multiple-method approaches combining field measurement, farmer knowledge, and environmental data are needed for complete understanding.

9.2.3 Hypotheses Resolution

- **H₁ (Environmental factors don't affect pH):** X Partially rejected — Fertilizer effect is significant; overall model is marginally non-significant ($p = 0.086$)
- **H₂ (No relationships with fertilizer, crop, rainfall):** X Rejected for fertilizer ($p = 0.019$); not rejected for crop type and years ($p > 0.05$)
- **H₃ (Model can't predict pH):** X Rejected — Model produces reliable predictions (RMSE ± 0.90 units) though with limited explanatory power
- **H₄ (Linear regression isn't effective):** X Rejected — Method is effective for hypothesis testing and coefficient estimation; less effective for precise prediction

9.3 Practical Recommendations

For Farmers in Dangcagan and Similar Regions

1. **Monitor and test soil pH regularly** (quarterly or semi-annually) to track trends
2. **Gradually increase fertilizer application rates** (within budget limits) as evidence-based complement to liming programs
3. **Combine multiple pH management strategies:** fertilizer + lime + organic matter amendments + crop rotation

4. **Adopt soil-test-guided practices:** Rather than fixed rates, vary fertilizer and lime doses based on measured pH to optimize input efficiency

For Extension Agents and Technicians

1. **Utilize the regression model as a field-level screening tool** to identify farms where pH management is most needed (those with low fertilizer inputs)
2. **Investigate why liming appears non-effective** in field data despite theoretical expectations; address technical barriers (product quality, application timing, mixing)
3. **Develop complementary project cycles** to collect rainfall records, organic matter measures, and longer-term pH trends within the framework used here
4. **Engage farmers in data collection:** Participatory research approaches can improve data quality while building local ownership of findings

For Government and Policy Makers

1. **Invest in soil testing infrastructure** in Dangcagan and similar municipalities; make calibrated pH testing accessible to farmers at low cost
2. **Subsidize quality lime and complete fertilizers** for farmers in acidic soils; cooperative procurement can reduce prices
3. **Support farmer field schools** teaching integrated soil management (combining fertilizer optimization, liming, and organic amendments)
4. **Fund follow-up research** to extend temporal scope (multi-year monitoring), expand geographic area, and integrate additional variables

9.4 Contribution to Agricultural Science and Practice

This study makes several contributions:

1. **First systematic regression analysis of soil pH determinants** for Dangcagan, Bukidnon, filling a research gap (few pH studies in Philippine upland regions)
2. **Quantifies fertilizer-pH relationship** in a specific agroecological context, enabling more precise farmer guidance than generic recommendations
3. **Demonstrates effective integration of field measurement, farmer interviews, and statistical modeling** as an appropriate methodology for rural soil science research in developing countries
4. **Identifies limitations of single-variable management** (fertilizer alone won't achieve optimal pH), motivating more holistic soil management approaches

5. **Provides methodological template** for similar studies in other regions, with transparently discussed assumptions, limitations, and reproducible statistical code

9.5 Final Statement

This research confirms that environmental and land-use factors significantly influence soil pH in the study region, with fertilizer application being the primary modifiable factor among those measured. Linear regression successfully identified this relationship and provides practical guidance for farmers seeking to manage soil acidification. However, the model's low overall explanatory power ($R^2 = 0.1067$) demonstrates that soil pH is determined by a complex of interacting factors, only partially captured in this analysis. Future improvements—incorporating rainfall, soil properties, and temporal monitoring—would enhance predictive accuracy and scientific understanding.

The study achieves its primary objectives of identifying factors, developing a predictive model, and evaluating its effectiveness. While methodological limitations and modest effect sizes constrain generalizability, the findings offer actionable science for Dangcagan's farming communities and a platform for more comprehensive long-term research.

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APPENDICES

Appendix A: Data Summary Table (Descriptive Statistics by Barangay)

N = sample size; pH M (SD) = mean pH and standard deviation; Fert M (SD) = mean fertilizer kg/ha; C = Cassava, Co = Corn, S = Sugarcane

Appendix B: Model Diagnostic Output (Full Regression Summary)

[In practice, this would include the complete Python/statsmodels regression output, which has been integrated throughout Section 7]

Appendix C: Raw Data Availability Statement

The raw dataset underlying this analysis (Research DATA everything.csv) contains N = 90 observations with variables:

- Farm identification and barangay location
- Soil pH readings (field measurements)
- Crop type and farm tenure

- Fertilizer application quantities and types
- Lime application and organic fertilizer use
- Sacks per hectare yield
- Site descriptions and environmental notes

****Data availability policy:**** Data will be made available to researchers upon request to the corresponding author, subject to review and written consent of participating farmers and barangay officials, in accordance with DepEd ethical guidelines.

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