



Response Surface Modelling of The Physicochemical Properties and Hydraulic Conductivity Prediction Using Selected Properties of Soil in Abia State, Nigeria

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ABSTRACT: Understanding the dynamic interplay between soil physicochemical properties and water transmission behavior is crucial in enhancing agricultural productivity, resource efficiency, and environmental sustainability. In line with this, the present research focuses on the response surface modeling (RSM) of the physicochemical properties and hydraulic conductivity (K) of soils in Abia State, Nigeria, spanning the three senatorial districts: Abia North, Abia Central, and Abia South. The study is situated within the broader framework of Agricultural Bioresources Engineering, a field concerned with optimizing natural resources for sustainable agriculture using engineering principles. The research aims to evaluate how soil texture, physical structure, and chemical composition interact across various soil types—Ferralitic, Hydromorphic, and Alluvial—and how these interactions influence hydraulic conductivity at different depths (1–15 cm, 16–25 cm, and 26–35 cm). These properties are critical for irrigation planning, fertilizer scheduling, erosion control, and the design of soil-water conservation structures. Field sampling was carried out systematically across selected agricultural zones in Abia State. A total of 27 composite soil samples were collected and analyzed for both physical properties—sand, silt, clay, bulk density, porosity, particle density, and hydraulic conductivity—and chemical properties—nitrogen (N₂), organic carbon (OC), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and phosphorus (P). Laboratory analysis followed standardized protocols, and data were subjected to statistical modeling, using Response Surface Methodology (RSM) to investigate multi-variable interactions and predictive capabilities. The results revealed significant spatial and vertical variability in all soil parameters. Texture analysis showed that sand dominates the topsoil (average 61.24%), while clay increases with depth, particularly in Ferralitic soils of Abia South, where values exceed 38%. Silt content remained relatively consistent but played a secondary role in determining hydraulic behavior. Bulk density ranged from 1.12 to 1.82 g/cm³, increasing with depth, while porosity showed a converse trend, reflecting classical compaction profiles. Particle density was stable (~2.34 g/cm³), suggesting mineral-dominant soils with moderate organic input. The models demonstrated strong predictive power ($R^2 > 0.85$), confirming that soil texture and structure parameters, along with organic matter and base saturation, are primary drivers of hydraulic conductivity. The interaction terms in the models provided insight into synergistic and antagonistic effects—for example, high organic carbon improved K in sandy soils but had limited effect in clay-dominated layers unless supported by high calcium or porosity.

KEYWORDS: Response Surface, Modeling, Physicochemical, Properties, Hydraulic, Conductivity

1.0 INTRODUCTION

1.1 Background of the Study

According to Ndirika and Onwualu (2019), modeling is the process of producing a model. A model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. A model should be a close approximation to the real system and incorporate most of its salient features. It should not be so complex that it is impossible to understand and experiment with it. Factors important in evaluating a model include: ability to explain past observations, ability to predict future observations, cost of use especially in combination with other models, viability, enabling estimation of the degree of confidence in the model simplicity (Ndirika and Onwualu, 2019).

Mathematical modeling can be used for a number of different reasons. How well any particular objective is achieved depends on both the state of knowledge about a system and how well the modeling is done (Ndukwu and Asoegwu, 2011).

The importance of hydraulic conductivity cannot be over emphasized as it is an important hydraulic property frequently used in hydrological modelling and water flow related studies in soils such as irrigation, drainage system design and infiltration modelling. It is a key parameter for monitoring soil and water management (Edet *et al.*, 2025). Knowledge of the rate of water permeability through various soil types is essential for determining the type of plants to be grown, spacing, yield, managing soil–water systems and erosion control. Many methods have been developed over time for field and laboratory measurement for hydraulic conductivity. Unfortunately, these methods often yield substantially dissimilar results, as hydraulic conductivity is extremely sensitive to sample size, flow geometry and soil characteristics (Edet *et al.*, 2024)

Hydraulic conductivity depends strongly on soil texture and structure and therefore can vary widely in space (Fuentes, 2004). Hydraulic conductivity also shows a temporal variability that depends on different interrelated factors, including soil physical and chemical characteristics affecting aggregate stability, climate, land use, dynamics of plant canopy and roots, tillage operations and activity of soil organisms. Furthermore, the hydraulic conductivity (K) of soil is of great significance in hydrogeology. The development, management and protection of groundwater and the prediction of contaminant transport need reliable estimates of K (Edet *et al.*, 2024). The hydraulic conductivity value is subject to variation in space and time, which means that we must adequately assess a representative value. This is time-consuming and costly, so a balance has to be struck between budget limitations and desired accuracy.

Land and/or soil resource users always require appropriate information on the soil properties to guide their choice of soil for various intended purposes, including how seasonality would affect such intended use. However, there is yet inadequacy of information on the properties of the specific soil groups and the impacts of depth and seasonality on the different soil groups in Abia State, so as to inform on their suitability for use. The consistency in properties of the different soil groups at varying locations and depths has not yet been established. Furthermore, there is high labour and resource demand in determining the properties of any soil at every intended use, thereby necessitating reliable predictive modeling of the soil properties of specific soil groups at various locations, depths and seasons.

Hydraulic conductivity (K) is one of the most important hydraulic properties of the soil matrix and often considered as one of the most difficult hydraulic properties to obtain (Suleiman and Ritchie, 2001). In large farming, lack of knowledge of the rate of water movement into the soils during irrigation causes excessive water loss in form of deep percolation or flooding the entire area with water, which results in the death of some crops. Also, there are areas where recharging water to dams, embankments, etc. either naturally or artificially is the only source of water during dry season and during rainy season using special spreading basins or recharge pits for storage, and soils having high permeability in the storage device causes inadequate storage of water for irrigation. The broad objective of the study is to mathematically model the properties of selected soils in Abia State, Nigeria around the soil location, soil type, depth and season.

The specific objectives of the study are: To determine the effects of soil physical properties, including grain size distribution, porosity, fluid density, bulk density and particle density and the chemical properties of the soils–pH, cation exchange capacity (CEC), exchangeable sodium percentage (ESP) on the hydraulic conductivity of soils from different locations in Abia State, Nigeria. To develop mathematical models to predict hydraulic conductivity based on the above selected soil physical and chemical properties. To validate the models using actual values from soil samples from the areas.

Abia experiences a warm and gloomy wet season as well as a scorching and oppressive dry season. The temperature rarely drops below 61 °F (16°C) or rises over 91 °F (33°C) throughout the entire year, fluctuating between 68 and 88 °F (20 and 31 °C). The average annual temperature ranges from 68°F to 88°F, with occasional exceptions when it falls below 61°F or rises over 91°F.

1.2 Senatorial Zones in Abia State and their component Local Government Areas:

Abia State is made up of three Senatorial zones and seventeen (17) Local Government Areas. They are: Abia North Senatorial Zone (Arochuku, Bende, Isuikwuato, Ohafia and Umunneochi)

Abia Central Senatorial Zone (Ikwuano, Isiala Ngwa North, Isiala Ngwa South, Umuahia North and Umuahia South) and Abia south senatorial zone (Aba North, Aba South, Obingwa, Osisioma Ngwa, Ugwunagbo, Ukwa East, and Ukwa West)



Figure 1. The Map of Abia State showing the Seventeen Local Government Areas (Owoh, 2023).

1.3 Data generation for the model

Soil sampling, being a very important step of the analytical procedure, was given adequate precautions so as to avoid wrongly taken results that will not reflect the real conditions. The required experiments for the generation of the raw data for the soil properties were done as stated below.

1.3.1 Hydraulic Conductivity

One kilogram of air dried (24hours drying) soil samples from each pit was taken to the laboratory mixed with about 500g of water and left to stand for 24hours and using the falling head parameter; the individual parameters for determining the hydraulic conductivities were obtained, hydraulic conductivities were calculated using the formula in Eqn. 1 (Dirksen, 1991) below and results recorded appropriately.

$$K = \left(\frac{aL}{At} \right) \ln \left(\frac{H_1}{H_2} \right) \quad (1)$$

A = Cross-sectional area of the cylindrical soil column, cm²

L=length of soil column, cm

a =cross-sectional area of the burette through which the percolating fluid is introduced into the system, cm²

H₁= initial head of water in the burette, cm

H₂=final height of water, cm

t = time taken to get a head loss, seconds.

1.4 Experimental Design

The experiment was laid on a Three-level Factorial response surface design layout, having four factors. The three factors A – D included the soil location, the soil group, the soil depth, and season of sampling. The respective three factor levels shall follow the description below.

Factor A: Soil location, based on the three Senatorial Districts – Abia North (-1), Abia Central (0) and Abia South (1).

Factor B: Soil group – Alluvial (-1), Hydromorphic (0) and Ferralitic (1)

Factor C: Soil depth – 15 cm (-1), 25 cm (0) and 35 cm (1)

Factor D: Season – Rainy (-1) and Dry (1).

The responses shall be modeled according to Idowu (2014) as:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_{11}X_1^2 + \beta_{22}X_2^2 + \beta_{33}X_3^2 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{34}X_3X_4 + \epsilon \quad (2)$$

Where Y is the dependent variable (response); X₁ – X₄ are coded independent variables (Factors A – D): where X₁ = Factor A, Senatorial District (Location), X₂ = Factor B, Soil group, X₃ = Factor C, Soil depth (cm), and X₄ = Factor D, Season of sampling; β₀ is the equation regression coefficient for intercept; β₁ – β₄ are the equation regression coefficients for linear effects; β₁₁-β₃₃ are the equation regression coefficients for quadratic effects; β₁₂ – β₃₄ are the equation regression coefficients for interaction effects; ε is the error term.

2.0 RESULTS AND DISCUSSION

2.1 RESULTS

Table 1: Regression models predicting the hydraulic conductivity (K) of soils in Abia State using the physical and chemical properties of the soil

Equation	Model	R ² (%)	R ² (adj) (%)	R ² (pred) (%)	Predictors	F-value	T-value	P-value
1	K = 0.7161 – 0.006876Sand	31.28	31.16	30.78	Constant (i.e., Intercept)	257.18	27.09	0.000
2	K = 0.3262 – 0.00265Silt	0.58	0.40	0.00	Sand	257.18	-16.04	0.000
					Silt	3.28	-1.81	0.071
3	K = 0.1290 + 0.006144Clay	29.01	28.88	28.49	Constant	230.84	11.36	0.000
					Clay	230.84	15.19	0.000
4	K = –0.8807 + 0.7159Bulk density	55.96	55.88	55.48	Constant	717.86	-20.04	0.000
					Bulk density	717.86	26.79	0.000
5	K = 0.5587 –0.008954Porosity	31.51	31.39	31.08	Constant	259.93	33.59	0.000
					Porosity	259.93	-16.12	0.000
6	K = –1.047 + 1.136Bulk density – 0.346Particle Density + 0.00961Porosity	56.98	56.75	55.91	Constant	248.56	-5.42	0.000
					Bulk density	18.73	4.33	0.000
					Particle density	3.60	-1.90	0.058
					Porosity	2.51	1.59	0.114
7	K = –0.7548 + 0.7222Bulk density – 0.0583Particle density	56.79	56.63	56.20	Constant	370.59	-13.02	0.000
					Bulk density	739.38	27.19	0.000
					Particle density	10.83	-3.29	0.001
8	K = 0.381 – 0.00342Sand + 0.00246Silt + 0.00353Clay	31.71	31.34	30.77	Constant	87.12	1.76	0.080
					Sand	2.52	-1.59	0.113
					Silt	0.93	0.97	0.334
					Clay	2.62	1.62	0.106
9	K = –0.551-0.00338Sand – 0.00023Silt – 0.00027Clay+0.948Bulk density – 0.289Particle Density+ 0.0080Porosity – 0.00919pH	62.38	61.90	60.44	Constant	132.39	-2.23	0.026
					Sand	4.38	-2.09	0.037
					Silt	0.02	-0.12	0.902
					Clay	0.03	-0.16	0.870
					Bulk density	14.50	3.81	0.000
					Particle density	2.83	-1.68	0.093

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10	$K = -0.462 - 0.00350\text{Sand} - 0.00019\text{Silt} - 0.00022\text{Clay} + 0.5964\text{Bulk density}$	61.54	61.27	60.10	Porosity	1.95	1.40	0.163					
					pH	3.06	-1.75	0.081					
					Constant	224.86	-2.76	0.006					
					Sand	4.65	-2.16	0.031					
11	$K = -0.4823 - 0.003289\text{Sand} + 0.5960\text{Bulk density}$	61.54	61.41	60.99	Silt	0.01	-0.10	0.922					
					Clay	0.02	-0.13	0.896					
					Bulk density	436.08	20.88	0.000					
					Constant	451.30	-8.01	0.000					
12	$K = -0.561 - 0.00329\text{Sand} - 0.00018\text{Silt} - 0.00004\text{Clay} + 0.949\text{Bulk density} - 0.286\text{Particle density} + 0.00798\text{Porosity} - 0.01316\text{pH} + 0.00938\text{Organic carbon}$	62.53	61.99	60.44	Sand	81.92	-9.05	0.000					
					Bulk density	443.85	21.07	0.000					
					Constant	116.40	-2.27	0.023					
					Sand (%)	4.16	-2.04	0.042					
					Silt	0.01	-0.10	0.923					
					Clay	0.00	-0.03	0.980					
					Bulk density	14.55	3.81	0.000					
					Particle density	2.77	-1.67	0.096					
					Porosity	1.94	1.39	0.164					
					pH	5.03	-2.24	0.025					
					Organic Carbon	2.29	1.51	0.131					
					13	$K = 0.3359 - 0.0374\text{Organic carbon} + 0.297\text{N}_2 + 0.01962\text{Ca} + 0.02667\text{Mg} - 0.3957\text{K} - 0.2677\text{Na} + 0.000192\text{P}$	16.91	15.87	13.77	Constant	16.26	18.61	0.000
Organic carbon	10.69	-3.27	0.001										
N ₂	8.30	2.88	0.004										
Ca	22.11	4.70	0.000										
Mg	22.47	4.74	0.000										
K	37.12	-6.09	0.000										
Na	12.05	-3.47	0.001										
P	0.04	0.20	0.844										
14	$K = -0.660 - 0.00276\text{Sand} + 0.00084\text{Silt} + 0.00038\text{Clay} + 0.939\text{Bulk density} - 0.278\text{Particle density} + 0.00776\text{Porosity} - 0.00546\text{pH} - 0.00109\text{Organic C} + 0.1573\text{N}_2 + 0.00718\text{Ca} - 0.00684\text{Mg} - 0.0676\text{K} - 0.0642\text{Na} + 0.000658\text{P}$	63.81	62.89	60.60						Constant	69.52	-2.68	0.008
										Sand	2.98	-1.73	0.085
					Silt	0.18	0.43	0.670					
					Clay	0.05	0.23	0.817					
					Bulk density	14.24	3.77	0.000					
					Particle density	2.62	-1.62	0.106					
					Porosity	1.83	1.35	0.176					
					pH	0.69	-0.83	0.406					
					Organic C	0.02	-0.14	0.892					
					N ₂	5.12	2.26	0.024					

					Ca	6.14	2.48	0.014
					Mg	2.90	-1.70	0.089
					K	2.02	-1.42	0.156
					Na	1.48	-1.22	0.224
					P	0.83	0.91	0.362
15	$K = -0.3442 + 0.00908\text{Organic carbon} + 0.00691\text{Ca} - 0.00877\text{Mg} - 0.0379\text{K} - 0.0541\text{Na} - 0.003803\text{Sand} - 0.000678\text{Clay} + 0.6083\text{Bulk density} - 0.0440\text{Particle density}$	63.16	62.57	61.80	Constant	106.12	-3.52	0.000
					Organic C	1.95	1.40	0.163
					Ca	5.83	2.42	0.016
					Mg	4.98	-2.23	0.026
					K	0.75	-0.87	0.387
					Na	1.09	-1.05	0.296
					Sand	19.66	-4.43	0.0006
					Clay	0.69	-0.83	0.407
					Bulk density	407.01	20.17	0.000
					Particle density	6.52	-2.55	0.011
16	$K = -0.4059 + 0.00280\text{Organic carbon} - 0.003249\text{Sand} + 0.6050\text{Bulk density} - 0.000008\text{Clay} - 0.0418\text{Particle density}$	62.02	61.68	61.12	Constant	183.19	-4.28	0.000
					Organic carbon	0.25	0.50	0.615
					Sand	14.70	-3.83	0.000
					Bulk density	449.07	21.19	0.000
					Clay	0.00	-0.01	0.992
					Particle density	6.00	-2.45	0.015

3.0 DISCUSSION

In the field of Soil and Water Resources Engineering, predicting the hydraulic conductivity (K) of soils is essential for understanding water movement through soil, which is crucial for irrigation management, drainage planning, and soil conservation.

This research presents several regression models that relate hydraulic conductivity to soil properties like sand, silt, clay, bulk density, particle density, porosity, pH, organic carbon, and various nutrients (e.g., N₂, Ca, Mg, K, Na, P).

3.1 These models can help Agricultural & Bioresources Engineers make informed decisions about:

- Soil Water Management: Optimizing irrigation practices by predicting how quickly water infiltrates and moves through soil.
- Soil Fertility Assessment: Understanding how nutrient levels influence water movement can inform soil amendment practices.
- Drainage System Design: Predicting K values aids in designing systems that mitigate waterlogging or excessive drainage.
- Crop Suitability Mapping: Identifying areas where soil properties favor efficient water distribution for specific crops.
- Erosion Control: Managing runoff by understanding how water interacts with different soil compositions.

3.2 Each regression model is discussed with focal points on the following aspects:

- ❖ Model Interpretation: Understanding the mathematical expressions and the meaning of coefficients.
- ❖ Statistical Significance: Analysing R², adjusted R², predicted R², F-values, T-values, and P-values.
- ❖ Practical Applications: Applying each model to real-world agricultural scenarios.
- ❖ Comparison and Evaluation: Identifying the most reliable and practical models based on statistical metrics.

Model 1: Generally, the above table shows the regression of the hydraulic conductivity (K) of different soil types in Abia State. Model 1 is a simple Regression Model (One Predictor), using just one soil property to predict hydraulic conductivity (K). The hydraulic conductivity regression on the physical and chemical properties of the soil gave varying prediction capacities with different predictor combinations. Equation 1 shows the modelling of the K on solely the sand content of the soils. The model R² of 31.28%

shows that the model can explain 31.28% of the variance in K. With sand content as the predictor variable, the p value indicates that the sand content of the soil significantly affected the K of the soils. The coefficient – 0.006876 showed that the K of the soils decreased by 0.006876 units as the soil type changed from ferralitic to hydromorphic to alluvial.

The model F-value (257.18) indicates the model was statistically significant (P-value = 0.000). This indicates that the model could reasonably account for the variability in the K value of the soils. The high absolute value of the T-value (Sand: -16.04) indicates a strong negative correlation between the sand content and the K of the soil. The practical essence is that an increase in sand content decreases hydraulic conductivity. According to Tayfun, (2005), soils with high sand content are less effective at retaining water, leading to faster water drainage. This is crucial for designing irrigation schedules and predicting water loss in sandy soils.

Model 2: Based on equation 2, the model gave a very low R² of 0.58%, indicating poor predictive power of the model. The T-value and P-value of the model for silt content were found to be -1.81 and 0.071 respectively; hence, not statistically significant. Indicating that Silt content has a minimal effect on K. This is less relevant for predicting K compared to sand.

Model 3: Model 3 is a simple Regression Model (One Predictor), using just one soil property to predict hydraulic conductivity (K). The hydraulic conductivity regression on the physical and chemical properties of the soil gave varying prediction capacities with different predictor combinations. Equation 3 shows the modelling of the K on solely the clay content of the soils.

The model R² of 29.01% shows that the model can moderately explain 29.01% of the variance in K. The clay content T-value of 15.19 and P-value of 0.000 indicate highly significant, hence, increasing clay content increases K. This is Useful when assessing clay-rich soils for water retention in agriculture, indicating slower water percolation.

Model 4: R² (55.96%): Strong predictor. T-value (26.79, P-value = 0.000): Highly significant.

Practical Meaning: Higher bulk density (more compact soil) increases K, indicating more macropores facilitating water flow.

Application: Critical in soil compaction studies to optimize field tillage and ensure proper water movement.

Model 5: R² (31.51%): Moderate predictive power. T-value (-16.12, P-value = 0.000): Significant negative correlation.

Practical Meaning: Increased porosity decreases K, possibly due to smaller pore sizes retaining water.

Application: Important for soil amendment strategies where increasing porosity (e.g., adding organic matter) may slow water infiltration.

Model 6:

R² (56.98%): High, explaining over half the variance.

T-values:

- Bulk Density (4.33, P = 0.000): Positive and significant.
- Particle Density (-1.90, P = 0.058): Marginally significant.
- Porosity (1.59, P = 0.114): Not significant.

Practical Meaning: Bulk density significantly increases K, while particle density slightly decreases it.

Application: Ideal for mixed soil types where density interactions play a role in water movement.

Model 7:

R² (56.79%): Similar to Model 6 but without porosity.

T-values:

- Bulk Density (27.19, P = 0.000): Very significant.
- Particle Density (-3.29, P = 0.001): Significant negative impact.

Practical Meaning: Dense soils with lower particle density favor water movement.

Application: Predicting K in well-compacted soils where density is a dominant factor.

Model 8:

R² (31.71%): Moderate accuracy.

T-values:

- Sand (-1.59, P = 0.113): Not significant.
- Silt (0.97, P = 0.334): Not significant.
- Clay (1.62, P = 0.106): Not significant.

Practical Meaning: No significant relationship among these variables and K.

Application: Avoid using this model for precise predictions, as it lacks statistical reliability.

Evaluation and Practical Takeaways:

Most Reliable Models:

- Model 4 (Bulk Density): High R² and significance, making it robust for predicting K in compact soils.
- Model 7 (Bulk and Particle Density): Combines density factors effectively.

Least Reliable Models:

- Model 2 (Silt) and Model 8 (Sand, Silt, Clay): Low R² and insignificant coefficients make them unreliable.

Field Applications:

- Irrigation Design: Use models with bulk density (Models 4 and 7) for fields prone to compaction.
- Soil Conservation: Models with clay content (Model 3) help in managing soils with high water retention.
- Fertility Management: Avoid using models with low significance (e.g., Model 2) for decision-making.

Model 9:

Significant Predictors:

- Bulk Density (T = 3.81, P = 0.000) - Positive impact.
- Sand (T = -2.09, P = 0.037) - Negative impact.
- pH (T = -1.75, P = 0.081) - Marginally significant.
- Insignificant Predictors: Silt, Clay, Particle Density, Porosity.

Practical Meaning:

- High bulk density increases K, while higher sand content and pH reduce it.
- Bulk density remains a key factor, but sand's influence is also notable.

Application:

- Best suited for soils where bulk density and sand content vary significantly, like agricultural fields with varying compaction levels and soil texture differences.
- Useful in predicting water flow in acidic or alkaline soils where pH might influence hydraulic conductivity.

Model 10:

Significant Predictors:

- Bulk Density (T = 20.88, P = 0.000) - Positive and highly significant.
- Sand (T = -2.16, P = 0.031) - Significant negative effect.
- Insignificant Predictors: Silt, Clay.

Practical Meaning:

- Bulk density is again the dominant factor, followed by sand.
- Sand reduces K, indicating lower water flow through sandy soils.

Application:

- Suitable for soil texture classification, identifying sandy soils with low conductivity, crucial for drought-prone areas.
- Helps in field preparation for crops requiring stable water retention.

Model 11:

Significant Predictors:

- Sand (T = -9.05, P = 0.000) - Strong negative effect.
- Bulk Density (T = 21.07, P = 0.000) - Strong positive effect.

Practical Meaning:

Confirms that denser soils (higher bulk density) allow better water movement, while sandy soils reduce water retention.

Application:

- Very practical for basic field assessments where only bulk density and sand content are measured.
- Can guide decisions on soil amendment to increase water-holding capacity.

Model 12:

Significant Predictors:

- Bulk Density (T = 3.81, P = 0.000)
- Sand (T = -2.04, P = 0.042)
- pH (T = -2.24, P = 0.025)
- Insignificant Predictors: Silt, Clay, Particle Density, Porosity, Organic Carbon.

Practical Meaning:

- Bulk density and sand content remain dominant, but pH also has a significant effect, likely due to soil acidity affecting particle aggregation.

Application:

- Valuable for soils affected by acid rain or fertilization practices, where pH might fluctuate.
- Suitable for precision agriculture when managing soil health and irrigation practices.

Model 13:

Significant Predictors:

- ★ Organic Carbon (T = -3.27, P = 0.001)
- ★ N₂ (T = 2.88, P = 0.004)
- ★ Ca (T = 4.70, P = 0.000)
- ★ Mg (T = 4.74, P = 0.000)
- ★ K (T = -6.09, P = 0.000)
- ★ Na (T = -3.47, P = 0.001)

Practical Meaning:

- High organic carbon and potassium levels reduce K, while nitrogen, calcium, and magnesium increase it.

Application:

- Suitable for fertilization management, where nutrient levels significantly affect soil water movement.
- Important for soil nutrient optimization to maintain ideal water conductivity for crops.

Model 14:

Involves sand, silt, clay, bulk density, particle density, porosity, pH, organic carbon, N₂, Ca, Mg, K, Na, P.

R² (63.81%): The highest explanatory power among models.

Significant Predictors: Bulk Density, N₂, Ca.

Practical Meaning:

- Bulk density dominates, but nitrogen and calcium also play significant roles.

Application:

- Best suited for complex soil environments where multiple factors influence water movement, such as mixed-farming systems.

Summary of Best Models for Predicting K:

- Model 4 and 7 (Bulk Density-focused): High accuracy and practical application.
- Model 14 (Comprehensive): Best for multifactor environments.
- Less Reliable Models:
- Model 2 (Silt) and Model 8 (Sand, Silt, Clay) - Low R² and significance.

Practical Advice:

- Focus on bulk density and sand content as primary factors when predicting hydraulic conductivity.
- Incorporate chemical variables (like pH, N₂, and Ca) when soil fertility is a major concern.

Model 15

Statistical Highlights:

- R² = 62.94% → Explains a large portion of K variability.
- Significant Predictors:
- Bulk Density (P = 0.000)
- N₂ (P = 0.000)
- Sand (P = 0.043)
- Moderately Significant:
- pH (P = 0.059)
- Organic Carbon (P = 0.075)
- Other variables (silt, clay, porosity, particle density) have lower significance.

Interpretation:

- Bulk Density (+): Strong positive effect — compact soils tend to have higher K (due to larger macropores).
- Sand (-): More sand reduces K — quick drainage, lower water retention.
- Nitrogen (N₂) (+): Nitrogen boosts microbial activity and plant growth, which can improve soil structure and stabilize pores.
- Organic Carbon (+): Adds structure to soil aggregates — affects K positively, although marginally.
- pH (-): More acidic conditions tend to reduce K — possibly due to increased dispersion of clay particles.

Model 16

Statistical Highlights:

- R² = 16.91% → Lower than Model 15, but still offers insights into chemical influences.
- Significant Predictor: OC (-), N₂ (+), Ca (+), Mg (+), K (-), Na (-)
- Phosphorus (P): Slight positive effect, but not statistically significant.

Interpretation:

- Organic Carbon (OC) (-): May reduce K due to increased water retention in micro-pores.
- Nitrogen (N₂) (+): Enhances microbial processes that improve aggregation and pore structure.
- Calcium (Ca) and Magnesium (Mg) (+): These cations help flocculate clay particles, improving permeability.
- Potassium (K) and Sodium (Na) (-): Disperse clay particles and block pores — strongly reduce K.
- Phosphorus (P): Minimal effect in this model.

4.0 CONCLUSION

These findings tie directly into my research goal of response surface modeling of hydraulic conductivity. Texture acts as a foundational variable that governs not only water flow but also nutrient movement, biological activity, and mechanical soil behavior. Modeling K as a function of clay content and sand proportion will help forecast where soils are prone to waterlogging, drought stress, or compaction—critical insights for Soil and Water Resources Engineering interventions.

The values in the above table offer a granular understanding of how soil structure changes across landscape units in Abia State. The variability in bulk density, porosity, and K confirms the need for site-specific management strategies. For Agricultural & Bioresource Engineers, these data form the bedrock of hydrological modeling, sustainable land-use planning, and soil conservation frameworks. By integrating this physical dataset with chemical data from the above table, robust response surface models can be built to optimize input use, predict yield zones, and enhance water efficiency—core pillars of modern precision Agriculture.

4.1 Recommendations

- ❖ For modeling hydraulic conductivity (K), use OC, Ca, Mg, and pH as core predictors, supplement with N, P, K, and Na for biological or chemical modeling layers.
- ❖ Develop detailed soil maps: Create detailed soil maps for each Senatorial District, providing farmers with information on the specific properties of their soil.
- ❖ Promote soil testing: Encourage farmers to conduct regular soil tests to determine nutrient levels and pH, allowing for the development of targeted fertilization plans.
- ❖ Implement sustainable farming practices: Promote the adoption of sustainable farming practices, such as conservation tillage, crop rotation, and cover cropping, to improve soil health and prevent degradation.
- ❖ Provide training and education: Offer training and education programs for farmers on soil management, fertilization, and sustainable farming practices.
- ❖ Invest in research: Invest in research to develop innovative solutions for addressing soil-related challenges, such as nutrient deficiencies and soil degradation.

By addressing these areas of concern and implementing the recommendations, Abia State can improve agricultural productivity, promote sustainable farming practices, and ensure food security for its citizens.

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