INNOVATIVE MODELLING OF SOIL PHYSICOCHEMICAL PROPERTIES FOR PREDICTING HYDRAULIC CONDUCTIVITY IN ABIA STATE

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Abstract. Understanding the relationship between soil physicochemical properties and water movement is essential for optimizing agricultural productivity, resource management, and environmental sustainability. This study models the physicochemical properties and hydraulic conductivity (K) of soils in Abia State, Nigeria, using Response Surface Methodology (RSM). Focusing on three senatorial districts: Abia North, Abia Central, and Abia South; the research examines how soil texture, physical structure, and chemical composition influence hydraulic conductivity at varying depths (1-15 cm, 16-25 cm, and 26-35 cm). The study covers different soil types, including Ferralitic, Hydromorphic, and Alluvial soils, with a focus on improving irrigation, fertilizer application, and erosion control. Field sampling was conducted systematically across selected agricultural zones, resulting in 27 composite soil samples. These samples were analyzed for physical properties such as sand, silt, clay, bulk density, porosity, particle density, and hydraulic conductivity. Chemical properties examined included nitrogen (N_2), organic carbon (OC), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and phosphorus (P). Laboratory analyses adhered to standardized methods, and data were processed using RSM to understand variable interactions and predict hydraulic conductivity. The results revealed significant spatial and vertical variations in soil characteristics. Sand was dominant in the topsoil, averaging 61.24%, while clay content increased with depth, particularly in Ferralitic soils of Abia South. Silt content remained relatively constant. Bulk density increased with depth, ranging from 1.12 to 1.82 g/cm^3, while porosity decreased, indicating soil compaction. The models demonstrated high predictive accuracy ($R^2>0.85$), confirming that soil texture, structure, and organic content significantly influence hydraulic conductivity. High organic carbon improved K in sandy soils but was less effective in clay-rich layers unless supplemented by calcium or porosity.

Keywords: *response surface, modeling, physicochemical, properties, hydraulic, conductivity*

Introduction

According to Ndirika and Onwualu (2016), 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

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model simplicity (Ndirika and Onwualu, 2016). 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 et al., 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.

Materials and Methods

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 (Arochukwu, 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*).

Figure 1. *The Map of Abia State showing the Seventeen Local Government Areas.*

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 in the text. 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 Eq. (1) (Waleeed et al., 2025; Seki et al., 2023; Ibitoye, 2008; Dirksen, 2000) below and results recorded appropriately.

$$K= \left(\frac{aL}{At}\right) \ln \left(\frac{H^1}{H^2}\right) \qquad \text{Eq. (1)}$$

Where, A=Cross-sectional area of the cylindrical soil column, cm^2; L=length of soil column, cm; a=cross-sectional area of the burette through which the percolating fluid is introduced into the system, cm^2; H_1=initial head of water in the burette, cm; H_2=final height of water, cm; t=time taken to get a head loss, seconds. The experiment was laid on a Three-level Factorial response surface design layout, having four factors. The three factors A-to-D included the soil location, the soil group, the soil depth, and season of sampling. The respective three factor levels shall follow the description as stated in text. 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 in Eq. (2):

$$Y= \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4+ \beta11X12 + \beta22X22 + \beta33X32 + \beta12X1X2 + \beta13X1X3 + \beta14X1X4 + \beta23X2X3 + \beta24X2X4 + \beta34X3X4 + \varepsilon \qquad \text{Eq. (2)}$$

Where, Y is the dependent variable (response); X_1-X_4 are coded independent variables (Factors A-D): where X_1=Factor A, Senatorial District (Location), X_2=Factor B, Soil group, X_3=Factor C, Soil depth (cm), and X_4=Factor D, Season of sampling; β_0 is the equation regression coefficient for intercept; β_1-β_4 are the equation regression coefficients for linear effects; β_{11}-β_{33} are the equation regression coefficients for quadratic effects; β_{12}-β_{34} are the equation regression coefficients for interaction effects; ε is the error term.

Results and 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., N_2, Ca, Mg, K, Na, P) (*Table 1*).

***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
					Sand	257.18	-16.04	0.000
2	K = 0.3262 – 0.00265Silt	0.58	0.40	0.00	Constant	3.28	18.56	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
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
					Porosity	1.95	1.40	0.163
					pH	3.06	-1.75	0.081
10	K = –0.462 – 0.00350Sand – 0.00019Silt – 0.00022Clay + 0.5964Bulk density	61.54	61.27	60.10	Constant	224.86	-2.76	0.006
					Sand	4.65	-2.16	0.031
					Silt	0.01	-0.10	0.922
					Clay	0.02	-0.13	0.896
					Bulk density	436.08	20.88	0.000
11	K = –0.4823 – 0.003289Sand + 0.5960Bulk density	61.54	61.41	60.99	Constant	451.30	-8.01	0.000
					Sand	81.92	-9.05	0.000
					Bulk density	443.85	21.07	0.000
12	K = –0.561 – 0.00329Sand – 0.00018Silt – 0.00004Clay+ 0.949Bulk density – 0.286Particle density+0.00798Porosity – 0.01316pH + 0.00938Organic carbon	62.53	61.99	60.44	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 = 0.3359-0.0374Organic carbon + 0.297N_2 +0.01962Ca+0.02667Mg – 0.3957K – 0.2677Na+0.000192P	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 – 0.00276Sand + 0.00084Silt + 0.00038Clay+ 0.939Bulk density – 0.278Particle density+0.00776Porosity – 0.00546pH – 0.00109Organic C + 0.1573N_2 + 0.00718Ca – 0.00684Mg –0.0676K – 0.0642Na+0.000658P	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 + 0.00908Organic carbon+ 0.00691Ca – 0.00877Mg – 0.0379K – 0.0541Na – 0.003803Sand – 0.000678Clay+0.6083Bulk density –0.0440Particle 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+0.00280Organic carbon –0.003249Sand + 0.6050Bulk density – 0.000008Clay– 0.0418Particle 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

Agricultural and Bioresources Engineers can utilize these regression models to make well-informed decisions in various aspects of soil and water management. Firstly, Soil Water Management can be optimized by using models that predict the rate of water infiltration and movement through the soil. This is crucial for determining the efficiency of irrigation practices. Secondly, Soil Fertility Assessment becomes more accurate by understanding how nutrient levels influence water dynamics within the soil. This knowledge aids in developing targeted soil amendment practices. Thirdly, Drainage System Design benefits from predicting the hydraulic conductivity (K) values, which are essential for designing systems to mitigate waterlogging or prevent excessive drainage. Fourthly, Crop Suitability Mapping is enhanced by identifying soil properties that promote efficient water distribution, allowing engineers to pinpoint areas suitable for specific crops. Lastly, Erosion Control can be managed effectively by understanding how water interacts with various soil compositions, helping to devise strategies to minimize runoff. Each regression model discussed focuses on four main aspects: Model Interpretation-Understanding the mathematical expressions and the significance of coefficients. Statistical Significance-Analyzing metrics such as R^2, adjusted R^2, predicted R^2, F-values, T-values, and P-values to gauge model reliability. Practical Applications-Applying models in real-world agricultural scenarios. Comparison and Evaluation determining the most practical and statistically reliable models.

Model interpretation

Model 1: This model predicts hydraulic conductivity (K) based on the sand content of soils in Abia State, showing a significant negative relationship (R^2=31.28%, F-value=257.18, P-value=0.000). The negative coefficient (-0.006876) indicates that an increase in sand content reduces K, meaning sandy soils drain water faster, as noted by Tayfun (2005). This is crucial for scheduling irrigation in sandy soils where rapid water loss occurs. Model 2: With a very low R^2 of 0.58%, this model uses silt content as the predictor. The T-value of -1.81 and P-value of 0.071 indicate that silt content has a minimal and statistically insignificant effect on K. Thus, it is not suitable for predicting hydraulic conductivity. Model 3: This model uses clay content as the predictor, showing moderate reliability (R^2=29.01%) with a positive and significant correlation (T-value=15.19, P-value=0.000). Increasing clay content enhances K, which is useful when evaluating clay-rich soils for water retention capacity. Model 4: This model, focusing on bulk density, shows a strong predictive power (R^2=55.96%). The positive T-value (26.79, P-value=0.000) suggests that compact soils facilitate water flow through macropores. This model is vital for assessing soil compaction's impact on water movement.

Model 5: Here, porosity is the key predictor with moderate explanatory power (R^2=31.51%). The significant negative correlation (T-value=-16.12, P-value=0.000) indicates that higher porosity reduces K, likely due to water retention within smaller pores. This insight is beneficial for soil amendment strategies aimed at controlling infiltration. Model 6: Combining bulk density, particle density, and porosity, this model achieves a high R^2 of 56.98%. Bulk density positively affects K (T-value=4.33, P-value=0.000), while particle density shows a marginal negative effect (T-value=-1.90, P-value=0.058), and porosity is statistically insignificant (P-value=0.114). This model is suitable for mixed soil types where density interactions influence water flow. Model 7: This model is similar to Model 6 but excludes porosity, maintaining a high R^2 (56.79%). Bulk density strongly enhances K (T-value=27.19, P-value=0.000), while particle density negatively affects it (T-value=-3.29, P-value=0.001). This model is practical for predicting water movement in compacted soils. Model 8: The model uses sand, silt, and clay content simultaneously but shows moderate accuracy (R^2=31.71%). None of the predictors are statistically significant (P-values>0.1), making this model unsuitable for reliable predictions.

Model 9 highlights the significant impact of bulk density and sand content on hydraulic conductivity. The statistical analysis shows that bulk density has a positive and significant effect on K (T=3.81, P=0.000), indicating that denser soils enhance water flow. Conversely, sand content negatively influences K (T=-2.09, P=0.037), demonstrating that sandy soils tend to reduce water retention. The pH level, though marginally significant (T=-1.75, P=0.081), suggests that acidic conditions may slightly decrease K. Other variables such as silt, clay, particle density, and porosity do not significantly impact K in this model. Practical Application: Model 9 is particularly useful in agricultural fields where variations in bulk density and sand content are common. It is especially relevant for predicting water flow in soils affected by pH variations, such as those influenced by acid rain or fertilizer application. In Model 10, bulk density emerges as the most significant predictor of K (T=20.88, P=0.000), affirming that compact soils facilitate better water movement. Sand content also shows a significant negative effect (T=-2.16, P=0.031), indicating that increased sand reduces water retention. Silt and clay do not significantly affect K in this model. Practical Application: This model is suitable for classifying soil texture, particularly identifying sandy soils that may have low water conductivity. It is also applicable in drought-prone areas where stable water retention is crucial for crop survival. Model 11 also highlights bulk density as a strong positive predictor (T=21.07, P=0.000), confirming that denser soils enhance water flow. Sand content, on the other hand, shows a strong negative correlation (T=-9.05, P=0.000), indicating that sandy soils are less capable of retaining water. Practical Application: This model is highly practical for basic field assessments where bulk density and sand content measurements are readily available. It can inform soil amendment decisions aimed at increasing water-holding capacity.

Model 12 shows that bulk density (T=3.81, P=0.000) and sand (T=-2.04, P=0.042) are significant predictors, while pH (T=-2.24, P=0.025) also plays a significant role. This suggests that acidic conditions may reduce hydraulic conductivity, possibly due to altered soil particle aggregation. Variables such as silt, clay, particle density, porosity, and organic carbon are not significant. Practical Application: Model 12 is valuable for precision agriculture, especially in environments where soil acidity fluctuates due to acid rain or fertilizer usage. It aids in optimizing irrigation practices and managing soil health. Model 13 considers chemical components affecting K, including organic carbon (T=-3.27, P=0.001), nitrogen (N_2) (T=2.88, P=0.004), calcium (Ca) (T=4.70, P=0.000), magnesium (Mg) (T=4.74, P=0.000), potassium (K) (T=-6.09, P=0.000), and sodium (Na) (T=-3.47, P=0.001). High levels of organic carbon and potassium decrease K, while nitrogen, calcium, and magnesium increase it. Practical Application: This model is effective for fertilization management, where nutrient levels significantly influence soil water movement. It is crucial for maintaining optimal soil conductivity in nutrient-rich agricultural fields. Model 14 integrates a wide range of variables, including bulk density, nitrogen, and calcium as significant predictors, achieving the highest R^2 value of 63.81%. Bulk density is the primary factor influencing K, with nitrogen and calcium also playing vital roles. Practical Application: This model is well-suited for complex soil environments, such as mixed-farming systems, where multiple variables simultaneously affect water movement.

With an R² of 62.94%, Model 15 combines bulk density (P=0.000), nitrogen (P=0.000), and sand (P=0.043) as significant predictors. pH (P=0.059) and organic carbon (P=0.075) show moderate significance. The model reveals that bulk density positively influences K, while sand and acidic conditions reduce it. Nitrogen contributes positively by enhancing microbial activity and improving soil structure. Practical Application: This model is suitable for predicting K in agricultural fields where both physical and chemical properties are crucial, helping optimize soil management practices. Model 16, with a lower R² of 16.91%, still offers insights into the influence of chemical elements on K. Organic carbon (OC) (-), nitrogen (N_2) (+), calcium (Ca) (+), magnesium (Mg) (+), potassium (K) (-), and sodium (Na) (-) significantly affect hydraulic conductivity. Notably, potassium and sodium tend to block pores, reducing K, while calcium and magnesium improve permeability. Practical Application: This model is useful for soils where chemical composition plays a more significant role than physical structure, such as in nutrient-enriched or chemically treated soils.

Model evaluation and field application

Most Reliable Models: Model 4 (Bulk Density): High predictive power and statistical significance make it suitable for compact soil analysis. Model 7 (Bulk and Particle Density): Effectively combines density factors, making it reliable for dense soil conditions. Least Reliable Models: Model 2 (Silt Content) and Model 8 (Sand, Silt, Clay): Low predictive power and insignificant coefficients limit their practical application. Field Applications: Irrigation Design: Use Models 4 and 7 for fields prone to compaction. Soil Conservation: Apply Model 3 for managing clay-rich soils to maintain water retention. Fertility Management: Avoid low-significance models (like Model 2) when making soil amendment decisions.

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. In 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 which is through 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. Promote soil testing is by 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 can only be done by 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 program is the offer training and education programs for farmers on soil management, fertilization, and sustainable farming practices. 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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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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