



Modeling of Soil Water Infiltration of Soil Amended with Selected Organic Matter using Design Expert Software

Timothy Lucky Ali^{1*}, Abejirin Matthew², Mohammed Aliyu Aliyu¹, Abdullahi Sule Argungu¹, Muhammad Mujahid Muhammad¹

¹ Department of Water Resources and Environmental Engineering, Ahmadu Bello University Zaria, Nigeria.

² Department of Chemical Engineering, Ahmadu Bello University Zaria, Nigeria.

Article Info	Abstract
Article history: Received 16 January 2025 Received in revised form 15 March 2025 Accepted 08 May 2025 Published online 20 May 2025 DOI:10.22044/JHWE.2025.15615.1049 Keywords Modeling Infiltration Soil amendment Design Expert	Soil water infiltration is a critical process that affects soil water availability, crop growth, and environmental sustainability. This study aimed to model soil infiltration of soil water amended with cow dung and poultry litters' organic matter using Design Expert 13.05.0 software. The organic matter mixing ratios percentages for the cow dung and the poultry litters are, respectively, 100/0 for T2, 0/100 for T3, 75/25 for T4, 50/50 for T5, 25/75 for T6, and T1 for the bare soil, to make up a total of six strips. Soil physical characteristics were determined in the laboratory and compared for the six strips. A double-ring infiltrometer was used for the infiltration fieldwork experiment during the dry season and the rainy season in Samaru, Zaria, Nigeria. The experimental fieldwork data were imported into Design Expert 13.05.0 software to analyze and model the soil water infiltration on the amended soil. The results of the study showed soil physical characteristics values; soil texture classification as loamy soil with silt fraction (46-53%), sand (37-43%), and clay (9-13%); pH range of 6.23 for T1 and 7.02 for T3; porosity percentage range of 33.93% for T4 and 48.71% for T3; gravimetric moisture content percentage range of 4.18% for T3 and 5.12% for T4; bulk density range of 1.24 g/cm³ for T1 and 1.32 g/cm³ for T2; hydraulic conductivity range of 0.52 mm/s for T6 and 2.76 mm/s for T5; electrical conductivity range of 0.05 ds/m for T1 and 1.29 ds/m for T2; organic matter content percentage range of 0.53% for T1 and 24.08% for T4; and organic carbon content percentage range of 0.92% for T1 and 2.20% for T5. The Design Expert result analyses showed that the dominance of the 2FI (2-Factor Interaction) model source during the dry season and the linear model source during the rainy season could be attributed to several factors. Some of these are low moisture content and more rigid soil structure during the dry season, and the soil may become saturated, leading to a more uniform infiltration rate during the rainy season. In addition, the highest R² value obtained from the Design Expert ANOVA analyses was used to determine the optimal combination as 75% cow dung and 25% poultry litters for T4 and compared with existing classical soil infiltration models (Modified Kostiakov and Horton's) under similar experimental conditions. The respective R² values for the dry season and rainy season are 0.8786 and 0.8901 for Design Expert, 0.989 and 0.992 for the Modified Kostiakov model, 0.716 and 0.871 for Horton's model. Based on the model results, the recommended optimal rates of organic matter application should be adopted to improve soil water infiltration and to develop sustainable soil management practices that enhance soil infiltration and reduce soil erosion.

* Corresponding author: timothyluckyali@gmail.com, Tel: +2347030912464

1. Introduction

Soil, a vital component of the earth's ecosystem, plays a crucial role in supporting plant growth, filtering water, and regulating the water cycle (Gavrilescu, 2021; Verm et al., 2021). Soil infiltration is the process by which water enters the soil and becomes available for plant growth (Avila-Davila et al., 2021; Mahapatra et al., 2020). It is a critical process that affects soil water availability, crop growth, and environmental sustainability (Basset et al., 2023; Wang et al., 2023; Mahapatra et al., 2020). Several factors, including soil type, moisture content, bulk density, and organic matter content, influence soil infiltration. However, intensive agricultural practices, climate change, and soil degradation have reduced soil functionality, compromising its ability to provide essential ecosystem services (Francaviglia et al., 2023). Intervention strategies such as conservation tillage, mulching, irrigation management, and soil amendment have been suggested. Among these, soil amendment is gaining acceptance. Ease and availability of materials are among the factors considered. Soil amendments are divided into inorganic amendments (such as fertilizers) and organic amendments (Cui et al., 2023; Dong et al., 2022). Organic amendments, such as cow dung and poultry litter, can improve soil infiltration by primarily enhancing soil structure through increased pore space, providing nutrients for microbial activity, boosting microbial diversity, and improving water retention capacity (Cui et al., 2023; Dong et al., 2022). The rate of organic amendment application can significantly affect soil properties, including hydraulic conductivity, water-holding capacity, water infiltration, and bulk density, which are critical parameters in water resources and environmental engineering (Das and Ghosh, 2024; Cui et al., 2023; Dong et al., 2022). Excessive application of organic matter can lead to decreased soil aeration and waterlogging, while insufficient application may not provide adequate benefits (Bo et al., 2023; Nicolas et al., 2023). Infiltration modeling approaches are often separated into

three categories: physically based, approximate/semi-empirical (analytical), and empirical models (Cui et al., 2023; Amir et al., 2022; Adhikari et al., 2022; Lajpat, 2022). Some of the commonly used existing soil water infiltration models are; Kostiakov, Philip's, Horton's, Modified Kostiakov, Kostiakov-Lewis, and NRCS (Bajirao and Vishnu, 2023; Xiao et al., 2020; Wang et al., 2017). In recent times, most engineering applications have recommended the use of Design-Expert software to generate experimental designs, perform statistical analyses, and build regression models (Adhikari et al., 2022; Lajpat, 2022). Design Expert is a statistical software package that uses response surface methodology (RSM) to model and optimize complex systems (Stat-Ease, 2020). RSM is a collection of mathematical and statistical techniques that can be used to model and analyze the relationships between input variables and response variables (Sura and Khalid, 2021; Stat-Ease, 2020). While there is a significant body of research on soil infiltration, organic amendments, and modelling techniques, further research is needed on the use of Design Expert to model soil infiltration processes amended with cow dung and poultry litter at different loading ratios. We hypothesized that Soil water infiltration rates would increase with the addition of cow dung and poultry litter organic matter, and that Design-Expert software could effectively model and optimize soil water infiltration rates. This study aims to address this research gap by using Design Expert to model and optimize soil infiltration processes amended with cow dung and poultry litter organic matter.

2. Materials and Methods

2.1. Study Area

The study was carried out at the open experimental field of the Institute of Agricultural Research, A.B.U. Samaru Zaria, Kaduna State, Nigeria. Zaria is located on a Latitude of 11° 11' N and a longitude of 07° 38' E, at an altitude of about 667m above mean sea level (Yusuf, 2023). It lies within the northern

Guinea Savannah bio-climatic zone, having distinct wet and dry seasons. The wet season in the study area occurs between May and early October, with a mean annual rainfall of about 1000mm, while the dry season occurs between the middle of October and early May (Ali and Toher, 2021).

2.2. Field Layout

The experimental field for this research covered an area of 200 m² (20m by 10m). The field was cleared of previously cultivated plant roots and residues. It was later divided into six (6) strips labeled T1–T6 to carry out infiltration tests and analyses of physical soil properties, as reported in a previous study by Timothy et al. (2024). Each strip was 16 m² (4m by 4m), and manure was added to the soil as appropriate, then ploughed to thoroughly mix the amended portion with the manure to a depth of 20 cm.

2.3. Study Design

The study was designed according to the reports by Ajaweed et al. (2022) and Blasius et al. (2020), and adopted the selected proportions of organic matter mass and loading ratio. The cow dung and poultry litter were collected from a local farm and a local poultry farm, respectively. The strips are labeled as stated below.

T1 = Control strip (Bare soil without amendment)

T2 = 50kg cow dung (100%)

T3 = 50kg poultry litter (100%)

T4 = 37.5kg cow dung + 12.5kg poultry litter (75:25%)

T5 = 25kg cow dung + 25kg poultry litter (50:50%)

T6 = 12.5kg cow dung + 37.5kg poultry litter (25:75%)

2.4. Determination of Soil Physical Properties

All soil physical property analyses were performed in the Soil Physics and Nitrogen Laboratory of the Department of Soil Science at Ahmadu Bello University. Subsamples (500 g) were collected from each strip after thorough ploughing and harrowing at depths of 0–15 cm

and 15–30 cm using Core Samplers of 5 cm diameter and 6 cm height, according to the methods reported by Aowa et al. (2024) and Ajaweed et al. (2022). It was then air-dried in an open container for 12 hours, crushed through a 2 mm sieve, and stored in polyethylene bags until analysis in the laboratory. The soil physical properties parameters, such as soil textural class analysis, gravimetric moisture content, volumetric moisture content, soil pH, hydraulic conductivity, bulk density, porosity, organic matter content and electrical conductivity (EC)) were determined following the standard laboratory procedures reported by Aowa et al. (2024) and Ajaweed et al. (2022).

2.5. Infiltration Measurement

The double-ring infiltrometer method was adopted for infiltration measurement, as described in previous studies by Avila-Davila et al. (2021) and Fatehnia et al. (2016). Quality control measures for infiltration measurements were observed. It was ensured that all equipment, such as infiltrometers, tensiometers, and data loggers, was calibrated and functioning correctly. The infiltrometer consists of two rings: an outer ring with a 40 cm diameter and 40 cm height, and an inner ring with a 30 cm diameter and 40 cm height. Both rings were hammered 15 cm into the soil with a plank to protect the surface of the ring from damage during hammering. The Test was carried out by pouring water into the inner ring to an appropriate depth and, concurrently, adding water to the space between the two rings to the same depth as quickly as possible. The time the test started and the water level on the measuring rod were recorded. After three (3) minutes, the drop in water level in the inner ring on the measuring ring was recorded, and water was added to bring the level back to approximately the initial water level at the beginning of the test. The Water level of the outer ring was maintained similarly to that of the inner ring. The Test was carried out repeatedly over weeks (week one, week three, and week six) after the application of the manure and infiltration measurements. The

experiment was conducted in triplicate using the formulated strips.

2.6. Design of Experiment

This method combines statistical and mathematical methods for model construction, assessing the effects of several independent variables, and determining optimal values of variables (Sura and Khalid, 2021). Design-Expert software version 13.05 (Stat-Ease, USA) was used to analyze and model the experimental data obtained during infiltration measurements for the dry and rainy seasons. The infiltration field data, containing the time taken in hours for each test and the respective water level in cm for the six strips during the dry and rainy seasons, were imported into Design-Expert 13.05.0. Infiltration rate was selected as the response variable. Design Expert was used to fit a suitable model, assess model performance, analyze factor effects, and predict interactions between dependent variables as a function of independent variables (Adhikari *et al.*, 2022; Lajpat, 2022; Stat-Ease, 2020).

2.6.1. Design Expert ANOVA Fit Statistics Interpretations

ANOVA fit statistics provide a comprehensive evaluation of model performance. By examining the R^2 , Adj R^2 , Pred R^2 , F-values, SD, and C.V% values, we can: Evaluate the goodness of fit of the model; Determine the significance of the model and its terms; Assess the predictive power of the model; Identify potential issues with the model, such as over-fitting or under-fitting. By considering these statistics together, we can gain a deeper understanding of your model's performance and make informed decisions about its use (Adhikari *et al.*, 2022; Lajpat, 2022; Stat-Ease, 2020).

2.6.2. 2FI Model (2-Factor Interaction Model)

The 2FI Model is a type of model that includes interactions between two factors. It is used to model non-linear relationships between factors (Sura and Khalid, 2021). It can provide more accurate predictions than linear models,

especially when interactions are significant (Adhikari *et al.*, 2022; Lajpat, 2022; Stat-Ease, 2020).

2.6.3. Linear Model

A Linear Model is a type of model that assumes a linear relationship between the factors and the response (Sura and Khalid, 2021). It is used when the relationship between factors is linear. It can be less accurate than 2FI models when interactions are significant (Adhikari *et al.*, 2022; Lajpat, 2022; Stat-Ease, 2020).

2.6.4. R-Square Value (R^2)

R-Square Value measures the proportion of the variance in the dependent variable that is predictable from the independent variable(s). Its values range from 0 (no correlation) to 1 (perfect correlation) (Sura and Khalid, 2021). A high R^2 value indicates a good fit of the model to the data (Adhikari *et al.*, 2022; Lajpat, 2022; Stat-Ease, 2020).

2.6.5. Standard Deviation (SD)

Standard Deviation measures the amount of variation or dispersion in the data. It is used to evaluate the spread of the data. A low SD indicates that the data points are close to the mean (Adhikari *et al.*, 2022; Lajpat, 2022; Stat-Ease, 2020).

2.7. Theory Background

2.7.1. Mechanism of Soil Amendment

Organic amendments have shown in previous studies (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021) to improve soil infiltration by primarily enhancing soil structure through increased pore space, providing nutrients for microbial activity, boosting microbial diversity, and improving water retention capacity (Cui *et al.*, 2023; Dong et al., 2022). When organic matter such as cow dung and poultry litter is added to the soil, it decomposes and releases nutrients into the soil over time, thereby improving plant growth and soil health (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). This process involves

mechanisms like increased cation exchange capacity (allowing it to hold onto positively charged nutrients, preventing them from leaching out), improved soil structure (acts as a binding agent, creating aggregates and improving soil structure by increasing pore space, allowing better water infiltration and aeration.), enhance microbial activity (provides a food source for soil microbes, stimulating their population and diversity, leading to increased nutrient cycling and decomposition processes) and nutrient availability (release essential nutrients like nitrogen, phosphorus, potassium, and micronutrients slowly as they decompose, making them readily available to plants) (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021).

2.7.2. Classical Infiltration Model Equations

Researchers have proposed various equations to model soil infiltration and have evaluated model accuracy by comparing computed and observed infiltration rates (Amir *et al.*, 2022; Cui *et al.*, 2023; Adhikari *et al.*, 2022; Lajpat, 2022). The two most widely used models are the Modified Kostiakov and the Horton infiltration models, which have the following equations:

For the Kostiakov infiltration model

$$I = kt^a \quad (1)$$

When Eq.1 is differentiated, the infiltration rate i (cm/hr) will be obtained as:

$$i = akt^{a-1} \quad (2)$$

Where I is cumulative infiltration (cm); t is time from the start of infiltration (hr); and a (dimensionless) and k (cm/hr^a) are empirical parameters.

For the Horton infiltration model

$$i = f_c + (f_0 - f_c)e^{-kt} \quad (3)$$

Then the cumulative Infiltration becomes the integral of Eq.4

$$I = f_c t + \frac{f_0 - f_c}{k} [1 - e^{-kt}] \quad (4)$$

Where I = cumulative infiltration (cm), f_0 = infiltration capacity, (f_c) = constant rate, i = rate of infiltration, k is the decay constant

specific to the soil, t = time from the start of infiltration (hr).

3. Results and Discussion

3.1. Soil Textural Class Analysis

Soil texture affects infiltration rate by influencing pore size and continuity (Ma et al., 2023; Adhikari et al., 2022). Coarse-textured soils (e.g., sandy soils) tend to have higher infiltration rates due to their larger pores, while fine-textured soils (e.g., clay soils) have lower infiltration rates due to their smaller pores (Cui et al., 2023; Voltr et al., 2021). In this study, the texture of mineral soils at the study site was dominated by silt fraction (46-53%), sand (37-43%), and clay (9-13%), which, according to the United States Department of Agriculture (USDA) classification, is Loamy soil. These values agree with the results presented in the literature (Cui et al., 2023; Ma et al., 2023; Adhikari et al., 2022; Voltr et al., 2021; USDA, 2008; Lowery et al., 1996; Hillel, 1982).

3.2. Comparison of Physical Characteristics of the Strips

The comparative physical characteristics (gravimetric moisture content, soil pH, hydraulic conductivity, bulk density, porosity, organic matter content, and electrical conductivity (EC)) of the six strips are presented in Table 1.

The results of the study showed soil physical characteristics values with pH range of 6.23 for T1 and 7.02 for T3; porosity percentage range of 33.93% for T4 and 48.71% for T3; gravimetric moisture content percentage range of 4.18% for T3 and 5.12% for T4; bulk density range of 1.24 g/cm³ for T1 and 1.32 g/cm³ for T2; hydraulic conductivity range of 0.52 mm/s for T6 and 2.76 mm/s for T5; electrical conductivity range of 0.05 ds/m for T1 and 1.29 ds/m for T2; organic matter content percentage range of 0.53% for T1 and 24.08% for T4; and organic carbon content percentage range of 0.92% for T1 and 2.20% for T5. Bo et al. (2023) reported that soil moisture content affects infiltration rate. The more saturated the soil, the lower the infiltration rate (Nicolas et al., 2023; Yassen et al., 2021). This is contrary

to the results of this study, which found that the amended strip with 37.5 kg cow dung + 12.5 kg poultry litter had higher gravimetric water content and organic carbon content, and recorded higher cumulative infiltration. However, the 25kg cow dung + 25kg poultry litter had a greater effect on soil physical properties, such as saturated hydraulic conductivity and organic matter content, significantly improving soil characteristics (Hammecker et al., 2022; Laderle et al., 2020). The above statement agrees with the result obtained by Nugroho *et al.* (2018) and

Mahapatra *et al.* (2020) who the former, studied the evaluation of infiltration models for mineral soils with different land uses in the tropics and the later, the effects of poultry manure and cow dung on the physical and chemical properties of crude oil polluted soil in Owerri, Nigeria. This is supported by the findings of Adhikari et al. (2022) and it was evidenced by the improvement in the soil physical properties in this study (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021).

Table 1. Average soil physical characteristics of the strips.

Strip	pH	EC (ds/m)	BD (g/cm ³)	P (%)	GM (%)	K (mm/s)	OC (%)	OM (%)
T1	6.23	0.05	1.24	44.59	4.93	0.78	0.53	0.92
T2	6.60	1.29	1.32	47.85	4.85	1.43	1.18	2.03
T3	7.02	0.79	1.27	48.71	4.18	2.12	0.96	1.65
T4	6.66	0.06	1.28	33.93	5.12	2.19	24.08	1.68
T5	6.86	0.21	1.25	46.59	4.88	2.76	1.28	2.20
T6	6.75	0.11	1.27	48.22	5.09	0.52	1.26	2.17

P = Porosity; GM = Gravimetric moisture content; BD = Bulk density; K= Hydraulic Conductivity; EC= Electrical conductivity; OM = Organic matter content; OC = Organic carbon content.

3.2. Field Measured Infiltration

The mean cumulative infiltration of each strip during the dry and rainy seasons is presented in Tables 2(a) and 2(b), respectively. The calculated values of the t-test for all the strips at a level of probability $p < 0.05$ show that, the incorporation of the organic amendments affected the infiltration characteristics (Cui et al., 2023; Ma et al., 2023; Robinson et al., 2022). The infiltration rate changes over time during the dry and rainy seasons were plotted and presented in Figures 1 and 2, respectively. The result shows an initial rapid infiltration, a constant infiltration rate, and a decreasing infiltration rate. The values obtained at these peaks for dry season and raining season are respectively; 64.67 cm/hr and 41.86 cm/hr for T1; 74.04 cm/hr and 68.52 for T2; 63.04 cm/hr and 59.22 cm/hr for T3; 93.42 cm/hr and 82.22 cm/hr for T4; 134.08 cm/hr and 112.70 cm/hr for T5; and 203.83 cm/hr and 143.33 cm/hr for T6. The trend for the initial infiltration rate was from 0.05 hr to about 0.08 hr. This may indicate a high rate of water entry

into the soil, often due to a high hydraulic conductivity or a dry soil surface, as reported by Ma et al. (2024) and Hassona (2023). In agreement with literature (Cui et al., 2023; Ma et al., 2023; Adhikari et al., 2022) it may suggest: improved soil structure or hydraulic conductivity, increased soil moisture content, allowing for faster water entry, and presence of macro-pores or preferential flow paths. The steady state infiltration rate was observed at 0.08 hr indicating that the infiltration rate has reached a constant value, often due to a balance between the rate of water entry and the rate of water movement through the soil (Nicolas et al., 2023; Ali and Toher, 2021; Yasen et al., 2021). The declining infiltration rate observed from 0.08 hr to 3.1 hr suggests that the soil's infiltration capacity is decreasing, which has been stated in previous studies to be due to soil compaction or crusting, increased soil moisture content and reduced hydraulic conductivity (Hammecker et al., 2022; Alireza et al., 2021; Laderle et al., 2020).

Table 2(a). Infiltration characteristics for model evaluation (Dry season)

	T1		T2		T3		T4		T5		T6	
Time(hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)
0.05	2.48	49.60	2.90	57.93	2.38	47.53	3.40	68.07	3.92	78.40	7.01	140.20
0.08	5.17	64.67	5.92	74.04	5.04	63.04	7.47	93.42	10.73	134.08	16.31	203.83
0.17	8.25	48.53	10.22	60.10	8.55	50.29	12.47	73.37	20.35	119.69	27.64	162.57
0.33	12.37	37.48	15.62	47.32	13.75	41.66	20.90	63.33	31.36	95.03	40.96	124.13
0.50	16.84	33.69	21.92	43.84	20.29	40.59	30.22	60.44	45.13	90.26	55.61	111.21
0.75	22.71	30.28	30.80	41.06	28.37	37.82	40.49	53.99	59.69	79.58	72.08	96.10
1.00	29.44	29.44	41.68	41.68	38.30	38.30	51.16	51.16	75.25	75.25	90.72	90.72
1.50	37.07	24.72	54.99	36.66	49.78	33.19	63.51	42.34	92.12	61.42	112.62	75.08
2.00	45.37	22.69	72.25	36.13	62.68	31.34	76.56	38.28	110.41	55.21	137.36	68.68
2.50	54.21	21.68	90.45	36.18	77.39	30.95	91.96	36.78	131.28	52.51	164.48	65.79
3.00	66.53	22.18	111.09	37.03	92.86	30.95	108.23	36.08	154.10	51.37	192.92	64.31
3.10	79.65	25.69	132.51	42.74	109.31	35.26	125.55	40.50	178.07	57.44	223.15	71.98
Mean	31.68		49.19		42.39		52.66		76.03		95.07	
SD*	25.27		43.53		36.16		40.88		57.83		71.62	

SD*- Standard Deviation**Table 2(b).** Infiltration characteristics for model evaluation (Raining season)

	T1		T2		T3		T4		T5		T6	
Time(hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)	I(cm)	i(cm/hr)
0.05	1.46	29.10	2.36	47.15	1.86	37.13	3.04	60.80	4.10	82.08	5.33	106.60
0.08	3.35	41.86	5.48	68.52	4.74	59.22	6.58	82.22	9.02	112.70	11.47	143.33
0.17	5.19	30.50	8.91	52.40	8.03	47.25	10.78	63.41	14.33	84.29	18.72	110.13
0.33	7.83	23.72	13.38	40.55	11.85	35.90	16.46	49.86	20.94	63.47	27.03	81.91
0.50	10.98	21.97	19.28	38.56	16.79	33.57	22.66	45.32	28.67	57.34	36.87	73.74
0.75	15.05	20.06	25.69	34.25	24.02	32.03	29.80	39.73	38.11	50.81	48.22	64.30
1.00	19.42	19.42	33.74	33.74	32.54	32.54	38.07	38.07	48.47	48.47	61.26	61.26
1.50	24.42	16.28	43.35	28.90	42.19	28.13	47.22	31.48	60.41	40.27	75.64	50.43
2.00	30.32	15.16	54.27	27.13	53.77	26.89	53.26	26.63	74.03	37.01	91.47	45.74
2.50	35.14	14.06	63.66	25.46	63.14	25.25	60.24	24.09	84.57	33.83	102.34	40.94
3.00	39.76	13.25	71.58	23.86	68.77	22.92	65.18	21.73	89.07	29.69	108.88	36.29
3.10	39.76	12.83	71.58	23.09	68.77	22.18	65.18	21.02	89.07	28.73	108.88	35.12
Mean	19.39		34.44		33.04		34.87		46.73		58.01	
SD*	14.23		25.86		25.52		23.14		32.06		38.81	

SD*-Standard Deviation

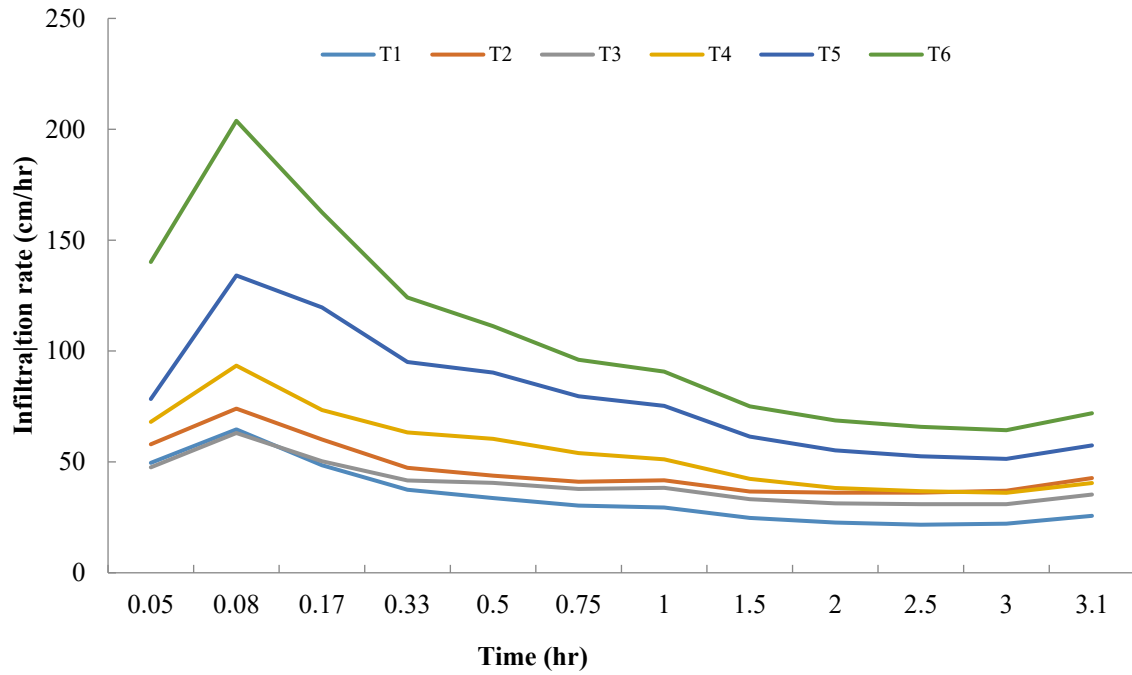


Figure 2. Infiltration rates change over time for dry season.

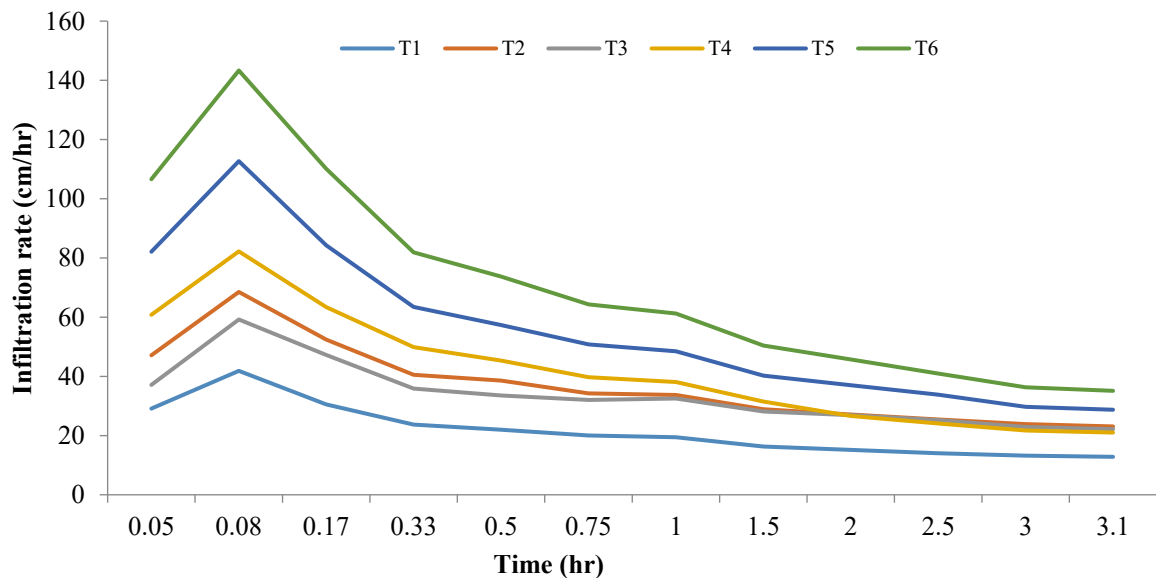


Figure 2. Infiltration rates change over time for the rainy season.

3.3. Result of analysis for dry and rainy seasons using Design Expert

The data from Tables 2(a) and Table 2(b) were separated differently into the six (6) strips for dry season and raining seasons, imported into Design Expert 13.05.0 (Stat Ease USA) to fit the suitable model, predict the interactions between the dependent variables as a function of independent variables, ANOVA fit statistics such as R^2 value, standard deviation

and the 3D contour plots for each of the strips in the field experiment (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Xiao et al., 2020). The ANOVA fit statistics for the dry and rainy seasons were compared and presented in Tables 3, 4, and 5. Table 3 shows the comparison of the model source obtained for the dry and rainy seasons for the strips (T1, T2, T3, T4, T5, and T6). When analyzing infiltration rate against time

and depth in an organic matter-amended soil, the dominance of the 2FI (2-Factor Interaction) model source during the dry season and the linear model source during the rainy season could be attributed to several factors (Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021).

During the dry season, the soil moisture content is typically low (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). The 2FI model may capture the interactive effects between soil moisture content and other factors, such as soil structure and organic matter content, which become more pronounced under dry conditions (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). The dry season may lead to a more rigid soil structure, which can affect infiltration rates (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). Also, the dry season may lead to a more rigid soil structure, which can affect infiltration rates (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). As a result, the 2FI model may account for the interactions between soil structure and other factors, such as soil moisture content and organic matter content (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021).

During the rainy season, the soil may become saturated, leading to a more uniform infiltration rate (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). In addition, the high soil moisture content during the rainy season may reduce the importance of interactive effects between soil moisture content and other factors. The Linear model may be sufficient to capture the relationship between infiltration rate and time or depth. The rainy season may lead to a greater emphasis on the role of other factors, such as soil structure and soil moisture content, in

influencing infiltration rates (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021). The Linear model may be sufficient to capture the relationship between infiltration rate and these factors (Ma et al., 2024; Hassona, 2023; Cui *et al.*, 2023; Dong et al., 2022; Robinson et al., 2022; Voltr et al., 2021; Xiao et al., 2020).

Table 4 shows the comparison of R^2 ANOVA Fit statistics between the dry and rainy seasons. The R^2 value indicates how well the model fits the data; values closer to 1 indicate a better fit. In this study, the value for dry season and the rainy season, respectively, was highest for T4 with a value of 0.8786 and 0.8901, followed by T6 with a value of 0.8539 and 0.8389; T3 with a value of 0.7994 and 0.6710; T2 with a value of 0.7969 and 0.7207; and the lowest value of 0.7994 and 0.6710 for T3. Higher R^2 observed in the dry season may indicate that the model is better suited to explain infiltration rate during dry conditions, possibly due to the greater importance of soil moisture content and organic matter content during this season (Mohd et al., 2023; Hossain et al., 2024; Balekundril et al., 2020; Choi and Kim, 2021; Balraj et al., 2022). Also, higher R^2 in the rainy season may indicate that the model is better suited to explain infiltration rate during wet conditions, possibly due to the greater importance of soil saturation and hydraulic conductivity during this season (Mohd et al., 2023; Hossain et al., 2024; Balekundril et al., 2020; Choi and Kim, 2021; Balraj et al., 2022).

The final ANOVA model equations for the dry and rainy seasons are shown in Table 5. The coefficient for each interaction term represents the change in the response variable due to the interaction between the two factors as observed in T1, T2, T3, T4, and T6. However, the linear model source coefficients for the rainy season as reported in the literature can be less accurate than 2FI models when interactions are significant (Mohd et al., 2023; Hossain et al., 2024; Balekundril et al., 2020; Choi and Kim, 2021; Balraj et al., 2022).

Table 3. Compared model source and analysis of variance for dry season and raining season

STRIP	MODEL SOURCE	
	DRY SEASON	RAINING SEASON
T1	2FI	Linear
T2	2FI	Linear
T3	2FI	Linear
T4	2FI	Linear
T5	Linear	Linear
T6	2FI	Linear

Table 4: Comparison R² ANOVA, and fit statistics for the dry season and the rainy season

STRIP	R ² VALUE		STANDARD DEVIATION		SIGNIFICANT P- VALUE	
	DRY SEASON	RAINING SEASON	DRY SEASON	RAINING SEASON	DRY SEASON	RAINING SEASON
T1	0.8672	0.8003	5.78	4.29	0.0007	0.0007
T2	0.7969	0.7866	6.27	6.94	0.0038	0.0010
T3	0.7994	0.6710	5.04	6.77	0.0037	0.0067
T4	0.8786	0.8901	7.22	7.02	0.0005	<0.0001
T5	0.6625	0.8412	17.20	11.41	0.0075	0.0003
T6	0.8539	0.8389	19.81	13.67	0.0011	0.0001

Table 5. ANOVA final model equations for dry season and rainy season

STRIP	INFILTRATION =	
	DRY SEASON	RAINING SEASON
T1	20.87 + 5.71A – 20.63B + 19.18AB	23.98 + 20.61A – 30.68B
T2	31.86 + 8.03A – 18.45B + 20.81AB	40.49 + 32.96A – 48.40B
T3	31.69 - 6.03A – 2.72B + 12.42AB	34.20 + 9.38A – 20.52B
T4	41.62 – 15.79A – 3.38B + 18.40AB	46.14 + 14.79A – 38.50B
T5	73.15 – 19.10A – 11.34B	62.99 + 32.88A – 62.78B
T6	71.87 – 11.77A – 37.61B + 50.58AB	80.65 + 39.39A – 79.94B

Where: A= time (hr); B= depth (cm)

Figures 3 and 4 show the 3D contour plots of infiltration rate against time and depth. In Figure 3, steep contour lines near the surface were observed for 1b, 1c, 1d, 1e, and 1f. Gentle contour lines at greater depths are observed for 1a and 1e in Figure 3 and also for all the strips (T1, T2, T3, T4, T5, and T6) in Figure 4. In addition, contour lines that are close together indicate a high infiltration rate (Mohd et al., 2023), suggesting that water is

racing into the soil while contour lines that are far apart indicate a low infiltration rate, suggesting that water is moving slowly into the soil (Hossain et al., 2024). This pattern aligns with the findings in the literature as determined by previous researchers (Mohd et al., 2023; Hossain et al., 2024; Balekundril et al., 2020; Choi and Kim, 2021; Balraj et al., 2022).

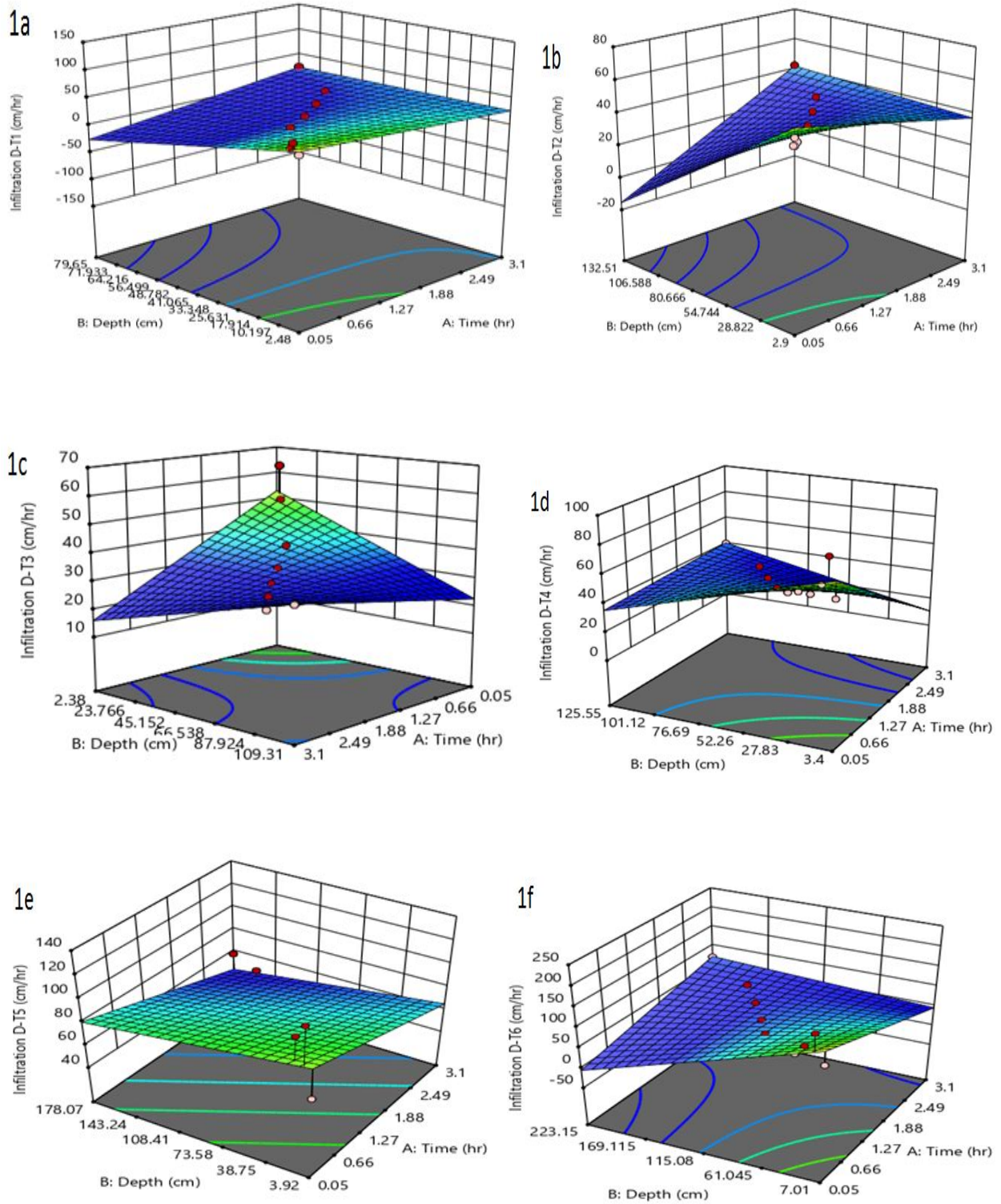


Figure 3. (1a) 3D contour plots for strip T1 (1b) 3D contour plots for strip T2 (1c) 3D contour plots for strip T3 (1d) 3D contour plots for strip T4 (1e) 3D contour plots for strip T5 (1f) 3D contour plots for strip T6 for Dry Season.

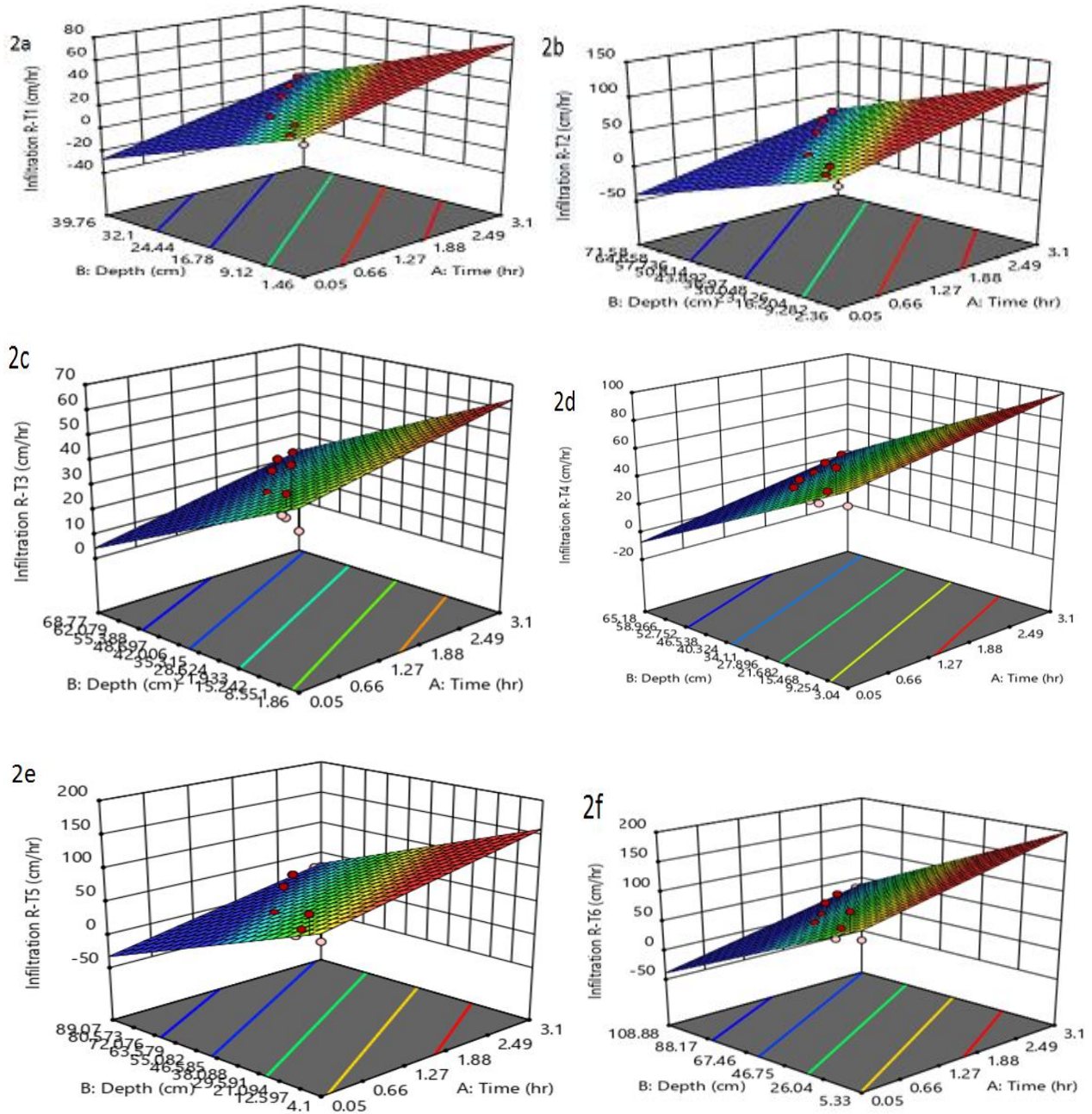


Figure 4. (2a) 3D contour plots for strip T1 (2b) 3D contour plots for strip T2 (2c) 3D contour plots for strip T3 (2d) 3D contour plots for strip T4 (2e) 3D contour plots for strip T5 (2f) 3D contour plots for strip T6 for the Raining Season.

3.4. Comparison of Design Expert with Classical Soil Infiltration Model

A comparison was conducted with the existing classical infiltration model to assess the potential of Design Expert software for effectively modelling and optimizing soil water infiltration rates. The selected classical infiltration models are Modified Kostiakov and Horton's model (Singh et al., 2022; Choi and Kim, 2021; Balekundril et al., 2020; Hossain et al., 2023; Pearl and Mangirish,

2023; Mohd et al., 2023). Table 6 presents the R^2 values of all the strips compared with the classical infiltration model. The highest R^2 value, strip 4, for the Design Expert during both the dry and rainy seasons was selected, plotted, and presented in Figure 5. The order of the results according to their models for the dry and rainy seasons is as follows: Design Expert (0.8786 and 0.8901); Modified Kostiakov model (0.989 and 0.992); Horton's model (0.716 and 0.871). This suggests that

the result of the current study falls within the acceptable range of high R² values, which indicate how well observed outcomes are replicated by the model, ranging from 0 to 1 (Alireza *et al.*, 2021). The classical soil infiltration models used as comparison showed that the Modified Kostiakov model performed better than the Horton's model in all the amended soils and the control, this is in contrast with the work done by Yi *et al.* (2020) and Igbadun *et al.* (2016). The former observed that the Horton's model had the overall best performance and the Modified Kostiakov model had the best performance amongst the empirically based

models evaluated for soils amended with cow dung, poultry litter, and Pig dung at the University of Uyo experimental plot, Akwa Ibom. The latter reported that the Modified Kostiakov model fitted the experimental data better for a hydromorphic soil at Samaru, Zaria, Nigeria. On the other hand, the result agrees with the findings of King *et al.* (2020) and Rui *et al.* (2021), who, in the former, showed that Kostiakov's and modified Kostiakov models were both found to be suitable for simulating water infiltration subjected to untilled mulched, tilled-mulched, and tilled-un mulched management systems in Semi-Arid areas.

Table 6. Comparison of Design Expert with classical infiltration models.

STRIP	DESIGN EXPERT		MODIFIED KOSTIAKOV MODEL		HORTON'S MODEL	
	Dry Season	Raining Season	Dry Season	Raining Season	Dry Season	Raining Season
T1	0.8672	0.8003	0.98	0.998	0.546	0.781
T2	0.7969	0.7866	0.998	0.998	0.548	0.725
T3	0.7994	0.671	0.989	0.991	0.576	0.721
T4	0.8786	0.8901	0.989	0.992	0.716	0.871
T5	0.6625	0.8412	0.988	0.994	0.724	0.821
T6	0.8539	0.8389	0.988	0.994	0.619	0.833

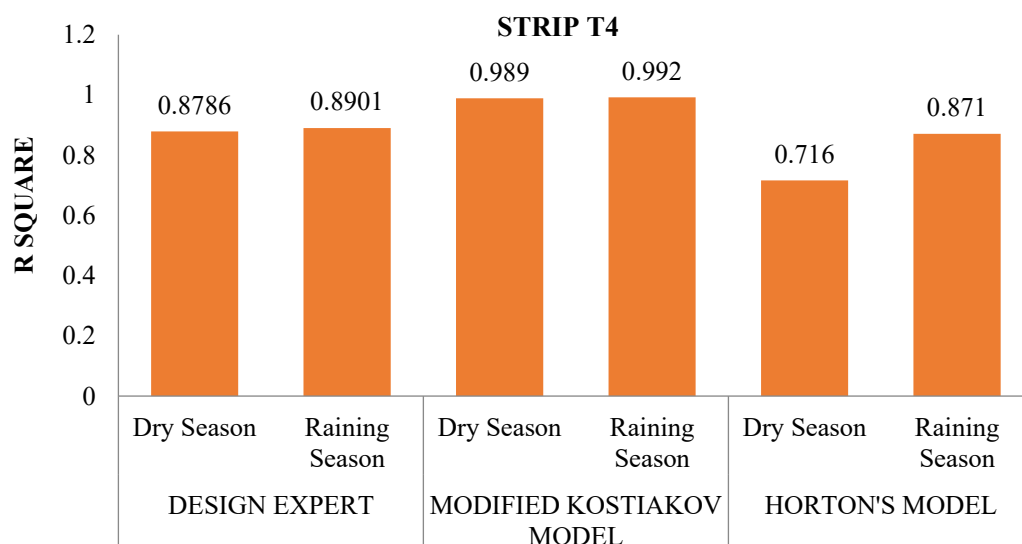


Figure 5. Comparison of R-squared values for Design Expert and classical infiltration models for the strip.

Generally, improved soil indices were observed in the study area with both amendments; however, this depended on the source of the organic materials. Several factors affect soil water infiltration, including soil moisture content, organic matter, and soil characteristics (Ma et al., 2023). Bo et al. (2023) and Nicolas et al. (2023) reported that soil moisture content affects infiltration rate: the more saturated the soil, the lower the infiltration rate. This is contrary to the results of this study, which found that the amended strip with 37.5 kg cow dung + 12.5 kg poultry litter had higher gravimetric water content and organic carbon content, and recorded higher cumulative infiltration. However, the 25kg cow dung + 25kg poultry litter had a greater effect on soil physical properties, such as saturated hydraulic conductivity and organic matter content, significantly improving soil characteristics. The above statement agrees with the result obtained by Nugroho et al. (2018) and Mahapatra et al. (2020) who the former, studied the Evaluation of infiltration models for mineral soils with different land uses in the tropics and the later, the effects of poultry Manure and cow dung on the Physical and Chemical Properties of Crude Oil Polluted Soil in Owerri, Nigeria. This is supported by the findings of Adhikari et al. (2022), and it was evidenced by the improvement in soil physical properties observed in this study. However, it was recorded that 100% of 50kg cow dung had higher bulk density and electrical conductivity, as well as higher organic matter and porosity values. This agrees with the results of Dang et al. (2022), who reported that the application of cow dung improves soil structure and aeration, thereby enhancing the activities of soil microorganisms. Nugroho et al. (2018) also indicated that bulk density designates the degree of soil compaction. Their report shows that the higher the bulk density, the more solid the soil, which means the more difficult the movement of water into the soil (slow infiltration). Soil porosity is associated with the soil's ability to absorb

water. Soil porosity is also closely related to bulk density (Robinson et al., 2022).

4. Conclusion

This study demonstrated the use of Design Expert to model soil infiltration of soil water amended with cow dung and poultry litter's organic matter. In this study, the texture of mineral soils at the study site was dominated by silt fraction (46-53%), sand (37-43%), and clay (9-13%) which according to the United States Department of Agriculture (USDA) classification is Loamy soil. The soil physical characteristics values with porosity percentage range of 33.93% for T4 and 48.71% for T3; gravimetric moisture content percentage range of 4.18% for T3 and 5.12% for T4; bulk density range of 1.24 g/cm³ for T1 and 1.32 g/cm³ for T2; organic matter content percentage range of 0.53% for T1 and 24.08% for T4; and organic carbon content percentage range of 0.92% for T1 and 2.20% for T5. The dominance of the 2FI (2-Factor Interaction) model source during the dry season and the linear model source during the rainy season could be attributed to several factors. Some of which are low moisture content and more rigid soil structure during the dry season, and the soil may become saturated, leading to a more uniform infiltration rate during the rainy season. In addition, the highest R² value obtained from the Design-Expert ANOVA analyses was used to determine the optimal combination as 75% cow dung and 25% poultry litter for T4, and this was compared with existing classical soil infiltration models (Modified Kostikov and Horton's) under similar experimental conditions. The respective R² values for dry season and rainy season are: 0.8786 and 0.8901 for Design Expert; 0.989 and 0.992 for Modified Kostikov model; 0.716 and 0.871 for Horton's model. Based on the model results, the recommended optimal rates of organic matter application should be adopted to improve soil water infiltration and to develop sustainable soil management practices that enhance soil infiltration and reduce soil erosion.

Limitation

The study only focuses on loamy soil, which may not be representative of other soil types. Also, the model used in the study may oversimplify the complex processes involved in soil water infiltration.

Data Availability

The data used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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