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Calibration of Existing Infiltration Models on Different Amended Soils

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ABSTRACT: *Organic amendments can affect soil properties. The predictive power of selected water infiltration models in organic amended soils were evaluated. Ten (10) infiltration models consisting of five (5) empirical (Philip (PH), Kostiakov (KT), Modified Kostiakov (MK), Kostiakov-Lewis (KL) and Natural Resource Conservative Service (NRCS)), Three (3) physically based (Green-Ampt (GA), Smith-Parlange (SP), Talsma-Parlange (TP)) and two semi-empirical (Swartzendruber (SW) and Horton (HT)), were evaluated for soils amended with cow dung, poultry litter and Pig dung. Ability of the models to accurately prediction the measured cumulative infiltration. The study was carried out at University of Uyo experimental plot at Uyo, Akwa Ibom. The field was ploughed to a depth of 20cm in order to mix the manure with the soil. Soil samples were taken from each strip, and the tests were repeated two weeks, four weeks and six weeks after manure application. The amendment with Cow dung increased cumulative infiltration by 56.05%, Poultry litter increased cumulative infiltration by 36.43% and Pig dung manure increased cumulative infiltration by 2.6%. The statistical model was used to evaluate the model performance. The coefficient of determination* $\boldsymbol{R^2}$ *between the models simulated cumulative infiltration and field measured cumulative infiltration ranged from 0.931 to 0.998. The value of the modelling efficiency* ($\boldsymbol{E}$) *index ranged from -0.048 to 0.998 while the Mean Absolute Error* ($\boldsymbol{MAE}$) *ranges from -0.955 to 5.454. The values of the coefficient of residual mass* ($\boldsymbol{CRM}$) *ranged from -1.320 to 0.572. Seven models (NRCS, Philips, Kostiakov, Kostiakov-Lewis, Modified Kostiakov, Talsma-Parlange and Swartzendruber's model) under-predicted while three models (Green-Ampt, Smith-Parlange and Horton) over-predicted cumulative infiltration. The NRCS's model had the overall best performance, Kostiakov model had best performance amongst the empirically based models, the Talsma-Parlange's model had the best performance in the physically based models, and Horton's model had the best performance in the semi-empirical group respectively. The NRCS's model were found to be most appropriate for cow dung, Poultry litter, and the Control while, Kostiakov model were found to be most suitable in the Pig dung amended soil.*

KEYWORDS: *Infiltration, Organic amendments, Soils, Models,*

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I. INTRODUCTION

The quality of irrigation water has the potential to significantly affect soil chemical, structural and hydrologic properties (Emdad *et. Al.*, 2016). The physical condition of a soil is one of the fundamental factors affecting crop growth, development and yield. This is because the soil physical properties have very high degree of correlation with crop production and have high influence on soil fertility and crop performance (Nnaji, 2009; Onwudiwe *et. Al.*, 2014). The quality of water for irrigation is a significant factor in crop production, when this either gets to agricultural lands by surface flow or by deliberate application by farmers for wants of an adequate quantity of fresh water, adds undesirable salts to the agricultural lands (Bhattacharya and Michael, 2010). While the effect of water quality on infiltration rate has been studied under laboratory conditions, the effect of municipal waste on infiltration rate, soil structural properties with different organic amendments have not been widely investigated under field conditions. The use of organic amendments in place of inorganic fertilizers in crop production by farmers in Nigeria is on the increase and research interest recently shifted to utilization of organic wastes as nutrient sources in crop production. Farmers use leguminous plants, cow dung, poultry litter, compost, goat yard manure, and mushroom, and rice husk, wood ash amongst others with the aim of maintaining water and nutrients at optimal levels within the root zone of plants to achieve high growth, yield and yield quality of crops(Atta *et. Al.*, 2014; Armin *et. Al.*, 2013; Katsumi and Khan, 2012; Ayeni and Adetunji, 2010). When soils are amended, water infiltration rate is affected among other physical properties. Water infiltration is the process of downward movement of water from the ground surface into the soil and it is an important process in the hydrologic cycle, wherein water from precipitation, ice, or irrigation amongst others enters the soil (Bhattacharya and Michael, 2010; Gana, 2011; Haghiabi *et. Al.*, 2011). Water from these sources may also runoff over land and cause erosion, flooding, or flow into streams, lakes, rivers and oceans (Tuffour and Abubakari, 2015; Rawls *et. al.*, 1993). Thus, infiltrating water, which constitutes the sole source of water to sustain the growth of vegetation, is filtered by the soil, which removes many contaminants through physical, chemical and biological processes, and replenishes the ground water supply to wells, springs and streams. Infiltration is the downward flow of water vertically through the soil surface. Infiltration is one of the physical property of soil that is very relevant to the design of irrigation drainage and water harvesting systems (Bhattacharya and Michael, 2010). Though it is a soil surface phenomenon, it necessarily depends on the soil condition below the surface. A homogeneous deep soil will result in more infiltration than soil, which is a little below the surface and has relatively compacted layer, though the surface soil condition in both the cases may be the same. The infiltrated water is held in the soil pores and the excess flows down causing water table to rise. The volume of water infiltrated from applied water (irrigation, rainfall, accumulated floodwater or other sources like municipal waste slurry) is an abstraction from the surface runoff. Hence, infiltration becomes a relevant parameter for both surface and subsurface drainage. At a given location, infiltration varies with time. For a specific infiltration invent, the rate of water entry at the surface reduces as the surface and lower soil layer become wet more and more, reaching a constant low value after a long time. This low value corresponds to the vertical hydraulic conductivity of the soil. Infiltration vary due to changes in soil conditions, mainly its compaction, texture and initial moisture content (Bhattacharya and Michael, 2010). The general aim of this study is to assess the performance of the selected and widely adaptable infiltration models for soils amended with cow dung and poultry litter.

II. MATERIALS AND METHODS

Description of the study area

The study was carried out at the University of Uyo experimental field, Nwaniba road, Uyo, Akwa Ibom State, Nigeria. Uyo is located on latitude $4^o 32'N$ and $5^o 33'N,$ and longitudes $7^o 25'E$ and$8^o 25'E$, at an altitude of about 54m/178ft above mean sea level (Wikipedia, 1987). Uyo lies within the southern Guinea Savannah bio-climatic zone, and itis characterized by two seasons- the wet rainy season and the dry season. In the south and central parts of the State, the wet or rainy season last for about ten to eleven months but towards the far north, it reduces to about nine months. The rainy season starts from February to March and last until mid-November, with a mean annual rainfall of about 4000mm(Udo-Inyang & Edem, 2012).

Field Layout and Experimental Plot Design

University of Uyo experimental field was cleared and divided into four strips, 50 kg each of Cow dung (CD), Pig dung (PD) and poultry litter (PL) was applied into the furrow of the first, second and third strip and the forth strip without amendments served as control (CT). The fieldwas ploughed to a depth of 20cm in order to mix the manure with the soil and left to decay before the test was carried out. This was to allow proper decay and decomposition of the organic amendments. After 6-months of application of organic amendments, soil samples was taken from each strip for soil's physical property determination, and infiltration runs was carried out using the double ring infiltrometer from six points on each strip. TheRandomized Complete Block Design (RCBD) was adopted for this study to give unbiased precise measurement of the different treatments.

Field Measured Infiltration

In order to determine the performance of the selected models in predicting the cumulative infiltration, the parameters of each mode was first determined. Infiltration runs were carried out per strip which were 1st week, 3rd week and 6th week after after application of organic amendments, for each strip. The average of the result was use for model's parameter evaluation and model validation, thesame was repeated for other strips.

The average results of the measured cumulative infiltration are summarized in Table 1. The respective infiltration rates are calculate and as can been seen in Table 1, final infiltration rates were 6.39 cm/hr for poultry litter amended strip, 4.81 cm/hr for pig dung amended strip, 7.31 cm/hr for cow dung amended strip and 4.69 cm/hr for the control strip and these were attained after four (4) hours respectively. Table 1 shows a variation in the cumulative infiltration depth at a given times across the strips, Cow dung strip having a higer infiltration values compared to the control strip, this indicates that the addition of these amendments increased the infiltration rate of the soil.

Table 1 shows the values of elapse time, cumulative infiltration and infiltration rate of the different strips with different amendments and control strip.

	Pig dung		Cow dung		Poultry litter		Control	
Time (hr)	Cum. Inf. (cm)	Inf. Rate (cm/hr)	Cum. Inf. (cm)	Inf. Rate (cm/hr)	Cum. Inf. (cm)	Inf. Rate (cm/hr)	Cum. Inf. (cm)	Inf. Rate (cm/hr)
0.04	1.788	44.708	2.442	61.042	2.403	60.083	1.612	40.292
0.07	2.738	39.119	3.875	55.357	3.767	53.810	2.545	36.357
0.16	3.940	24.625	6.193	38.708	5.693	35.583	3.657	22.854
0.32	5.712	17.849	8.050	25.156	7.833	24.479	5.403	16.885
0.49	7.165	14.622	10.295	21.010	10.200	20.816	6.840	13.959
0.74	8.715	11.777	13.077	17.671	12.483	16.869	8.188	11.065
1.00	10.302	10.302	15.597	15.597	14.843	14.843	10.160	10.160
1.50	12.437	8.291	18.477	12.318	16.885	11.257	12.182	8.121
2.00	14.223	7.112	21.740	10.870	19.228	9.614	13.898	6.949
2.50	15.945	6.378	24.315	9.726	21.165	8.466	15.642	6.257
3.00	17.320	5.773	26.508	8.836	22.667	7.556	17.057	5.686
3.40	18.712	5.503	28.035	8.246	24.655	7.251	18.165	5.343
4.00	19.247	4.812	29.255	7.314	25.577	6.394	18.752	4.688

Table 2: Statistical Analysis

Time (hr)	Obs	KT	GA	MK	PH	HT	KL	NRCS	TP	SZ	SP
0.04	1.79	2.11	0.28	0.41	2.00	1.39	7.22	2.41	1.07	2.55	0.28
0.07	2.74	2.77	0.49	0.79	2.65	2.20	7.68	3.00	1.47	3.08	0.49
0.16	3.94	4.14	1.12	1.84	4.00	3.84	8.61	4.25	2.39	4.03	1.12
0.32	5.71	5.80	2.24	3.54	5.66	5.36	9.81	5.81	3.70	5.11	2.24
0.49	7.17	7.14	3.43	5.23	7.00	6.36	10.91	7.09	4.93	6.04	3.43
0.74	8.72	8.73	5.17	7.57	8.60	7.59	12.40	8.64	6.62	7.32	5.17
1.00	10.30	10.11	6.99	9.91	10.00	8.81	13.86	10.00	8.31	8.60	6.99
1.50	12.44	12.32	10.49	14.20	12.25	11.16	16.56	12.21	11.50	11.03	10.49
2.00	14.22	14.17	13.98	18.30	14.15	13.50	19.18	14.09	14.69	13.44	13.98
2.50	15.95	15.80	17.48	22.28	15.82	15.84	21.76	15.76	17.93	15.84	17.48
3.00	17.32	17.26	20.97	26.15	17.33	18.19	24.30	17.27	21.21	18.25	20.97
3.40	18.71	18.35	23.77	29.19	18.44	20.06	26.33	18.40	23.89	20.18	23.77
4.00	19.25	19.86	27.96	33.67	20.01	22.88	29.34	19.98	27.98	23.06	27.96
	R^2	0.998	0.940	0.961	0.998	0.975	0.964	0.997	0.950	0.960	0.940
	RMSE	8.324	10.920	14.566	12.727	9.000	10.617	10.009	10.529	11.002	11.350
	E	0.998	0.591	-0.048	0.998	0.950	0.082	0.997	0.680	0.940	0.591
	CRM	-0.002	0.028	-0.252	0.002	0.008	-0.504	-0.005	-0.054	-0.002	0.028
	MAE	0.023	-0.300	2.681	-0.026	-0.082	5.363	0.051	0.572	0.022	-0.300

From table 2 the coefficient of determination (R^2) between the field-measured and model simulated data were very high (greater 90%) which implied that the ten models were able to simulate water infiltration in the study area adequately. The result of the coefficient of determination (R^2) ranged from 0.93 to 1.00, which is an indication of agreement between the measured and the predicted data for each of the infiltration models. Considering the individual performance of the models in the respective strips, the Kostiakov's, NRCS were the best in all the strips including the Control strip with R^2 values of 0.998 while the Kostiakov's, Modified Kostiakov, Philips and NRCS models were the best for control strip.

The values of Nash-Sutcliffe modelling efficiency *E* ranges from -0.05 to 0.998 for the entire study area. Kostiakov, Modified Kostiakov, Philips, NRCS, and Talsma-Parlange models with values of 0.998, 0.996, 0.998 0.997 and 0.979 respectively gave a close agreement between observed and predicted values for Cow dung strips while Kostiakov-Lewis model showed the poorest agreement with value of 0.759 for Cow dung strip. Kostiakov model gave a close agreement between observed and predicted with value of 0.996 and the poorest is Kostiakov-Lewis with value of 0.624 for the Poultry litter strip. Kostiakov, Philips, and NRCS models gave a close agreement with values of 0.998, 0.998, and 0.997 respectively for Pig dung strip. Modified

Kostiakov showed the poorest agreement with value of -0.048. Kostiakov, Philips NRCS gave the closest agreement between observed and the predicted with values of $0.997, 0.997$ and 0.997 respectively, while Kostiakov-Lewis gave the poorest agreement for Control strip with value of 0.027. For the entire study area, the mean absolute error (MAE), which has a statistical inference closely related to RMSE ranged from $-1.969\ to\ 5.484$ with the poorest performance coming from Kostiakov-Lewis model under the Control strip. Which implies that Kostiakov-Lewis model is less suitable under the natural condition of the study area.

The coefficient of residual mass (CRM) ranged from $-0.532\ to\ 0.148$ for the study area, with Kostiakov, Philips, Kostiakov-Lewis, Talsma-Parlange, Natural Resource Conservative Service (NRCS), Modified Kostiakov, and Swartzendruber's models under estimating or under predicting the cumulative infiltration while Green and Ampt, Horton, and Smith Parlange models over estimating or over predicting the cumulative infiltration rate of the study area.

Table 3: Percentage predictability of Infiltration Models

Model	Amendment	Over Predicted (%)
Green Ampt	Cow dung	6%
Green Ampt	Poultry litter	12%
Green Ampt	Pig Dung	2.8%
Green Ampt	Control	9%
Horton	Cow dung	14.8%
Horton	Poultry litter	1.5%
Horton	Pig dung	0.8%
Horton	Control	0.5%
Smith Parlange	Cow dung	6%
Smith Parlange	Poultry litter	12%
Smith Parlange	Pig dung	2.8%
Smith Parlange	Control	9.2%

From table 3 Green and Ampt model over predicted for Cow dung strip with 6% and 12% for Poultry litter strip, 2.8% for Pig dung strip, and 9% for the Control s respectively. Horton model over predicted with 14.8%, 1.5%, 0.8%, and 0.5% for Cow dung, Poultry litter, Pig dung, and Control respectively. Smith and Parlange model over predicted with 6%, 12%, 2.8%, 9.2% for Cow dung, Poultry litter, Pig dung, and Control while the remaining seven models under predicted with Swartzendruber's, Philips, and Kostiakov closer to zero which indicates more accuracy in prediction.

The results from the Cow dung strip showed that, Swartzendruber's, NRCS, Philips, Kostiakov-Lewis, Kostiakov, Modified Kostiakov, and Talsma Parlange under predicted cumulative infiltration with percentages of 0.2%, 0.4%, 0.3%, 23.3%, 0.3%, 2.4% respectively. While the remaining three models over estimated or predicted. For the Control, Green and Ampt, Horton, and Smith and Parlange model over predicted while the remaining seven under predicted. Generally, Kostiakov and Modified Kostiakov, Swartzendruber, Philips model had the lowest mean absolute error. Which means that these models are efficient in predicting water infiltration in organic amended soils but for coefficient of residual mass seven of the models overestimated the cumulative infiltration. For a perfect fit between observed and predicted values, the Modified Kostiakov model was found to be closer to zero. Kostiakov Lewis model was found to be farther away than every other model with 27.8% under predicting. This shows that Kostiakov-Lewis model is not very efficient in predicting water infiltration in organic amended soils.

In order to further check for discrepancies between the predicted and the measured values, Root Mean Square Error (RMSE) was used. The result of the values obtained from the RMSE calculation is shown in Table 2. The performance of the models was ranked in descending order of accuracy showing their numerical value.

Table 4 RMSE Ranking Tale

	CT RMSE Values	Rank	PD RMSE Values	Rank	PL RMSE Values	Rank	CD RMSE Values	Rank
Kostiakov	8.222	2	8.324	1	10.809	2	12.766	2
Green and Ampt	9.618	9	10.920	5	13.204	10	14.149	9
Modified Kostiakov	8.303	4	14.566	10	10.817	3	12.779	4
Philips	8.233	3	12.727	9	11.097	4	12.775	3
Horton	8.865	6	9.000	2	11.326	5	15.091	10
Kostiakov-Lewis	9.998	10	10.617	4	12.260	7	14.034	7
NRCS	8.184	1	10.009	3	10.776	1	12.740	1
Talsma Parlange	9.012	7	10.529	6	12.375	8	13.387	5
Swartzendruber	8.736	5	11.002	7	11.710	6	13.573	6
Smith and Parlange	9.618	9	11.350	8	13.204	10	14.149	9

Table 4 shows that NRCS model had the least error in comparing the predicted values with field measured values followed by Kostiakov for the control, Poultry litter and Cow dung amended strip. The predictions of NRCS model are very close to that of the Kostiakov, this might be due to similarity with both models; the only difference is the rectifying constant in the NRCS model of 0.6985. However, their similarity in prediction was more in the Cow dung strip, which means that the addition of the constant value 0.6985 in NRCS model make the model very suitable for predicting nitration in soils amended with Cow dung.

Table 4 shows that the physically based models, i.e. Talsma-Parlange, Smith-Parlange, and Green-Ampt models perform fairly in all strips especially Smith and Parlange model perform poorly in all strips that one would have expected to perform better since its parameters were derived from measured data. This result clearly shows that the physically based models especially Green-Ampt and Smith-Parlange perform poorly in Poultry litter, Cow dung and the control.

The semi-empirical models, which are Swartzendruber, and Horton's model perform fairly in their prediction. This may be because their parameters lack a consistent physical interpretation and the process involved in the evaluation of the parameters might be very sensitive to approximation errors while determining the initial and steady state infiltration rates from the graph as inputs for the prediction of cumulative infiltration.

Kostiakov model performed better than Philips model, this is in agreement with the work done by Igbadun and Idris (2007), who observed that Kostiakov model, fitted experimental data better than Philip model for a hydromorphic soil at Samaru, Zaria, Nigeria. The result of this study agrees with the findings of Al-Azawi(1985), who evaluated six infiltration models on a relatively homogeneous, coarse-textured soil. He found that Kostiakov, Modified Kostiakov, Green-Ampt performed in that order respectively. Hsu *et al.*,(2002) evaluated three models (Horton, Philip and Green-Ampt) for three soil types to assess the models based on Ricgard's equation. The result shows that all three models provided similar predition to the numerical results, but the Horton Model differed most as compared to the other two models in terms of infiltration rates. The result of this study shows that Green-Ampt model perform poorly compared to Horton and Philip models in terms of predicting infiltration rates. It is intresting to find that semi-emperical and emperical models (Horton and Philip) could perform bertter in predicting infiltration rate than the physically based models.

Mbagwu (1995) recommended modified Kostiakov equation fr routine modellig of the infiltration process on soils with rapid water intake rates. The Kostiakov and modified Kostiakov model tend to be the prefered models used for irrigation infiltration, probaly because it is less restictive as to the mode of water application than some other models.

Discussion of Result

The overall suitability of a model from the point of view of accuracy of its predictions can be examined by considering the various evaluation indices; however, as a rule, the RMSE was used to indicate the relative performance of the models. It will be good to know that some of the estimation parameters are often prone to estimation error. This estimation error may affect the performance of the models. This means that the performance of a given model is affected by site, which may be due to the effect of specific field condition present at the site, the accuracy of the input parameters and the assumption made in developing the models. Gana (2011) studied the effect of cow dung on soil with higher sand percentage in BidA, Niger state, the effect of cow dung was not significant and also showed that cow dung with inorganic fertiler cannot easily influence the soil texture. However, according to Gupta *et. Al.*, (2008) application of cow dung helps in improving soil structure, soil aeration and therefore improves the activities of soil micro-organisms. Odofin (2012) showed that Kostiakov's, modified Kostiakov and Philip infiltration models were all found to be suitable for simulating water infiltration into an Alfisol subjected to untilled mulched, tilled-mulcched and tilled-unmulched management systems at Minna, Nigeria. However, modified Kostiakov model simulated water infiltration more accuratelt than Philip model while Kostiakov model was the least accurate. Infiltration data from highly permeable soils under five different land use histories on Nsukka plains of south-eastern Nigeria showed that either the modified Kostiakov model or Philip model could be used for routine characterization of the infiltration process (Mbagwu, 1995). The Kostiakov and modified Kostiakov equations tend to be the prefered models used for irrigation design, probaly because it is less restrictive as to the mode of water application than some other models.

III. CONCLUSIONS

The predictive power of selected water infiltration models in organic amended soils were evaluated. Ten (10) infiltration models consisting of five (5) empirical (Philip (PH), Kostiakov (KT), Modified Kostiakov (MK), Kostiakov-Lewis (KL) and Natural Resource Conservative Service (NRCS)), Three (3) physically based (Green-Ampt (GA), Smith-Parlange (SP), Talsma-Parlange (TP)) and two semi-empirical (Swartzendruber (SW) and Horton (HT)), were evaluated for soils amended with cow dung, poultry litter and Pig dung. Ability of the models to accurately prediction the measured cumulative infiltration. The study was carried out at University of Uyo experimental plot at Uyo, Akwa Ibom. The field was ploughed to a depth of 20cm in order to mix the manure with the soil. Soil samples were taken from each strip, and the tests were repeated two weeks, four weeks and six weeks after manure application. The amendment with Cow dung increased cumulative infiltration by 56.05%, Poultry litter increased cumulative infiltration by 36.43% and Pig dung manure increased cumulative infiltration by 2.6%. The statistical model was used to evaluate the model performance. The coefficient of determination $\boldsymbol{R^2}$ between the models simulated cumulative infiltration and field measured cumulative infiltration ranged from 0.931 to 0.998. The value of the modelling efficiency ($\boldsymbol{E}$) index ranged from -0.048 to 0.998 while the Mean Absolute Error ($\boldsymbol{MAE}$) ranges from -0.955 to 5.454. The values of the coefficient of residual mass ($\boldsymbol{CRM}$) ranged from -1.320 to 0.572. Seven models (NRCS, Philips, Kostiakov, Kostiakov-Lewis, Modified Kostiakov, Talsma-Parlange and Swartzendruber's model) under-predicted while three models (Green-Ampt, Smith-Parlange and Horton) over-predicted cumulative infiltration. The NRCS's model had the overall best performance, Kostiakov model had best performance amongst the empirically based models, the Talsma-Parlange's model had the best performance in the physically based models, and Horton's model had the best performance in the semi-empirical

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