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Determination of Saturated Hydraulic Conductivity Using Laboratory Method and Predicted Model of Some Farmlands in Yola South, Northeastern Nigeria

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Abstract

The study aimed to determine saturated hydraulic conductivity (K_{sat}) using laboratory method and predicted model of some farmlands in Yola South, North-eastern Nigeria. Two profile pits were dug in each of the three selected farmlands (Mbamba, Bole and Yolde pate) and representative soil samples were collected from three points in each of the locations at depths of 0-15cm, 15-30 cm and 30-60 cm respectively. The K_{sat} value for each of the sample was measured in the laboratory using simplified permeameter method and predicted using Relative Effective Porosity Model (REPM). The results revealed that the soil texture at Mbamba and Bole areas were dominated by sandy loam and loam textures at Yolde-pate. In addition, the Bd, Pd, TP and AP were characterized as moderate to high ranges from 1.5-1.79 g/cm^3, 2.53-2.71 g/cm^3, 32.0-40.07 % and 19.99-32.32% respectively. The measured and predicted Ksat values show a unit magnitude difference at Mbamaba (1.4 to 2.0 ×10^{-4} m/s and 1.1x 10^{-5} m/s to 8.1×10^{-6} m/s) and Bole arable lands (2.8×10^{-3}-5.7×10^{-5} m/s and 1.2×10^{-4} m/s to 6.4×10^{-6} m/s) while Yolde-pate shows irregular Ksat magnitude differences. It is concluded that the measured and the REPM model could not be used to determine K_{sat} for the low porous soils (loamy, clay loam, clay) for all locations in the study area.

Keywords: ***farmlands, predicted model, saturated hydraulic conductivity, Yola South***

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Introduction

Soil hydraulic conductivity is a measurement of its capacity to transmit water. It is used to define the rate at which water moves through the soil pore system when it is saturated. Soil water conductivity also plays an important role in the effective use of water resources, as well. Saturated hydraulic conductivity (K_{sat}) is a constant associated with the flow of a fluid through a saturated conducting medium (Oshunsanya, 2013, p.140). K_{sat} of the surface soil is required for agronomic and water management purposes including the design of irrigation systems.

Saturated hydraulic conductivity is the most critical soil hydraulic property of the soil matrix (Rawls *et al.,* 1998, p.985) and one of the most difficult hydraulic properties to obtain (Suleiman and Ritchie, 2001, p.3). It is a key parameter that is important for irrigation, drainage, water balance, modelling of water flow and chemical transport through the soil, and has been estimated from various soil properties by several researchers with success (Ihakur *et al.*, 2007, p.26). Different methods have been used to determine the K_{sat} of soils which include direct and indirect methods. The direct measurement of soil hydraulic properties is expensive and time consuming, and consequently, indirect methods are increasingly used to predict soil hydraulic properties from easily measurable soil parameters such as soil texture and bulk density. Thus, pedo-transfer functions (PTF) is the most commonly used indirect method (Wosten *et al.,* 2001, p.123).

PTF could be derived from an empirical relationship established by Darcy's law which involves the rates of flow of water through saturated columns of soil and hydraulic head loss. It is influenced by soil texture and structure which in turn are influenced by total porosity and pore size distribution (Oshunsanya, 2013, p.136). In addition, Ankeny *et al.,* (1991, p.467) method was adopted for determining in-situ hydraulic conductivity near saturation from steady state infiltration rates measured using a disc permeameter. Saturated hydraulic conductivity has also been estimated by

Mbagwu (1995, p.55) from effective porosity using the generalized Kozeny-Carman equation.

The hydro-physical parameters of the soils of the arable lands in Yola South Local Government Area are seriously undergoing changes due to indiscriminate deforestation, intensive agricultural activities and overgrazing which eventually reduce their productivity (Sadiq *et al.*, 2019, p.44). Based on the findings of the preliminary survey conducted by the authors, crops are significantly affected in most of the farmlands in the area during dry-spell. Thus, long term cultivation decreased hydraulic conductivity of soils indicating surface sealing, consequently influencing water infiltration as reported by Cook *et al.* (1992, p.46). From the foregoing, there is the need to determine the K_{sat} of some farmlands in the area for sustainable crop production. This background emphasizes the relevance of this present work aimed which is aimed at determining the saturated hydraulic conductivity of the soils using laboratory method and predictive models of the selected parameters of some farmlands in Yola South, North-eastern Nigeria.

Methodology

Study Area

The study was conducted in Yola South Local Government Area of Adamawa State, Nigeria. The study area lies between Latitude 9˚14'N of the Equator and Longitude 12˚28'E of the Greenwich Meridian, having an average elevation of about 192 m (Adebayo 2020, p.23). The area falls within the Northern Guinea Savannah Zone and has a tropical wet and dry climate. The dry season commences in November and ends in April; while the wet season is from May to September (Adebayo, 2020, p.26). Mean annual rainfall is about 700 mm (Adebayo *et al.*, 2012, p.104). Yola South Local Government Area has a tropical type of climate marked by distinct dry and raining seasons (Adebayo, 2020 p.26 and Zemba, 2010, p.56).

Soil Sampling Techniques

Three (3) farmlands were selected in the Study Areas namely Mbamba, Yolde pate and Bole. Two profile pits were dug at each site where soil samples were collected from the identified horizons. In addition, at each site three (3) augering was done to collect samples from the month of November 2020 to March 2021 so that to cover the dry season period. Random sampling method was adopted at three (3) different depths of 0-15 cm, 15-30 cm and 30-60 cm at each of soils thereby amounting to samples for the selected three farmlands. Samples collected were transferred into already labeled polythene bags for the determination of $K_{sat.}$

Determination of some selected soil properties

Particle Size Distribution

Particle size distribution was determined using Bouyocous Hydrometer Method (Bouyoucos, 1962, p.464). The texture of the soil was then determined using Marshal's Textural Triangle.

Bulk Density

The soil bulk density was determined by collecting undisturbed sampled using soil core sampler, the collected samples were oven dried at 105 ^{0}C for hours to a constant weight. The volume of e soil core was determined from the internal radius and height and the height of the core. The weights of 100 cm^3 stainless steel cylinders (m0) and soil cores with fresh soil samples (m1) were recorded. The soil cores were placed in a large plastic container, and water was added to the plastic container until the water surface was just at the top of the soil cores. The soil cores were kept saturated for 24 h. After that, the soil core was placed on dry sand for 2 h at room temperature, and the resulting weight was recorded (m2). In that way, only the capillary water remained in the soil core. Then, the soil core was moved back onto the dry sands for 48 h, and the soil core (m3) was weighed. In the end, the soil cores were moved into the oven to dry at 105 °C until constant weight (m4). The BD (g/cm^3), was calculated as follows:BD = m4–m0/ 100 (Dumitru *et al.* 2009,p.4).

Total Porosity

Total porositywas calculated according to the following formula (Dumitru *et al.* 2009, p.6):TP = 100 (1- Bd/Pd) where Bd is bulk density (g/cm^3) and Pd is particle density (g/cm^3).

Compaction Rate

Soil compaction was appreciated depending on the values obtained for CR (%,), calculated according to the formula (Dumitru *et al.,* 2009, p.8): CR = [(MNP - TP)/MNP] 100, where MNP is minim necessary porosity, established on the basis of the following calculation: MNP = 45 + 0.163C (where C is the <0.002 mm clay content, %).

Determination of Saturated Hydraulic Conductivity (K_{sat} m/s)

The laboratory measured Ksat was conducted using simplified permeameter method as described by Diminescu *et al*., (2019, p.850). Meanwhile, the predicted method was achieved using Relative Effective Porosity Model (REPM) described by Suleiman, and Ritchie, (2001, p.3).

Simplified Permeameter Method

The simplified permeameter method involved the use of plastic container tubes with one end covered by a filter. The cylinder was placed in a water tank. The soil samples tested were 100 % saturated with water and left to compacted naturally to stimulate an underground environment. Then, a column of 17 cm of soil samples were added into the cylinder and compacted. The cylinder was then inserted into the container and the soil sample was filled with water from the bottom up, to remove the air. Next, water was carefully poured into the top of the cylinder, above the top reference mark. Water level decreases and the time needed to travel 50 mm, the distance highlighted on the cylinder by Star and Stop notations, was measured. The water temperature during the testing was 20 ^{o}C.

Relative Effective Porosity Model (REPM)

Relative Effective Porosity Model (REPM) proposed by Suleiman and Ritchie (2001) given as follows;

$Ks = 75 (\phi er)^2$ (cm/d).

Therefore, using the concept of relative effective porosity (ϕer),

which is defined as = ϕe / FC,

where ϕer = relative effective porosity,

ϕe = the total porosity,

FC = field capacity.

Results and Discussion

Saturated Hydraulic Conductivity (K_{sat}) of the Laboratory method and Predicted model (m/s) of the Studied Soil Profile

Mbamba Farm Location

At Mbamba farm location, three distinct pedons (Ap, Bw1 and Bw2) where described with the profile pit 1. It was revealed that at horizons Ap (0-20 cm) and Bw2 (70-160 cm) depths shows that the measured K_{sat} was lower than the predicted K_{sat} by two orders of magnitude with the corresponding values of 1.0×10^{-4} m/s and 3.5×10^{-6}, and 1.5×10^{-5} m/s and 2.3×10^{-7} m/s respectively as depicted on Table (1). These trends might be attributed to the homogeneity of the textural class of loamy sand at the two horizons (Ap and Bw2) coupled with the influence of low porosity and low aeration percentage than the middle horizon (Bw1) 20-70 cm depth which was dominated by sand.

Conversely, at horizon Bw1 depth the Ksat shows the same order of magnitude with the laboratory measured value of 4.0 x 10^{-5} m/s and 1.1×10^{-5} m/s predicted value (REPM). This might be linked to the sandy texture of the soil class with low bulk density of 1.50 g/cm^3, high porosity (47 %) as shown in table 1. However, it has been reported by Suleiman and Ritchie, (2013) that model prediction of K_{sat} revealed similar order of magnitude when compared with the laboratory test values on sandy soils considering the REMP as good for K_{sat} predictions. They also concluded that these results suggest that new model gives reasonable estimates of K_{sat} for different soils. However, sandy soils were known to have high hydraulic conductivity than the loamy sand, clay loam or clay soils. Thus, it relatively gives nearer values for both laboratory and predicted (REPM) methods.

It might be assumed that decrease in soil permeability with depth is as a result of decreasing porosity resulting from greater packing density of soil particles. These findings are in conformity with that of Mamadou (1977, p.26), who stated that the hydraulic conductivity of a tillman-hollister soil decrease with depth having Ksat values of 1.4 x 10^{-5} m/s at 20-30 cm 3.2×10^{-5}m/s at 40-50 cm and 9.6×10^{-6} m/s 120-130 cm depth. When a soil shows a distinct layering, it is often found that the representative K-values of the layers may differ. Generally, the more clayey layers have a lower K-value than the sandier layers, but this is not always true (Oosterbaan and Nijland, 1994, p.1). However, the experimental results of Childs and Bybordi, (1969, p.446) refute this supposition. It would be argued that this variation might be influenced by the structural and porosity dispositions of the soil at the upper horizon as influenced by either agronomic factor such as tillage practices within the plow layer which enhances porosity and eventually affects the soil permeability. It is generally accepted that such management practices modify the soil structure and pore size distribution (PSD). In effects, the saturated and near-saturated soil hydraulic properties are very sensitive to these management-induced changes (Ahuja *et al.,* 2006, p.331).

Similarly, in the 0-17 cm depth (Ap horizon) of Profile 2 of Mbamba arable soils both the measured and predicted K_{sat} values show similar order of magnitude with both the methods having the K_{sat} values of 5.6×10^{-5} m/s and 3.1×10^{-5} m/s predicted values respectively. In contrast, the horizon AB (17- 55 cm) of the soil profile revealed has difference of three orders of magnitude between the measured and the predicted K_{sat} with the corresponding values of 1.8×10^{-5} m/s and 7.0×10^{-8} m/s, (Table 1). The greater variation obtained from the predicted method of low K_{sat} could be connected to the very low aeration percentage (3.96 %) coupled with an extremely high compaction rate (> 19 %) cause by intensive tillage practices and overgrazing on the arable lands making the soils loose adequate porosity and highly compacted, thereby reducing the permeability capacity. Similarly, Osman (2013, p.32) reported that tillage operations could stimulate soil compaction and then destroy soil structure, increase BD, reduce soil porosity, and limit movement of water and air within the soil. In agricultural practice, the applied force is related to soil water potential which is dependent on the size and shape of particles, the compactness of structures and some other factors (Eruola *et al.,* 2019, p.93).

In addition, Pedon Bw (55-164 cm) which is characterized with loamy sand textured soil, shows a relative decline in the trend with one order magnitude difference which exist between the measured (3.0×10^{-5} m/s) and predicted (6.7×10^{-6} m/s) K_{sat} values with predicted method having the higher order magnitude than the measured K_{sat} value (Table 1). Nevertheless, all the three (3) pedons (Ap, AB and Bw) were found to have similar order magnitude of 10^{-5} m/s using laboratory method while the REPM method shows relative variations of an order magnitude. It has been noted that the predictive model methods usually provide higher K_{sat} values than the laboratory values. Similar findings were reported by Hyoun-Tae *et al.* (2017) who concluded that empirical methods produced the highest relative variation in the estimation results of hydraulic conductivity. However, Ahuja *et al.,* (1984, p.699) explained that models did not give good estimates of the saturated hydraulic conductivity when applied to soils different from a homogenous granular medium.

Bole Farm Location

The results of hydraulic conductivity for both the laboratory measured and predicted using (REPM) model methods were also portrayed on table 1. Pit 1 show distinctive four (4) horizon which ranges from 0-164 cm depth. At horizon Ap (0-25 cm), AB (25-70 cm) and Bw1 (70-140 cm), K_{sat} values of measured and predicted (REPM) methods were found to have two order magnitude differences with the REPM K_{sat} values higher (10^{-7} m/s) than the measured values (10^{-5} m/s) with soil texture ranges from loamy sand to sandy loam. Lee et *al.* (1985, p.567) make it clearly by saying that the measured K_{sat} values ranged over an order of magnitude on the sand, one to two orders of magnitude on the loams, and three orders of magnitude on the clay.

In contrast, in the horizon Bw2 (140-164 cm depth) a very wider variation was found between the two methods of K_{sat} determination employed in this research work, with four (4) orders magnitude of predicted (REPM) method higher than the laboratory measured method with corresponding values of 1.0×10^{-8} m/s and 1.7×10^{-4} m/s. The irregularity was observed with the laboratory method at horizon Bw2 (140-164 cm) which shows relatively high permeability of K_{sat} (1.7×10^{-4} m/s) than the upper horizons above it, despite the fact that the horizon (140-164 cm) possessed highest rate of compaction (65.97 %), very low aeration percentage (-3. 49 %) coupled with lowest total porosity. Furthermore, in profile (2) three different horizons were identified (Ap, Bw1 and Bw2). The result (Table 1) revealed that the laboratory measured K_{sat} values were low which signifies high permeability of water compared with the predictive values with one order magnitude at pedon Ap and Bw1 (0-23 cm and 23-80 cm) with a corresponding measured values of 4.0×10^{-5} m/s and 5.5×10^{-5} m/s, and 6.3×10^{-6} m/s and 3.1×10^{-6} m/s predicted K_{sat} values respectively. The laboratory method of K_{sat} values of sand and sandy loam soils obtained is buttressed apparently with the measured laboratory K_{sat} values found by Eruola, *et al.* (2019, p.96), with arable soils of Federal University of Agriculture Abeokuta (FUNAAB) having permeability coefficient ranges from 2.7×10^{-5} to 4.2×10^{-5} m/s, of sandy-loam and loamy sand textures.

Conversely, in pedon Bw2 (80-164 cm depth) of the profile 2 of Bole arable soils it was found that two order magnitude variation exist between the measured and the predicted saturated hydraulic conductivity. This increase of variation of order of magnitude between the methods should be clearly viewed and relate to the soil properties. However, the texture shows a relative homogeneity of sand to sandy loam within the horizons, but notwithstanding other driving properties explained apparently an increase of Ksat using prediction method with an order magnitude where presence of lowest total porosity (30.76%), very low aeration percentage (8.32 %), high bulk density (1.8 g/cm^3) and strongly compacted (31.64) leading to decrease in permeability of water as positively and linearly predicted by REPM (1.0×10^{-7} m/s) unlike the measured K_{sat} which decline with one order magnitude (1.7×10^{-4} m/s) signifying the increase in permeability of the soil despite the existing soil properties. Thus, K_{sat} significantly decreased with increasing soil BD.

On the other hand, it could be intensively argued that soil texture plays a pivotal role towards influencing the rate of soil permeability using field, laboratory or predictive models. Smedema and Rycroft (1983, p.376) warn that soils with identical texture may have quite different K-values due to differences in structure. In relation to the findings of this research, it could be concluded that REPM gives an overestimate of K_{sat} values which is in conformity with the statuses of the soil properties (TP, Bd, CR and AP), likewise the laboratory measured method provides K_{sat} values within the range of the soil texture (sand to sandy loam) within the horizons of the profile as observed in the area.

Conclusively, the results of K_{sat} obtained from this study were compared and in conformity with Bear's values (1972) which gave hydraulic conductivity of fine sand and loam in the range of 10^{-3} to 10^{-5}, thus making them semi pervious in nature and varying from very fine sand to silt, loess and loam. The figure 1 below shows the range of values of hydraulic conductivity for various geological materials. Values are for typical fresh groundwater conditions using standard values of viscosity and specific gravity for water at 20°C and 1 atm.

K (cm/s)	10^2	10^1	10^0=1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							

Fig. 1: ***The saturated hydraulic conductivity (K) values found in nature.***
Source: Modified from Bear, (1972)

Yolde Pate Farm Location

Two profile pits were dug in the area where the first profile shows four (4) discrete horizons (Ap, AB, Bw1and Bw2) ranges from 0-174 cm depth (table 1). The results on the measured and predicted (REPM) K_{sat} values were also depicted on table 1. The findings revealed that one order magnitude difference exist between the two adopted method of K_{sat} determination in the horizon Ap (0-30 cm), AB (30-70 cm) and Bw2 (116-174 cm) with the following corresponding values of 2.7×10^{-5} m/s, 2.0×10^{-5} m/s and 1.7×10^{-5} m/s of measured K_{sat}, while the predicted K_{sat} were 1.6×10^{-6} m/s, 5.5×10^{-6} m/s, and 4.7×10^{-6} m/s, respectively. In contrast, at horizon Bw1 (70-116 cm) predicted (REPM) method shows an overestimated Ksat value of three (3) order magnitudes (7.5×10^{-8} m/s) over the laboratory measured method (1.8×10^{-5} m/s). This abrupt variation of order magnitude attained by the REPM is directly connected to the strongly compacted rate of the soil (40.44 %), with extreme poor aeration (-4.67 %) and low total porosity (26.8 %) due to high bulk density (1.7 g/cm^3) than the other existing horizons with the profile. Even though, the measured K_{sat} value was in conformity with the result of Bears (1972, p.764) and validated using the soil texture uniformity of sandy loam (figure 1) respectively. In addition, measured K_{sat} shows uniformity of 10^{-5} order of magnitude within all the horizons indicating the semi permeability of the soil materials within the profiles.

Profile 2 of Yolde pate soils expressed difference of one order magnitude in all the three (3) divergent pedons (Ap, B and Bw) with predicted K_{sat} higher than the measured K_{sat} with the recorded values of $2.5×10^{-6}$ m/s, $8.7×10^{-6}$ m/s and $1.2×10^{-6}$ m/s of REPM method, while $3.8×10^{-5}$ m/s, $1.8×10^{-5}$ m/s and $5.0×10^{-5}$ m/s of laboratory method correspondingly. This uniformity of order magnitude in both the methods might be attributed to the homogeneously defined properties of the soils with little and /or insignificant different which has less effects on the saturated hydraulic conductivity variations.

Measured and Predicted Saturated Hydraulic Conductivity (m/s) of the collected Soil Samples

Bole Farmlands

The results of hydraulic conductivity obtained for Bole arable soils were depicted on table 2. The results show that for all the three replicated samples there was a consistent difference of one order magnitude between the predicted and measured hydraulic conductivity. For the first replication high K_{sat} was obtained at 15-30 cm depth with a measured value of $2.8×10^{-3}$ m/s while the predicted (REPM) value of $1.2×10^{-4}$ m/s. This might be enhanced by the bulk density (1.65 g /cm^3) of the soil due to the intensive tillage practices which gives rise to moderate porosity that permits the relatively high free flow of water through the soil medium as was also observed by Moret and

Arrúe, (2007, p.103).In addition, at the depth of 0-15 cm medium K_{sat} was measured to be $2.8×10^{-4}$ m/s with a predicted (REPM) value of $8.7×10^{-5}$ m/s respectively. At 30-60 cm depth the predicted (REPM) method increases with one order magnitude than the laboratory measured K_{sat} values of 6.5×10^{-6} m/s and 5.7×10^{-5} m/s correspondingly, signifying the low permeability of water compared with the other horizons which might be attributed to the clay loam texture with extremely low draining capacity (-1.02 %). However, it was observed that there was a relative decrease in saturated hydraulic conductivity with an increasing depth in all the soil depths at point A of Bole soils as influenced by the relative uniformity of the soil texture. At point B, the measured K_{sat} shows low conductivity in all the soil depths with measured value varies from $1.6×10^{-5}$ m/s to $5.5×10^{-5}$ m/s while the predicted K_{sat} was consistently higher with one order of magnitude having an estimated value ranges from $3.3 ×10^{-6}$ m/s to $6.4×10^{-6}$ m/s respectively.

Generally, it was revealed that there was consistent similar difference of one order of magnitude at point B for both the measured (10^{-5} m/s) and REMP method (10^{-6} m/s) respectively. Similar finding was reported that the estimated K_{sat} values for all the samples using REMP method were within an order of magnitude (Hyoun-Tae *et al.,* 2017, p.27).

Conversely, at point C, the K_{sat} was found to have similar order of magnitude for both methods at 0-15 cm and 30-60 cm soil depths with a corresponding laboratory measured values of $3.9×10^{-5}$ m/s and 5.6×10^{-5} m/s and $5.6×10^{-5}$ m/s and $1.5×10^{-5}$ m/s using predicted method respectively. In contrast, at 15-30 cm shows a magnitude difference of one order ($1.0×10^{-5}$ m/s REMP method) compared with the measured value ($1.7×10^{-4}$ m/s) as presented on table 4. However, Hyoun-Tae *et al.,* (2017, p.29) drew a conclusion that disagreed with this result outcome; they noted that estimates from the REPM method were consistently lower than those obtained from the other methods.

Mbamba Farmlands

The values for saturated hydraulic conductivity obtained for Mbamba arable soils were depicted on table 2. The K_{sat} result shows that at point A, there were consistently lower values using laboratory measured method in all the three depths (0-15cm, 15-30cm and 30-60 cm) with corresponding values of 1.5×10^{-4} m/s, 1.7×10^{-4} m/s and 2.0×10^{-4} m/s respectively. However, the values increased with one order of magnitude at 0-15 cm (1.1×10^{-5} m/s) and 15-30 cm (4.0×10^{-5} m/s) using predictive (REPM) method which signifies the relative increase in K_{sat} using the predictive (REPM) method within the soil horizons. Thus, Hyoun-Tae, *et al.,* (2017, p.27) showed that the empirical methods overestimated the saturated hydraulic conductivities when compared to those derived from the measured or tracer test analyses. In opposite narration, Cheng and Chen (2007, p.447) reported that the saturated hydraulic conductivities obtained from the empirical methods were relatively lower than those estimated by laboratory pumping test method. In addition, it could be observed that the K_{sat} values increases with an increasing depth in all the horizons using both the laboratory measured and REPM methods. Conversely, at 30-60 cm depth shows two orders of magnitude differences with an overestimated predicted method (REPM) Ksat value of 4.1×10^{-6} m/s than the measured K_{sat} value of 2.0×10^{-4}). At Point B of Mbamba soils the predicted values of K_{sat} was higher than the measured Ksat values with one order magnitude unit at 0-15 cm and 15-30 cm depths with predicted K_{sat} values of 1.5×10^{-5} m/s and 1.7×10^{-4} m/s and 1.8×10^{-6} m/s and 5.6×10^{-5} m/s values. In contrast, at 30-60 cm depth both the methods were found with the same order of magnitude of 2.8×10^{-5} m/s and 6.7×10^{-5} m/s K_{sat} values. Similar conclusion was drawn by Hyoun-Tae, *et al.,* (2017, p.28) stated that the REPM method provided relatively similar estimates compared to the measured method because the differences analyses were less than one order of magnitude except for the medium sand. Conversely, at point C the soil depth 0-15 cm and 15-30 cm shows low K_{sat} values with similar magnitude of 10^{-5} m/s of both the methods as shown table 2 while variation of two orders magnitude was found between the measured and predicted methods at 30-60 cm depth with the K_{sat} values of 1.4×10^{-4} m/s and 8.1×10^{-6} m/s.

Table 1: **Measured and predicted K_{sat} of studied profiles as influenced by some soil properties in the selected farmlands**

Location	Pedon	Depth (cm)	Textural class	Bd (g/cm3)	Pd (g/cm3)	TP (%)	CR (%)	FC (%)	Relative effective porosity (ϕer)	Measured Ksat (m/s)	Predicted Ksat (m/s)
	Ap	0-20	LS	1.92	2.35	18.90	59.35	11.11	1.70	1.0 x 10-4	3.5 x 10-6
MBAMBA1	Bw1	20-70	S	1.50	2.85	47.36	-5.24	22.00	2.15	4.0 x10-5	1.1 x 10-5
	Bw2	70-160	LS	1.60	2.22	27.92	37.95	24.00	1.16	1.5 x 10-5	2.3 x10-7
	Ap	0-17	SL	1.66	2.35	29.36	34.75	10.10	2.90	5.6 x10-5	3.1 x10-5
BAMBA2	AB	17-55	SL	1.53	2.35	34.89	22.46	32.03	1.08	1.8 x 10-5	7.0 x10-5
	Bw	55-164	LS	1.60	2.66	39.84	11.46	21.21	1.87	3.0 x10-5	6.7 x10-6
	Ap	0-25	LS	1.80	2.85	36.84	18.13	28.00	1.31	1.7 x10-5	8.1 x10-7
	AB	25-70	LS	1.80	2.50	28.00	37.77	32.35	0.86	1.7 x10-5	1.1 x10-7
BOLE 1	Bw1	70-140	SL	1.40	2.35	40.42	10.22	33.33	1.21	5.5 x 10-5	3.4 x 10-7
	Bw2	140-164	LS	1.88	2.22	15.31	65.97	17.17	0.89	1.7 x10-4	1.0 x 10-8
	Ap	0-23	S	1.60	2.66	39.84	11.46	21.42	0.53	4.0 x 10-5	6.3 x 10-6
BOLE 2	Bw1	23-80	SL	1.63	2.66	38.72	13.95	24.24	1.59	5.5 x 10-5	3.1 x 10-6
	Bw2	80-164	SL	1.80	2.60	30.76	31.64	26.26	1.17	1.7 x 10-5	2.3 x 10-7
	Ap	0-30	S	1.60	2.85	43.85	2.55	30.47	1.43	2.7 x 10-5	1.6 x 10-6
	B	30-70	L	1.63	2.85	42.80	4.88	23.76	1.80	2.0 x 10-5	5.5 x 10-6
YOLDE PATE 1	Bw1	70-116	SL	1.72	2.35	26.8	40.44	29.52	0.90	1.8 x 10-5	7.5 x 10-8
	Bw2	116-174	LS	1.56	2.85	45.26	-0.57	26.00	1.74	1.7 x 10-5	4.7 x 10-6
	Ap	0-23	LS	1.80	2.66	32.33	28.15	21.00	1.53	3.8 x 10-5	2.5 x 10-6
YOLDE PATE 2	B	23-55	SL	1.42	2.66	46.6	-3.55	23.23	2.00	1.8 x 10-5	8.7 x 10-6
	Bw	55-165	SL	1.60	2.85	43.85	2.55	31.62	1.38	5.0 x 10-5	1.2 x 10-6

Yolde Pate Farmlands

The hydraulic conductivity values for Yolde pate arable soils were presented on table 2. The result shows distinct variations of K_{sat} values between the measured and predicted methods. At 0-15 cm depth of point A, the measured K_{sat} value was found to be 1.0×10^{-4} m/s while the predicted K_{sat} value which shows very low conductivity of 6.8×10^{-6} m/s with two orders magnitude variation. In this finding measured K_{sat} was found to give a closed value in relation to soil texture of sandy loam (10^{-4}) to that of Bear's values (1972) having semi porous permeability. Likewise, the present study result concords and was validated with permeability and drainage characteristics of soils as adopted after Terzaghi *et al.* (1996, p.201) describing the soil with good drainage sands ranges from 10^{-1} to 10^{-6} m/s as depicted in figure 2 below.

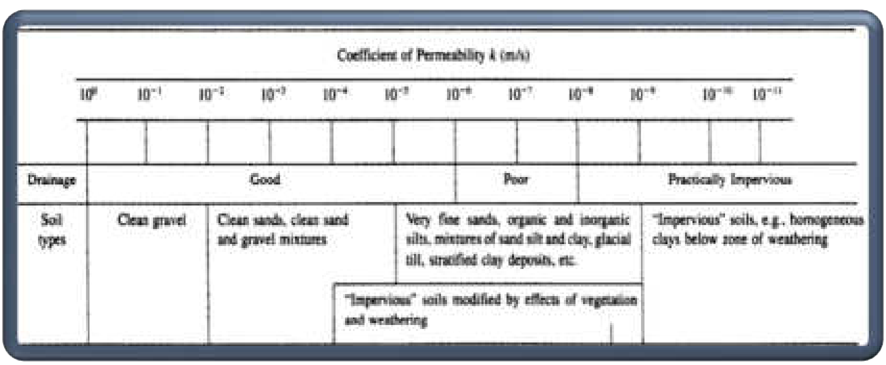

Fig. 2: Permeability and drainage characteristics of soils (adopted after Terzaghi et al.1996).

Moreover, the trend also progressed at 15-30 cm depth with four order magnitudes variation between the measured K_{sat} of 3.8×10^{-5} m/s and predicted Ksat of 3.7×10^{-9} m/s respectively. This result shows low permeability level of K_{sat} which is directly linked to the loam texture of the floodplains soils of Yolde pate with bended stable soil aggregates, low bulk density (1.9 g/cm^3) that gives rise to low total porosity (24.0 %) making the soil strongly compacted rate (46.66 %) as shown on table 2 which enhanced extremely low draining capacity and eventually retardates the flow of water through the soil horizons. This finding was validated by Bear (1972, 764) K_{sat} values and Terzaghi *et al.* (1996, p.206), defined as practically less or impermeable. Thus, REPM predicted method gives a nearer estimate (10^{-9} m/s) than the laboratory measured values (10^{-5} m/s). Similarly, Smedema and Rycroft (1983) identified K_{sat} values of loam, clay loam and clay ranges from 6.0×10^{-9} m/s to 2.4×10^{-8} m/s and very fine sandy loam ranges from $2.4\times10^{-9}$to 6.0×10^{-9} m/s which was also concords with the K_{sat} values identified in the study area.

One order magnitude variation exists at 30-60 cm depth where measured K_{sat} value was obtained to be 1.8×10^{-5} m/s while the predicted K_{sat} was estimated to have 3.7×10^{-6} m/s (table 2). This trend of high K_{sat} conductivity with the Yolde pate soils at point A, one could have linked to illuvial depositions of soil textural materials ranges from clay loam-silt loam–clay with double layer of sedimentation. At point B of the Yolde pate arable lands variations of K_{sat} values were obtained with one order magnitude difference of both the measured (10^{-4} m/s) and predicted methods (10^{-5} m/s) at 0-15 cm and 30-60 cm depth as described on table 2. In contrast, at 15-30 cm depth, both methods show similar K_{sat} values of 10^{-4} m/s which signifies high porous flow of water through the soil medium within the depth of 15-30 cm. Laboratory method was found to give similar consistent order of magnitude in all the soil depths as presented in table 2. In this study it has been noted that laboratory measured K_{sat} gives results within the order magnitude of 10^{-3} m/s to 10^{-5}m/s as was validated by Bear' values which described significant effectiveness of the method as predicated by the textural class. Similarly, at point C, K_{sat} value shows one order magnitude variation of both the measured (10^{-5} m/s) and predicted methods (10^{-6})m/s at 0-15 cm and 30-60 cm depths while at 15-30 cm depth two orders of difference of magnitude was obtained with measured K_{sat} value of 1.9×10^{-5} m/s considered lower than the predicted K_{sat} value of 2.6×10^{-7} m/s characterized as impermeable or very low conductivity influenced by silt loam soils having 1.85 g/cm3 bulk density, strongly compacted soil with about 42.22 % rate, low porosity (26 %), with extremely low draining capacity of -17.62 % and underlying clay textured soils above the upper horizons due to alluvial depositions due to the tillage operations respectively.

Table 2: Measured and predicted saturated hydraulic conductivity (Ksat m/s) of the selected soil samples at the three (3) location

Points	Samples	Depth (cm)	Measured K_{sat} (m/s)	Estimated K_{sat} (m/s)	Measured K_{sat} (m/s)	Estimated K_{sat} (m/s)	Measured K_{sa} (m/s)	Estimated K_{sa} (m/s)
Point A	1	0-15	1.0×10^{-4}	6.8×10^{-6}	2.8×10^{-4}	8.7×10^{-5}	1.5×10^{-4}	1.1×10^{-5}
	2	15-30	3.8×10^{-5}	3.7×10^{-9}	2.8×10^{-3}	1.2×10^{-4}	1.7×10^{-4}	4.0×10^{-5}
	3	30-60	1.8×10^{-5}	3.7×10^{-6}	5.7×10^{-5}	6.5×10^{-6}	2.0×10^{-4}	4.1×10^{-6}
Point B	1	0-15	1.4×10^{-4}	7.2×10^{-5}	1.6×10^{-5}	6.4×10^{-6}	1.7×10^{-4}	1.5×10^{-5}
	2	15-30	1.0×10^{-4}	1.2×10^{-4}	2.6×10^{-5}	3.3×10^{-6}	5.6×10^{-5}	1.8×10^{-6}
	3	30-60	1.5×10^{-4}	1.3×10^{-5}	5.5×10^{-5}	5.5×10^{-6}	2.8×10^{-5}	6.7×10^{-5}
Point C	1	0-15	2.0×10^{-5}	1.2×10^{-6}	3.9×10^{-5}	1.1×10^{-5}	5.6×10^{-5}	2.9×10^{-5}
	2	15-30	1.9×10^{-5}	2.6×10^{-7}	1.7×10^{-4}	1.0×10^{-5}	5.4×10^{-5}	4.8×10^{-5}
	3	30-60	1.5×10^{-5}	6.5×10^{-6}	5.6×10^{-5}	1.5×10^{-5}	1.4×10^{-4}	8.1×10^{-6}

Conclusion

The results revealed that the measured K_{sat} (m/s) shows uniform order magnitude of a unit difference while the predicted model revealed irregular variations of order magnitude which could be a result of the presence of finer particles of the soil textural class of some farmlands in the area. Therefore, it could be concluded that both the laboratory and predicted model methods used in this study can be suitable on medium to high coarse textured soils (sandy loam, loamy sand) than on the finer textured soils (loamy, clay-loam and clay) respectively, and cannot be adopted efficiently and effectively in all the locations of the study area. However, their application on medium to high porous soils are highly imperative in assessing the K_{sat} values as revealed in this study for further decision making. It is recommended therefore, farmers at Bole and Mbamba farmlands should therefore integrate the use of organic materials (such as green manure, animal dung, residues incorporation etc) that helps to retain sufficient moisture within the soil horizon with the aim of improving the soil permeability and moisture characteristics of the soils. The use of REPM should be adopted on the soils (sandy loam-loamy sand) of area in order to revalidate the outcome of the other methods (field and laboratory) as it gives reasonable estimate of K_{sat} values.

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