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# Field capacity (FC) and permanent wilty point (PWP) of clay soils developed on Quaternary alluvium in Niger River loop (Mali)

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## Abstract

**Measurement of soil water retention and soil hydraulic conductivity are laborious and expensive. So, development and utilization of pedotransfer functions (PTFs) have been very important in soil water evaluation. It is recognized that a given model is not suitable for all soil types and there are needs of verification before a pedotransfer function (PTF) utilization outside its original development context. The present study is related to clay soils developed on Quaternary alluvium of Niger River in Mali. It covers comparison of field capacity (FC) values measured in laboratory and calculated (with three formulas), development of a formula for estimating FC according to local soil properties and definition of a relation between FC and permanent wilting point (PWP). Two parametric tests (Student t test and z-test) show that the formulas give different values of the FC and all the calculated values deviate from the measured values. FC values of the study soils are explained by their clay content and the cation exchange capacity (CEC) (R= 0,80).**

**Key words**: Clay, Field capacity, Mali, Pedotransfer function, quaternary alluvium

## 1. Introduction

In many scientific discipline (climatology, hydrology, agronomy, etc) and practical fields (crop management, irrigation, civil engineering, etc), soil water retention and soil hydraulic conductivity are an important concern. About soil water, the field capacity (FC) and the permanent wilting point (PWP) are two levels of moisture that are used to calculate available water for plant and water depth to be applied by irrigation; they are subject of the present article. Classically, field capacity is defined as the amount of water after excess water has drained away and the rate of downward movement has materially decreased. The permanent wilting point is defined as the value of soil wetness when plants wilt. Generally, measurement of soil moisture is a complex and expensive operation [1]. That is why, since the development of pedotransfer functions (PTFs) in Soil Science, they are much applied to the soil water. We must remember that the PTFs are models for estimation and prediction of certain soil properties from the basic ones usually available in soil data bases [2, 1, 3]. The used data derived from in situ soil characterization (eg soil morphology), and mainly laboratory analysis (particle size distribution, carbon content, cation exchange capacity, pH, etc.) [2, 4]. The pedotransfer functions can add value to the basic soil information by transforming them into estimated soil properties, more elaborate and expensive. Initially, most of PTFs have been developed to estimate soil water [5, 4, 6]. Subsequently, the PTFs were established to estimate the physical, chemical and biological properties of soils [3]. It should be noted that the PTFs are generally established by linear regression and correspond to empirical models that describe the relationship between certain basic parameters of soils and their properties, as hydraulic ones for example. It is recognized that a given PTF is not suitable for all soil types [7]. So the need to find formulas adapted to local pedological context is a real necessity. In this order, the present work has been undertaken about clay soils developed on alluvial material of the loop of the Niger River in Mali. It covers:
- comparison of measured and calculated values of the field capacity (FC);
- finding a formula for estimating FC according to local soil characteristics
- defining a relation between FC and permanent wilting point (PWP) in the studied context.

## 2. Materials and methods

### 2.1 Soil data

For this study, analytical data of 68 soil horizons from 29 profiles are used: particle size distribution, organic matter (OM or MO for abbreviation in formula from French), cation exchange capacity (CEC). These soils are developed on Quaternary alluvium deposited by Niger River [8]. The concern region (Niger River loop) has a semi-arid climate with three seasons:
- A short rainy season (late June to early September); annual rainfall is about 250 mm;
- A cool dry season (November to February) with night temperature below 20°C;

- A dry season (August to June) with daytime temperatures above 40°C.
The development of the soils concerned by the study, has been dominate by hydromorphic process. In Mali, the delta and loop of Niger River are seen as areas with high potentiality for irrigation [8, 9]

Table1: Studied soil samples origin

| Site | Longitude | Latitude | Number of sample |
|---|---|---|---|
| Ansongo | 0°30’16’’ E | 15°39’55’’ N | 38 |
| Forgho | 0°3’24’’ W | 16°28’21’’ N | 13 |
| Tachran | 0°41’15’ W | 16°09’6’’ N | 17 |
| Total | | | 68 |

**2.2 Calculation of field capacity (FC) with formulas**

The formulas proposed for FC calculation are generally in the form below [1] :

$$FC = \alpha A + \beta Lf + K$$
$$FC = \alpha A + \beta MO + KA$$

A and Lf are respectively clay and fine silt contents, MO, the organic matter content, K is a constant; $\alpha$, $\beta$ and $\gamma$ are parameters.
However, about clay horizons, studies [10, 11] have shown better correlation between:
- FC and the cation exchange capacity (CEC);
- FC and the in situ specific volume (inverse of density).
It is also known that FC is correlated to textural classes [1, 12, 13].
In the present study, FC measured in laboratory (noted $FC_m$) is compared with FC calculated with three different formulas (F1, F2 and F3) shown below:
FC = 0.60 A + 0.19 L + 0.96 M.O. + 4.11 F1
FC = 0. 34 A + 0,90 MO + 1.8 F2
FC = (0.701 x CEC) + 9.69 F3

F1 is the formula of Bold and F2 is from Osty [1]. F3 is the formula proposed by Bruand et al. (1988) [11]. These three formulas are developed in France, respectively on alluvial soils of the Loire Valley, upstream of Orleans (F1 and F2), and from various soils samples of Lorraine (F3). FC calculated with F1, F2 and F3 will be point out respectively by $FC_{F1}$, $FC_{F2}$, and $FC_{F3}$.

**3.3 Statistical analysis and developing pedotransfer function**

Data have been analyzed with a macro Excel XLSTAT (version 5.0) [14]. After checking the normality of the series (constitute by measured and calculated values of FC) the hypothesis H0 had be verified, with two parametric tests (Student t test and z-test). These tests have been used to compare two by two the means of $FC_m$ (measured in laboratory), $FC_{F1}$ (calculated with F1), $FC_{F2}$ (calculated with F2) and $FC_{F3}$ (calculated with F3).

To identify, in the local context, the factors that best explain the values of FC, a multiple linear regression was made between $FC_m$ and soil basic parameters: particle size, organic matter and cation exchange capacity.

**4. Results and Discussion**
**4.1 Soil data characteristics**

Statistical analysis of data related to the studied 68 soil horizons (Table 2) shows high differences between the maximum values and the minimum ones, except the case of clay content. But differences between means and maximum values are not generally very high. According the mean content of clay and the related standard deviation, the studied soils are predominantly clay. CEC and OM contents are optimum for the local context.
The high variability of OM content can be explain by the variability of drainage context of lands in Niger River valley: in some sites, the drainage is deficient during long time by year, microbiological activity is low and there is OM accumulation; at the opposite, excessive drainage sites are observed with high activity of soil fauna and intense degradation of OM. The heterogeneous of alluvial material and the presence of different types of clay can explain the variability of CEC values.
$FC_m$ values are variable from 45.90 % of dry soil to 16.01 % with an arithmetic means about 29.80%. According these laboratory measurements, the relation between FC and PWP is :

$$\frac{FC\,m}{PWP\ m} = 1.6$$

**Table 2**: Statistics of used soil data (n= 68 samples)

| Statistic parameter | Clay content | Silt content | OM content | CEC | $FC_m$ | $PWP_m$ | $\frac{FCm}{PWPm}$ |
|---|---|---|---|---|---|---|---|
| | % dry soil | | | meq/100g de sol | % dry soil | | |
| Maximum | 79.50 | 44.40 | 5.86 | 45.90 | 45.90 | 27.10 | 5.50 |
| Minimum | 34.9 | 7.40 | 0.31 | 16.01 | 16.01 | 3.95 | 1.0 |
| Arithmetic mean | 57.20 | 25.34 | 1.50 | 29.80 | 29.83 | 18.90 | 1.6 |
| Standard deviation | 10.1 | 8.47 | 1.01 | 6.20 | 6.20 | 4.40 | 0.5 |

NB: Clay is noted A in original formula from French; OM (organic matter)/ MO (matière organique); CEC: Cation exchange capacity;
$FC_m$ : Field capacity measured in laboratory; $PWP_m$ : Permanent wilting point measured in laboratory

### 4.2 Measured and calculated values of FC

The curves representing FC values measured in the laboratory ($FC_m$) and those obtained with the formulas F1, F2, F3 (respectively $FC_{F1}$, $FC_{F2}$ and $FC_{F3}$) have the same shape (Figure.1). However, at the significance level alpha /2 = 0.025, the hypothesis of equal means is rejected in all cases (Table 3), ie the three tested formulas give different values of the FC and all the calculated values deviate from the values measured in the laboratory. F1 and F2 give FC values higher than the measured one and F3 give lower values.

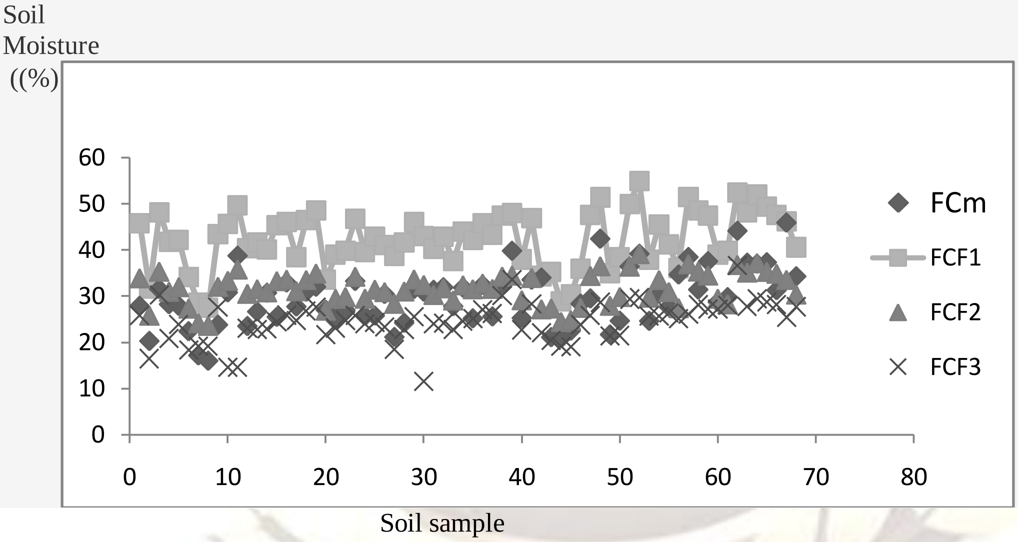


**Figure 1**: Comparison of measured and calculated values of FC (clay soil of Niger River loop in Mali)

$FC_m$ : Field Capacity measured in laboratory; $FC_{F1}$ : Field Capacity calculated with formula F1 ; $FC_{F2}$ : Field Capacity calculated with formula formula F2 ; $FC_{F3}$ : Field Capacity calculated with formula F3.

**Tableau 3** : Statistic comparison of measured and calculated values of FC (n = 68 samples)

| Soil moisture | Observation | Arithmetic Mean | Variance | Standard deviation | Comparaison according Test t et Test z |
|---|---|---|---|---|---|
| $FC_m$ | measured | 29,83 | 38,16 | 6,177 | a |
| $FC_{F1}$ | calculated | 42, 30 | 37,71 | 6,141 | b |
| $FC_{F2}$ | | 31,50 | 12,00 | 3,464 | c |
| $FC_{F3}$ | | 24,56 | 18,96 | 4, 354 | d |

NB : Different letter (a, b, c, d) show that the compared values are different.

Rejection of H0 in comparisons shows that the formulas used in this study are not suitable for alluvial soils of the Niger loop in Mali. This confirms that the application of such formulas outside their place of obtaining is generally a source of bias [7].

### 4.3 Relationship between FC measured and soil basic properties

According the correlation coefficient (R= 0.801) and regression characteristics given in Table 4, FC measured in the laboratory is correlated with clay content (noted A) and cation exchange capacity (CEC). This relationship is expressed by the equation below:

$$FCm = 0{,}412\ A + 0{,}196\ CEC + 1{,}998$$

**Table 4**: Statistics of the regression

| Paramètre | Coefficient | Erreur type | Statistique t | Probabilité |
|---|---|---|---|---|
| Constante | 1,988 | 2,685 | 0,740 | 0,462 |
| A | 0,412 | 0,0540 | 7,629 | <0,001 |
| CEC | 0,196 | 0,0884 | 2,219 | 0,030 |

The good relationship between the FC and the two soil basic properties (clay content and CEC) confirm the central place of these properties in soil hydrological comportment.
According the results of the present study, FC and PWP in clay soil of Niger River loop in Mali can be expressed as follow:

$$\mathbf{FC = 0{,}412\ A + 0{,}196\ CEC + 1{,}998}$$

$$\frac{\mathbf{FC}}{\mathbf{PWP}} = \mathbf{1.6}$$

## 5. Conclusion

This study confirms that pedotransfer functions are not adapted at all pedological context and all soil types. The equation proposed for Quaternary alluvium soils of the Niger loop, take into account their clay content and cation exchange capacity. It must be tested further on other soil types of Niger River valley were the development of irrigation is a high concern in Mali .

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