Scholars Journal of Agriculture and Veterinary Sciences OPEN ACCESS
Abbreviated Key Title: Sch J Agric Vet Sci
ISSN 2348–8883 (Print) | ISSN 2348–1854 (Online)
Journal homepage: www.saspublishers.com

Identification of Some Physico-Chemical Constraints of Hyperdystric Ferralsols Used in Rainfed Plateau: Case of Gagnoa in the West-Central of Côte d'Ivoire

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DOI: 10.36347/sjavs.2019.v06i07.001 | **Received:** 07.06.2019 | **Accepted:** 14.06.2019 | **Published:** 22.07.2019

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Abstract **Original Research Article**

A study was conducted in Gagnoa in West-Central of Côte d'Ivoire, in one of the main areas of production of plateau rice, with a view to identifying the physico-chemical constraints of soils that are causing yield declines. The test was carried out at the research station of the National Agronomic Research Center (CNRA) in Gagnoa. Soil samples were collected using the diagonal method and sent to the soil analysis laboratory for the determination of physical and chemical parameters. Soil chemical analyses included particle size, acidity, total organic carbon, organic matter content, total organic nitrogen, total and assimilable phosphorus, exchangeable cations, the capacity of cationic exchange (CEC), the sum of the exchangeable bases and the rate of saturation in bases of the adsorbent complex of the soil. The results showed that the soil horizons are compact with a high level of coarse elements (> 50%), consisting mainly of ferruginous nodules, gravel and quartz fragments in the 0-20 cm horizon. Soils are acidic (pH = 5.2) and poorly humidified with a low organic matter content (2.53%) and a cationic exchange capacity (CEC) of 28.6 $cmol.kg^{-1}$ very high. The sum of the exchangeable bases (1.53 $cmol.kg^{-1}$) and the saturation rate of the base adsorbent complex are also very low (5.35%). As a result, high concentrations of certain acidity-generating ions such as iron Fe^{2+} (177 $mg.kg^{-1}$) and manganese Mn^{2+} (205 $mg.kg^{-1}$) were observed in these soils. Organic amendments would be needed to improve the fertility of these soils and the productivity of the rice in Gagnoa area.

Keywords: Acidity, Adsorbent complex, rain rice, assimilable phosphorus, Organic matter.

INTRODUCTION

In Côte d'Ivoire, rice (*Oryza sp.*) is the main component of the population's diet, both urban and rural [1]. Rice has evolved from a basic cultural food in the western and central-western regions of the country, to an almost daily diet for Ivorians. It is the first cereal consumed, with an annual per capita share of 58 kg [2]. In terms of food production, rice ranks third after yam and cassava. Its cultivation accounts for more than half (57%) of the area under cereals [3] and employs more than 600,000 people [4]. This performance is ensured by the rainfed rice sector, which provides 80 % [5] of the estimated annual national rice production of 700,000 tons of bleached rice. However, the rice yields obtained in this cropping system are low [6], rarely exceeding 1.5 t ha^{-1} [7], [8], even if improved varieties are used [9]. This situation requires Côte d'Ivoire to import more than half of its consumption needs in rice [4], whereas according to [10], Côte d'Ivoire, because of its natural potential, is able to meet its consumption in rice. In order to compensate for these yield decreases, it appeared appropriate to identify the physico-chemical constraints of the soils which induce the low productivity of the soils in plateau rainfed rice farming in the region of Gagnoa, one of the main rice-producing areas of Côte d'Ivoire. The identification of these constraints will make it possible to make the necessary amendments to improve soil fertility and increase production of upland rice in order to contribute to the food security of rice in Côte d'Ivoire and preservation of the environment.

MATERIAL AND METHODS

Characteristics of the test site

The study was carried out at the research station of the National Agronomic Research Center

(CNRA) of Gagnoa, in the West-Central of Côte d'Ivoire, one of the main rice production areas of the country (altitude: 376 m, latitude: 7°44' N, longitude: 5°04'W) (Figure 1). The test site was a natural fallow of at least three years, during which time the soil did not receive any chemical or organic fertilizer inputs. The test is located on the top of the slope. The study site consists of *maximum Panicum* (Guinea Grass) and *Chromolaena odorata* (Lao Grass) vegetation. According to [11], the mean annual temperature is 27°C. The rainfall regime is bimodal, with one peak in June and the other in October. Rainfall is between 1400 and 1600 mm per year, with a mean annual of 1460 mm. In recent years, there has been a decline in rainfall in this region [12]. This could be a major constraint on agriculture in the region, and in particular on rainfed rice. The bedrock is essentially granitic, with intrusions of shale bands [13]. The soils observed are hyperdystric ferralsols [14], with a clay-sandy to clay texture [15].

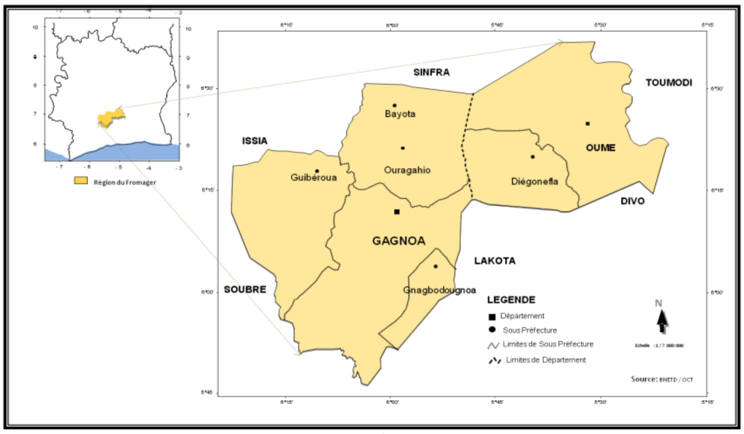

Fig -1: Map of study area

MATERIAL

The material used is the usual field study material used for the implantation of toposequences and the opening of soil pits, and then the usual laboratory study material.

METHODS

Morphopedological Soil Characterization Method

Soil morphological characteristics of the test were described using the Morphopedological method [16]. A toposequence was installed along the line of the largest slope, perpendicular to the level curves, to intersect the test and locate it along the toposequence. A pit was opened to confirm soil samples with the cylindrical tube. The soil horizons of the profile were described according to the following parameters: depth, texture, internal drainage, nature and rate of coarse elements, presence of roots, consistency of the horizon, color of soil.

Methods for Soil Sampling and Determination of Physico-Chemical Parameters of Soils

Soil samples were taken using the diagonal method in the 0-20 cm range using the cylindrical soil sampling tube [15]. Soil samples were dried and screened for chemical analysis in the laboratory. The chemical parameters were determined after analysis of soil samples at the soil and plant analysis laboratory of the National Polytechnic Institute Houphouët Boigny of Yamoussoukro. Soil chemical analyses included the following parameters:

- Soil size: it was determined on the basis of the Stokes Law, which made it possible to assess the composition of soils in silt, clay and sand;
- soil acidity: it was assessed by measuring pH, using an electronic pH meter in a soil/solution ratio of 1/2.5;
- total organic carbon of soil : determined by Walkley and Black (1934);
- organic matter content : it was obtained by multiplying the total organic carbon content of the soil by 1.72;
- total organic soil nitrogen: determined using the Kjeldhal method [17];
- total soil phosphorus: it was determined by the molybdenum blue colorimetric method and optical densities were read to the colorimeter, at the wavelength of 882 nm;
- soil assimilable phosphorus: it was determined by the Olsen method modified by [18], by colorimetry to molybdenum blue and optical densities were read at the wavelength of 882 nm;
- soil exchangeable cations, determined by the buffered ammonium acetate method at pH 7, and readings were made at wavelengths of 623 nm, 285 nm, 768 nm and 589 nm, respectively for Ca^{2+}, Mg^{2}+, K^{+}, and Na^{+};
- soil cation exchange capacity (CEC): this was determined using the Kjeldhal method.

RESULTS

Granulometric Characteristics of the Horizon 0-20 Cm

Chemical analyses of 0-20 cm horizon soils showed that the soil texture is sandy-clayey with 44.80% coarse sand and 22.85% clay (Table 1).

Morphological Characteristics of the Soils of the Study Site

Soils were slightly humic, with a sandy-clay texture (0-60 cm), clay-sandy (60-80 cm) and clay-silty or silty-clay (80-100 cm). They have good internal drainage and are movable at the level of the upper horizons (0-5 cm). However, these soils presented a compact horizon with a high rate of coarse elements (>50%), consisting mainly of ferruginous nodules, gravels and quartz fragments from the horizon 20 cm. The coloration of soils is located in the upper horizons in the range 10 YR (0-60 cm) with dark brown color. That of the intermediate horizons (60-80 cm) is located in the range 7.5 YR and dominated by the brown color. The soils in the lower horizons (> 80 cm) are located in the 2.5 YR range with the reddish color (Figure 2).

Physico-Chemical Initial Features of the Horizon 0-20 Cm

Chemical analysis carried out on soil samples prior to testing showed that soils have a pH of 5.2 with a total organic matter and nitrogen content of 2.53 and 0.14 $g.kg^{-1}$ of soil, respectively. Phosphorus levels were 650 $mg.kg^{-1}$ for total phosphorus and 31 $mg.kg^{-1}$ for assimilable phosphorus. The sum of exchangeable bases was 1.53 $cmol.kg^{-1}$, with a cation adsorbent complex saturation rate of 5.35% (Table 2).

Table-1:Initial soil size range 0-20 cm from the study site

Description of the elements					
	Clay	Fine silt	Coarse silt	fine sand	Coarse sand
Values (%)	22,85	6,20	7,37	17,57	44,80

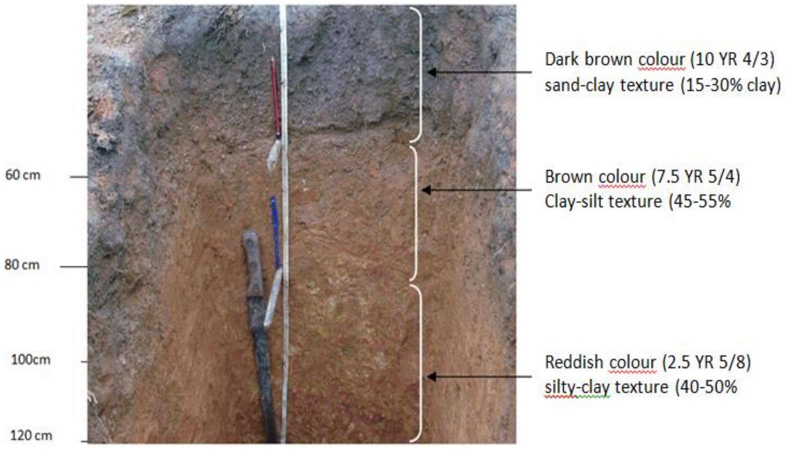

Fig -2: Main soil colorations of the open profile at the study site

Table -2: Initial physico-chemical characteristics of the 0-20 cm soil horizon

Parameters		Units	Values
pH		-	5.2
Organic carbon (C)		(g kg^{-1})	1.47
Total nitrogen (N)		(g kg^{-1})	0.14
Organic matter (M.O.)		(g kg^{-1})	2.53
C/N		-	10.5
Total phosphorus ($P_2O_{5\ total}$)		($mg.kg^{-1}$)	650
Assimilable Soil Phosphorus ($P_2O_{5\ ass.}$)			31
Capacity of Exchange Cationique (CEC)		($cmol.kg^{-1}$)	28.6
Exchangeable bases	Calcium (Ca^{2+})	($cmol.kg^{-1}$)	0.76
	Magnesium (Mg^{2+})	($cmol.kg^{-1}$)	0.69
	Potassium (K^{+})	($cmol.kg^{-1}$)	0.08
Trace elements	iron (Fe^{2+})	($mg.kg^{-1}$)	177
	Manganese (Mn^{2+})	($mg.kg^{-1}$)	205
	Zinc (Zn^{2+})	($mg.kg^{-1}$)	34
Sum of the exchangeable bases (S)		($cmol.kg^{-1}$)	1.53
Complex saturation rate adsorbent (V)		%	5.35

DISCUSSION

The proportion of coarse sands (44.80%) in the upper horizons of the study site soils is higher compared to the proportion of fine elements (silt and clay). This seems to be probably a consequence, not only of the topographical position (plateau) of the study site, but also of peasant farming practices. Indeed, these elements, which lead to the appearance of runoff and erosion, have removed the finest elements (silts and clays) and enriched the site's soil with coarse elements [19]. This is what would be at the origin of the formation of the compact horizon with a high rate of coarse elements (>50%) observed at shallow depths in the surface horizons of the study site thus contributing to reduce the fertility of the studied soils [20],[21]. According to [22], the presence of these coarse elements in the shallow depths of the soil could constitute cultural constraints, especially for the root development and water nutrition of rice plants.

The low soil pH values (5.2) of the upper horizons of the study site could be explained by the acidity of hyperdystric ferralsols as observed by [23]. According to these authors, the majority of rainfed rice soils are acidic hyperdystric ferralsols. These results are in line with those of [24], which showed that tropical soils are characterized in most cases by high acidity and high desaturation of the adsorbent complex into exchangeable cations (Ca^{2+}, Mg^{2+}, K+, Na^{+}), responsible for low soil productivity. According to [25], low pH values could lead to a number of harmful phenomenal to the plant growth of rice plants, such as reduced nitrification, phosphorus deficiency, aluminic and manganese toxicities and the high availability of some heavy metals. This would explain the low levels of nitrogen (0.14 $g.kg^{-1}$ of soil) found at the soil level of the study site as demonstrated by the work of [26] and [27] and which, however, is a limiting nutrient for rice production. According to this author, soils with nitrogen levels below 1 $g.kg^{-1}$ of soil are called nitrogen-poor soils. Therefore, the work of [28] has shown that pH values below 5.5 can lead to low uptake of nutrients such as nitrogen, Phosphorus and potassium are essential elements in the mineral nutrition of rice. Low pH values can also contribute to lower organic matter levels, damage soil structure as reported [28] and lead to lower soil fertility [29].

Low levels of organic matter observed at the surface within 0-20 cm of the soils of the study site, suggest low activity of micro-organisms and soil fauna [30] which, however, are favorable to the placing at the disposal of the plants, thanks to the mineralization of this organic matter, the mineral elements indispensable for the good development of the plants. According to [30], organic matter (MO) plays a fundamental role in the long-term maintenance of living soils. This is what makes some authors say, such as [31] that pH is a good indicator of the physico-chemical environment of a soil. These low levels of soil organic matter would also be linked to a loss of clay in the upper part of the soil profile, which would also result in a large proportion of the available organic matter. The low levels of assimilable phosphorus observed in the soils of the study site, despite high levels of total phosphorus, would be related to low pH values. Indeed, at low pH values, iron (Fe) and aluminum (Al) oxides and their hydroxides react with the assimilable phosphorus and form insoluble complexes, such as Variscite and strengite [31]. This would explain why the assimilable phosphorus levels (31 $mg.kg^{-1}$ of soil) found at the soil level of the study site were low. According to [26] and [27], soils with assimilable phosphorus levels in the range of 30 to 50 $mg.kg^{-1}$ are classified as phosphorus-poor soils. These low levels of assimilable phosphorus could also be explained by the acidity of the soils at the study site. Indeed, according to [32], aluminic toxicities appear and inhibit the absorption of nutrients, especially phosphorus in soils with low pH values (pH around 5 and especially below 5).

The low saturation rate of the adsorbent complex in exchangeable bases is thought to be due to the nature of the clay present in these soils. According to [32], kaolinite is the dominant clay in ferrallic soils. This clay is characterized by low chemical activity. Indeed, according to [33], this clay has a low exchange capacity, limited to the variable negative loads of the lateral fracture zones of the sheets. As a result, it confers a low fixation power to ferralitic soils [32], thus justifying the small sum of exchangeable bases observed at the soil level of the study site. This corroborates the findings of work on tropical soils in Burkina Faso [34]. According to [35] and [26], the base sum (1.53 $cmol.kg^{-1}$) of the soils at the study site, which is in the range of 1.5 to 3 $cmol.kg^{-1}$, is classified as low saturated soil. This could be the cause of the low values of the base saturation rates of the adsorbent complex of the soils of the surface horizons. Indeed, the base saturation rate of 5.49%, which is well below 50% would classify these soils as low saturated soils, as demonstrated by the work of [35].

High levels of iron and manganese have also been observed in soils. These high levels in soils could be explained by low pH values. Indeed, the low pH values have led to the presence in the medium of certain acidity-generating ions such as H^{+}, Al^{3+} and Fe^{3+} ions, which will occupy the fixing sites of basic cations such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} on the adsorbent complex, also justifying the small sum of exchangeable bases and consequently the low saturation rate in bases of the adsorbent complex of the soil, as found in the study despite high CEC values. This reflects the predominance of acidity-generating ions such as Fe^{2+}, Al^{3+}, H^{+}, Mn^{2+} ions over the other various cations of the adsorbent complex. The presence of these ions can play a major nutritional role, which would lead to the disruption of the mineral nutrition of rice plants, such as iron, which is also one of the main causes of ferrous toxicity [36].

The strong presence of iron is corroborated by the reddish color observed at the level of the entire profile of the soil horizon. These results are consistent with those of [37], which showed that the red color in a soil comes from the high free iron content.

CONCLUSION

This study consists on identifying the constraints that lead to yield declines in rainfed rice production in the Gagnoa region in central-western of Côte d'Ivoire. It has emerged that low soil fertility is one of the major constraints on the productivity of plateau rainfed rice in the Gagnoa region. Soils have compact horizons with a high rate of coarse elements (> 50%), consisting mainly of ferruginous nodules, gravels and quartz fragments in the horizon 0-20 cm. They are also acidic (pH = 5.2) and low humic with low organic matter content (2.53%) and exchangeable base amounts (1.53 cmol.kg-1) and very low adsorbent complex saturation rates (5.35%) This does not allow rice plants to have access to major nutrients for good rice productivity. Also, high concentrations of certain acidic-generating ions such as iron (177 $mg.kg^{-1}$) and manganese (205 $mg.kg^{-1}$) characterize the soils at the study site. Faced with these constraints, it is therefore appropriate to make the necessary amendments to improve soil fertility and the productivity of plateau rainfed rice in the Gagnoa region.

ACKNOWLEDGEMENTS

The authors thank the Strategic Support Program for Scientific Research (PASRES) and the National Agronomic Research Center (CNRA) for their collaboration and financial support. The authors also thank the research professors at the Jean Lorougnon Guédé University in Daloa for their contribution to the writing and formatting of the manuscript.

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