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Original Research Article

Physico-Chemical Characterization of Soils for the Promotion of Precision Agriculture in Irrigated Rice Cultivation in the Zio Valley in Togo

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Abstract: To sustainably improve rice production in the Zio valley, this study characterized the soils of the developed area. More specifically, the study: (i) determined the Physico-chemical properties of soils and (ii) analyzed the impact of rice cultivation on these chemical parameters. Thirty-six (36) fields of producers were selected and distributed in the 4 villages of the irrigated perimeter: 10 in Kovié, 9 in Mission Tové; 9 in Ziwonou, and 8 in Assomé. The samples were manually collected at a depth of 0-30 cm and analyzed at the soil laboratory of the Togolese Institute of Agronomic Research (ITRA). Physically, the soils are sandy-loamy in Kovié (100%), sandy-loamy in Mission Tové (56%), clayey in Assomé (57%), and Ziovonou (78%). Chemically, the soils are acidic with an average pH of 5.57. They present low (0.89%) and moderate (1.3%) limitation levels respectively for nitrogen and organic matter, very severe for assimilable phosphate (2.3±0.16 ppm), and cation exchange capacity (4.64±0.26 meq/100g of soil) and severe for exchangeable potassium (0.14±0.01 meq/100g of soil). The study also showed a significant decrease in the quantities of Nitrogen, Carbon, Potassium exchangeable, and cation exchange capacity respectively of 57%, 72%, 56%, and 85% compared to 1964. The adoption of cultural practices having a less negative impact on the chemical characteristics of the soil combined with an update of the adapted fertilization formulas become imperatives to ensure sustainable exploitation of the perimeter.

Keywords: Soil, fertility indicators, rice cultivation, Physico-chemical properties.

INTRODUCTION

Soil is one of the determining components of agricultural production. Three main roles are attributed to the soil in plant production processes: (i) essential source of minerals on which plants feed (ii) capacity to eliminate excess water by percolation and build up the optimal stock through clay and organic matter to the benefit of plants and (iii) facilitation of air circulation constituting an ideal living environment for plants and microorganisms (Kintche, 2011). There is therefore no doubt that the implementation of programs to improve agricultural production must go through a better knowledge of the state of cultivated soils to better plan the external inputs of fertilizers, whether chemical or organic.

In Togo, programs to improve agricultural productivity focused mainly on improving the availability of fertilizers to producers and on popularizing the pan-territorial recommendation of a fertilization formula for all cereal crops. This practice, which does not consider the real needs of the crops, nor the state of the fertility of the soil, does not allow producers to obtain economically acceptable yields.

In the irrigated perimeter of the Zio valley, data on the chemical state of the soil are almost non-existent over the last two decades. Indeed, most of the data go back to 1964 at the beginning of the development of the irrigated perimeter. This lack of data on the soils of the perimeter remains detrimental to rice producers. Indeed, despite heavy investments for the development of the perimeter, rice yields in the irrigated perimeter of the Zio valley remain low. This is potentially due to a decline in the level of soil fertility (Kombienou *et al.*, 2015) . In addition, the national rice

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development strategy 2018-2028 has identified four main factors including climatic hazards, insufficient water control, low adoption of new production techniques and the decline in the level of fertility. Soils to explain the country's poor performance in rice production.

Indeed, if in irrigated perimeters, the problems of water and the adoption of new farming practices can be better controlled, the practice of intensive rice cultivation on these perimeters can become a factor in the degradation of soil fertility.

It is with a view to providing an answer on the current level of fertility indicators that this study was carried out. Its objectives are to (i) determine the Physico-chemical properties of soils and (ii) analyze the impact of rice cultivation on these chemical parameters.

1. MATERIALS AND METHODS

Study Area

The study was carried out in a peasant environment in the irrigated perimeter of the Zio valley where irrigated rice cultivation has been practiced since 1965. This area enjoys a Sudano-Guinean climate with an average annual rainfall of about 800 mm (Meertens, 2003) . This perimeter of an area of 660 ha including 373 ha developed for irrigated rice cultivation extends over four villages including Kovié , Mission- Tové , Assomé and Ziovonou with respectively 174 ha, 92 ha, 67 ha and 40 ha developed.

Soil Sampling and Preparation of Composite Samples

A total of thirty-six (36) producer fields with an area of one (01) ha each were selected for the study, including 10 in Kovié , 9 in Mission Tové , 9 in Ziovonou and 8 in Assomé . Each field is made up of 16 traps with an area of 625 m^2. A soil sample was taken from each plot before plowing at a depth of 0 - 30 cm to constitute a composite sample of 1 kg per field.

The processing of the samples before the analyzes consisted of drying at room temperature in the laboratory and then separating the coarse elements from the fine earth, using a 2 mm round mesh sieve. The treated samples were analyzed in the "Soil-Water-Vegetals-Fertilizers" laboratory of the Togolese Institute for Agronomic Research (ITRA). The analyses focused on the physical and chemical aspects of the soil.

Determination of the Physical Characteristics of Soils

The particle size analysis was carried out by the Robinson Pipette Method according to standard **NF X** 31-107 (Buol *et al.*, 2011) . Five (05) particle size classes were determined according to the size of the elements**:** clays (0 to 2 micrometers), fine silt (2 to 20 micrometers), coarse silt (20 to 50 micrometers), fine sands (50 to 200 micrometers) and coarse sands (200 to 2000 micrometers).

R software, in particular the " soiltexture " package, was used to determine soil textures using the USDA-NCSS texture triangle.

Characterization of Chemical Indicators of Rice Soil Fertility

The main chemical parameters analyzed were: total carbon, organic matter, total nitrogen, assimilable phosphorus, cation exchange capacity (CEC), exchangeable bases (Ca2+, Mg2+, Na+ and K+), electrical conductivity and pH (water and KCl).

The pH was determined using the pH meter according to the NF ISO 10390 standard (Staff, 2017) . For carbon, the colorimetric method was used according to the method of (Walkley *et al.*, 1934) and the total nitrogen was determined according to the Kjeldhal method (Hillebrand *et al.*, 1953). Bray 's method 1 was used to determine available phosphorus (Dickman *et al.*, 1940) . The cation exchange capacity was measured by the Metson method according to the AFNOR NF X31-130 standard (Saragoni *et al.*, 1992) , while the contents of exchangeable bases are measured after extraction with an ammonium acetate solution normal and neutral (AFNOR X 31-108).

The chemical analysis data were compared with the reference values used by the "Sol-Water-Vegetals- Fertilizers" laboratory of the Togolese Institute for Agronomic Research (ITRA) to establish a chemical characterization of the soils of the irrigated perimeter of the valley from Zio (Table 1).

Table 1: Interpretation grid of ITRA soil chemical analysis results for Togo

Settings chemicals	Very poor	Poor	Medium	Rich	Very rich
MO (%)	<0.7	0.7-2	2-3.5	3.5-4.5	>4.5
N (%)	< 0.05	0.05-0.1	0.1-0.2	0.2-0.3	>0.3
P. ass. (mg/kg)	< 8	8-15	15-23	23-30	>30
K (meq /l00g) of soil	<9	9-13	13-17	17-20	>20
Sum (S) (meq /l00g of soil)	<2	2-5	5-10	10-15	>15
Base Saturation (%)	<15	15-40	40-60	60-90	90-100
CEC (meq /l00g of soil)	< 5	5-10	10-25	25-40	>40

Source : https://fertitogo.tg/fmap

Evaluation of the Chemical Fertility Limitations of the Soils Studied

The class assessment criteria for limiting fertility levels used by (Issah *et al.*, 2018) were used to study the level of soil fertility. The definition of the classes is based on limitations imposed by specific characteristics as shown in Table 2.

- Class I: low limitations, referring to situations that could slightly reduce yields without however imposing special cultivation techniques.
- Class II: moderate limitations, referring to situations that cause a greater decrease in yields or the implementation of special cultivation techniques. These limitations do not affect profitability;
- Class III: severe limitations, referring to situations that cause a decrease in yields.
- Class IV: very severe limitations, referring to situations that no longer allow the use of the land for a specific purpose.

Table 2: Grid for determining soil fertility classes (Sys *et al.*, 1976)

Restrictions	Weak	Moderate	severe	Very severe
MO (%)	> 2	1-2	< 1	< 0.5
N (%)	> 0.08	0.045-0.08	< 0.045	< 0.03
P. ass. Bray 1	> 20	10-20	< 10	< 5
K (meq /l00g of soil	> 0.4	0.2-0.4	< 0.2	< 0.1
Sum (S) (meq /l00g of soil)	> 10	5-10	< 5	< 2
Base Saturation (%)	> 60	40-60	< 40	< 15
CEC (meq /l00g of soil)	>25	10-25	< 10	< 5

2. RESULTS

2.1. Sol Texture

The particle size analysis of the soil samples globally shows a predominance of sandy-loamy soils in Kovié (100%) and loamy-sand soils in Mission Tové (56%). However, the soils are more clayey in Assomé and Ziovonou with respectively 57% and 78% clay.

Table 3: Soil texture of the Zio irrigated perimeter

Villages	Number of samples	Texture	Frequency	Percentage
Kovie	10	Sandy-loam	10	100%
Mission Tove	9	Sandy-loam	2	22%
		Loamy-sand	5	56%
		clay	1	11%
		Sandy Clay Loam	1	11%
Ziovonou	9	clay	7	78%
		Loamy-sand	2	22%
Assomé	7	Clay	4	57%
		Clay -loam	3	43%

2.2- Evaluation of the Acidity of the Soils Studied According To the Villages

The analysis of the pH of the samples (Table 4) shows an acidity of the soils of the irrigated perimeter of Zio. On average, the soils of Ziovonou are acidic while those of the other three villages are not very acidic.

Table 4: Soil water pH of the irrigated perimeter

Villages	average pH	Acidity
Kovie	5.54± 0.16a	Little acid
Mission Tove	5.80± 0.07a	Low acid
Ziovonou	5.1 7±0.11b	acid _
Assomé	5.79± 0.07a	Low acid
Mean	5.57 ±0.07	Low acid

Average soil pH values by villages are accompanied by the standard error

2.3- Analysis of the Current State of Chemical Fertility of the Soils of the Irrigated Perimeter of Zio

The chemical analysis of the soil samples shows overall very critical fertility levels of the soils of the irrigated perimeter of Zio. The various chemical indicators are below critical thresholds.

The organic matter content is less than 2%, varying on average between 1.07% in Kovié and 1.63% in Assomé with a C/N ratio of less than 15 (Table 5). The cation exchange capacity varied between 4 and 5 meq /100g of soil. Similarly, the soils are poor in nitrogen, assimilable phosphate and exchangeable potassium. The rate of nitrogen varies from 0.07% to 0.12%, while the level of recorded assimilable phosphorus varied from 1.94 to 3.75 mg/kg and potassium between 0.1 and 0.25 meq. /100g of soil. The analysis of the level of soil saturation in bases shows rates lower than 15% indicating a very low level of reserve in the soils. These are heavily leached.

In terms of the level of chemical limitation, the soils analysed show low to moderate levels of limitation for organic matter, nitrogen, and carbon and severe to very severe limitations for assimilable phosphorus, potassium, the exchange capacity cationic.

Table 5: Level of limitation of the chemical elements of the soils of the rice-growing perimeter of the Zio valley

Chemical parameters	**Kovie**	**Mission Tove**	**Ziowonou**	**knocked out**	**Mean**
Organic matter	1.07±0.2b (M)	1.13±0.3b (M)	1.48±0.3A (M)	1.63±0.4a (M)	1.30 ±0.06 (M)
Carbon (C)	0.62±0.15b	0.66±0.17b	0.83±0.21a	1.07±0.24a	0.76 ±0.03
Total nitrogen (N)	0.07±0.02b (M)	0.07±0.02b (M)	0.11±0.03a (F)	0.12±0.02a (F)	0.89 ±0.01 (F)
C/N ratio	9.37±2.33ns	10.43±3.28ns	8.12±2.49ns	8.65±0.99ns	8.99 ±0.43
Available phosphate	1.94±0.76b (TS)	2.32±0.89b (TS)	2.09±0.63b (TS)	3.75±0.69a (TS)	2.44±0.16 (TS)
Potassium K (meq /100g of soil)	0.10±0.04b (S)	0.11±0.01b (S)	0.16±0.08ab (S)	0.24± 0.02a(M)	0.14 ±0.01 (S)
Sum of bases (S) (meq /l00g of soil)	0.18±0.04b (TS)	0.27±0.17ab (TS)	0.31±0.15ab (TS)	0.40±0.07a (TS)	0.27 ±0.02 (TS)
Base Saturation (%)	4.85±1.49ns (TS)	7.10±4.41ns (TS)	5.22±2.01ns (TS)	8.49±2.96ns (TS)	6.25 ±0.52 (TS)
CEC (meq /l00g of soil)	3.99±1.21ns (TS)	4.10±1.75ns (TS)	5.47±1.38ns (S)	5.20±1.43ns (S)	4.64±0.26 (TS)
Class	IV	IV	IV	IV	IV

F=weak, M=moderate, S= severe, TS=very severe, the means are accompanied by the standard error and the discrimination of the means is made horizontally; ns=not significant

2.4. Analysis of the Chemical Evolution of the Soils of the Perimeter

The values of the main chemical parameters were compared with the data obtained by (Millet *et al.*, 1964). A significant decrease in the quantities of exchangeable Nitrogen, Carbon, Potassium and the cation exchange capacity of 57%, 72%, 56%, 85% respectively (Table 6) emerges.

Table 6: Evolution of the chemical parameters of the soils of the irrigated perimeter of the Zio valley

Soil chemical parameters	**Years**	
	1964*	**2020**
C arbon (c)	2.70±0.68a	0.756±0.03b
Nitrogen (N)	0.21±0.06a	0.09±0.05b
Report (C/N)	12.53±0.28a	8.99±0.43b
pH _	5.7±0.20ns	5.57±0.07ns
Ca lcium (Ca $^{2+}$)	13.46± 3.08A	0.03±0.01b
Magnesium (Mg $^{2+}$)	7.03± 1.34A	0.06± 0.01b
Potassium (K+)	0.33± 0.17a	0.146± 0.02b
Sodium (Na +)	0.37± 0.08a	0.030± 0.003b
Cation exchange capacity (CEC)	30.12± 6.08A	4.646± 0.26b

The means are accompanied by the standard error and the discrimination of the means is done horizontally; ns=not significant

***Source:* (Millet *et al.*, 1964)**

3. DISCUSSION

The granulometric analysis of the soils of the Zio valley showed a predominance of the sandy-silty texture. Although rice adapts to a wide variety of soil textures, the sandy tendency of the soils of the Zio irrigated perimeter could represent a major obstacle to the development of rice cultivation. Indeed, the sandy structure is less favourable to the retention of nutrients and water, unlike soils richer in clays (Zro Bi *et al.*, 2012) . For (Vanlauwe *et al.*, 2011) , soils with a sandy-loamy texture are excellent and more suitable for crops and therefore for rice.

Chemically, the soils are acidic and have moderate limitations for organic matter, but very severe for ionic complex. The overexploitation of the land with the intensive use of chemical fertilizers on the irrigated perimeter can be blamed for the evolution of the acidity of the soil and the low level of the cationic load. According to (Guo *et al.*, 2010) , soil acidification is largely related to the repeated and excessive application of nitrogen fertilizers. According to their studies, the pH values have decreased between 0.13 and 0.32 units in 20 years of farming, whereas naturally the evolution of pH is very slow in the soil.

According to (Kopittke *et al.,* 2017) , increased soil acidity reduces plant growth and crop yields. This reduction in plant growth occurs through multiple mechanisms, grouped as the acid soil infertility complex. Soil acidification is also implicated in the accumulation of toxic metals in food (Zhao *et al.,* 2015) . In terms of rice production, it is however possible with better water control to attenuate the effects of pH on the availability of nutrients for the plants.

Regarding organic matter, the analysis values obtained are low with a moderate level of limitation. The organic matter rate is less than 2%. The first soil characterization studies of the irrigated perimeter of the Zio Valley carried out by Lamouroux, (1961) and (Millette *et al.*, 1964) showed on the one hand a rate of organic matter for the hydromorphic soils of the Zio valley varied between 3.5% and 4% (Meertens, 2001) and on the other hand a C/N ratio of 12.53 against 8.99 in 2020. This decrease in organic matter and the acceleration of mineralization can be explained by cultivation practices less concerned with the conservation of soil quality. Since the start of irrigated cultivation, rice production has intensified in the perimeter without the implementation of corrective or preventive measures aimed at improving the quality of the soils of these rice fields. For example, it is noted that most producers burn the straw after harvest to facilitate plowing with motorized cultivators. Indeed, the removal of harvested products without replacing the nutrients exported by the crops leads to a continuous decline in soil fertility (Mills *et al.,* 2004) .

The assimilable phosphorus contents of the soils vary from 1.9 to 3.75 ppm which is very low and corresponds to a very severe limitation according to the classification (Table 1). Regarding potassium, the class of limitation ranges from moderate to severe. This confirms the very extensive state of soil degradation in the irrigated perimeter of the Zio valley. Thus, beyond the use of inputs aimed at improving the production values in the perimeter, it is becoming increasingly urgent to implement corrective and/or soil conservation measures to ensure rice production. sustainable both economically and agronomically.

CONCLUSION

This study has shed light on the very degraded state of the soils in the rice-growing area. Overall, the soils of the irrigated perimeter are acidic and very poor in organic matter. The levels of other soil chemical indicators (CEC, N, assimilable P, exchangeable K) are very critical. These low levels of soil fertility indicators would be mainly due to the intensive monoculture of rice carried out for more than 50 years. Soils are rarely left to rest and crop residues are rarely incorporated into the soil.

This situation could become an obstacle to the efficiency of cultivation practices in the perimeter and deserves particular attention to identify the best practices to improve the levels of the various chemical indicators. While waiting for studies to identify suitable practices that promote the maintenance of soil fertility at acceptable levels, it is important to minimize the removal or burning of biomass on production sites. Moreover, it is important, in view of the results of this study, to update the various recommendations in terms of fertilization.

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