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Research Article

Physicochemical Characteristics and Soil Suitability for Semi-Irrigated Rice Cultivation in The Tandjile Province of Chad

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Abstract

A study carried out in Tandjilé-Est, a region located in the South-Central part of Chad, aimed to examine the pedoclimatic and socio-economic parameters that cause the variability of rice yield (Oryza sativa) in an irrigated system. Three sites in the Kabalaye canton were chosen for soil sampling; these are Satégui, Mala and Djongo; in each site, five soil samples were taken. To assess the suitability of irrigated areas, two assessment methods were used on the two types of soils in the study area, including a Vertisol and a Planosol. This assessment shows that Vertisols are suitable for growing rice in an irrigated system, while Planosols are marginal. The main limitation in Planosols is the low nutrient content. To overcome this problem, it is necessary to improve the management of field fertility, rotate crops, and train producers in integrated fertility management and provide them with credit and adequate agricultural equipment.

Introduction

Most of sub-Saharan Africa is classified as arid and semi-arid (Savadogo, 2018). These areas are highly vulnerable to climate variability and change because they are characterized by factors that are conducive to soil degradation (Niasse *et al.*, 2004); agricultural productivity remains low (IFPRI, 2016). Low productivity may be due in particular to the continuous degradation of soils, climatic hazards and demographic pressure (Tittonell and Giller, 2013). In some of these countries, the presence of large rivers such as the Chari and the Logone in the case of Chad makes it possible to enhance water resources by creating large irrigated areas (Assoué, 2014). Many of these irrigated areas are experiencing a drop in yield due to the effects of climate change, the decline in the fertility of cultivated land, endogenous crop factors and the social conditions of producers (Issiné *et al.*, 2023). The decline in yields in flooded areas exposes local populations to a situation of chronic food insecurity. Low productivity of irrigated rice is also due to poor land management, climate change and population growth, which aggravate soil nutrient depletion (Jones, 2009). In Chad, agriculture is highly dependent on climatic and soil conditions and on the socio-economic conditions of farmers (Issiné, 2023); the Sudanian zone, which provided the bulk of cereal production, seems to encounter many difficulties due to climatic variability (Naitormbaidé, 2007). Due to the difficulties related to climatic hazards, semi-irrigated cultivation is proving to be an alternative to the problem of food self-sufficiency which is very far from being achieved in rainfed cultivation alone. Unfortunately, the latter has also been experiencing yield instability for some time due to monoculture systems and low use of inputs.

Methods and Materials

Presentation of the Study Area

The study area is located at 9°23′24″ to 9°25′37″North latitude and 16°17′5″ to 16°18′0″ East longitude. The relief is relatively flat. The soils are formed of several layers of sandstone separated by sands or clays. The main pedogenic processes are ferrallitization, ferruginization, hydromorphy, vertisolization, carbonation and halomorphy (Pias, 1970). The region is covered by herbaceous vegetation with a dominance of species such as *Zizyphus mauritiania*, Khaya senegalensis, *Borassus aethiopium* and *Hyphaene tebaeca*. Tandjilé enjoys a Sudanian climate with an annual rainfall ranging from 1000 to 1200 mm. The hydrographic network is made up of the Logone River and the Tandjilé River.

Methods

The study was conducted in three randomly selected villages; fifteen soil samples were taken, five per village. The first group is that of the Satégui rice plot, the second group is made up of soils from Mala and the last group is made up of soils from Djongo (Table 1). To assess the suitability of the land for irrigated rice cultivation, two soil profiles were made in Sategui, one on a hydromorphic soil and the other on a Vertisol. Then, the climatic data from 1991 to 2021 were taken from the Chad meteorology service for the pedoclimatic assessment. The samples collected after sieving composed of more or less fine soil were used to determine the texture, pH, electrical conductivity, organic matter, total nitrogen, assimilable phosphorus, cation exchange capacity (CEC) and exchangeable cations.

Pedoclimatic Assessment of Semi-Irrigated Rice Cultivation According to FAO

The parametric method is the one we used. In this method, a numerical value or rate, between 0 and 100, was assigned to each characteristic or property. The value reflects the effectiveness or efficiency of the characteristic or property in meeting the requirement of the selected use. The characteristic or quality was all the more satisfactory as its parametric value approached 100. Thus, the pedoclimatic assessment will consist of first making a climatic assessment and then the soil assessment.

Table 1: Geographic coordinates of sampling points

Points	Latitudes	Longitudes	Altitudes (m)
Djongo 1	9°29'596"	16°15'719"	363
Djongo 2	9°28'734"	16°16'215"	361
Djongo 3	9°29'546"	16°15'738"	364
Djongo 4	9°29'590"	16°15'782"	364
Djongo 5	9°28'676"	16°16'218"	361
Mala1	9°29'611"	16°15'615"	366
Mala 2	9°29'610"	16°15'571"	363
Mala 3	9°28'703"	16°16'151"	360
Mala 4	9°29'582"	16°15'685"	363
Mala 5	9°29'595"	16°15'735"	363
Satégui 1	9°31'619"	16°14'375"	355
Satégui 2	9°31'731"	16°14'473"	355
Satégui 3	9°31'668"	16°14'415"	358
Satégui 4	9°31'626"	16°14'405"	358
Satégui 5	9°31'566"	16°14'411"	358

Climatic Suitability Evaluation

Climatic characteristics are divided into rating groups with respect to the crop and its climatic requirements (Sys *et al*., 1991). The evaluation groups listed are: rainfall, temperature, relative humidity and insolation during the growing period from June to October. A parametric value is assigned to each characteristic of the climate and a climate index Ic calculated after Khiddir (1986) is obtained according to the following formula:

Ic = Rmin x $\sqrt{\frac{A}{100} x \frac{B}{100} x \ldots}$, Rmin= smallest parametric value. A, B,… = other parametric values. If Ic is between 25 and 92.5, it will be adjusted from Sys *et al*. (1991) by the following equation:

Ic (aj) = 16.67 + 0.9 Ic, Ic (aj)= adjusted climate index, Ic= unadjusted climate index.

If Ic <25, the equation becomes: Ic (aj) = 1.6 Ic.

Soil Evaluation

Soil evaluation was carried out in accordance with the table of soil and climate characteristics of Sys *et al*. (1993). Parametric values were attributed to each soil characteristic and the formula below was used to determine the calculated land index:

I_T = Ic = Rmin x $\sqrt{\frac{A}{100} x \frac{B}{100} x \ldots}$. where I_T is the land index, Rmin is the minimum parametric value, A, B,… are the other parametric values. The suitability class corresponding to the land index will be preceded by a letter showing the most limiting factors such as: t = for topography, c = for climate, w = drainage, s = texture and structure, f = fertility and n = salinity.

Results and Discussion

Climate Indicators

The results obtained show that the growth period or vegetative period goes from April to November; in fact, this period is the time interval during which the climate allows rain-fed plant production (Table 2).

Description of the Two Soil Profiles

The first profile consisting of high clay contents dug in Stagui is a chromic vertisol according to the WRB (1998), a vertisol with zero drainage according to the CPCS (1967) and a hapluserts according to Soil surveil Staff (2003). The second profile dug in the same village, is a Eutric Planosol according to ISSS /FAO/ISRIC WRB (2014), an Aqualf according to U.S. Taxonomy (Soil Survey Staff, 2003) and a degraded planic soil according to CPCS (1967).

Physicochemical Characteristics

All the collected samples are acidic with pH ranging from 5.4 to 6.2; the sums of exchangeable bases are low (Table 3). Nitrogen, phosphorus and potassium also have low values. Sand contents reach 71% in Sategui and clay contents range from 22 to 34% and silt contents vary from 7 to 51%; in Mala and Djongo, sand contents are lower and never reach 40%; likewise, silt and clay contents are relatively higher than those in Sategui. In general, CEC values are very high in all three sites; the values of the sums of exchangeable bases vary from 2.66 to 9.25 mEq/100g. The high CEC values could explain the predominance of type 2:1 clays, contrary to the results obtained by Basga *et al*. (2018) in Cameroon. The organic matter rate is also low, but organic matter plays a physical role in the soil for cohesion, structure, porosity, retention or storage of water (Hubert and Schaub 2011); It is also a potential indicator of the sustainability of cropping systems since it plays an important role in many edaphic properties that partly determine plant production and soil and water conservation (Valery and Pansu, 2022). The very low levels of nitrogen, phosphorus and other nutrients are explained by the low level of organic matter (Abdou *et al*., 2022); Here, the acidity of the sampled soils could be explained by the absence of limestone in the soils, in addition the roots of the cultivated plants can also secrete acids which lower the pH (Duchaufour, 1977). Similarly, phosphorus deficiency in the soil is explained by the fact that its fixation on the clay-humic complex depends on the percentage of organic matter, the percentage of clay, the pH and the calcium (Luciens *et al*., 2012).

Table 2: Monthly average climate data from 1991-2021

Month	Tmin (°C)	Tmax (°C)	P (mm)	HR (%)	Wind (m/s)	Insolation (hr/j)	Radiation (Mj/m²/j)	ETP (mm/j)
January	17,5	32,0	0	24	3,6	9,5	31,6	7,87
February	18,0	37,0	0	25	2,8	9,7	35,1	8,85
March	23,0	41,2	6,2	29	4,2	9,2	36,0	8,58
April	26,3	41,5	67,4	30	1,2	8,4	35,1	9,67
May	27,2	39,0	90,3	43	1,5	9,4	36,4	9,00
June	26,0	36,0	172	53	2,1	8,7	36,4	7,58
July	24,5	35,0	185,1	65	3,2	8,5	35,0	6,43
August	24,8	33,0	246,8	72	2,6	7,9	34,0	8,32
September	24,0	33,7	191,9	63	1,7	8,0	33,2	5,50
October	23,0	35,9	73,6	54	2,1	9,0	32,1	5,60
November	21,0	37,2	4,00	39	2,7	9,4	32,0	6,32
December	17,0	33,1	0	28	1,9	9,3	31,0	6,45

Tmin: minimum temperature; **Tmax:** maximum temperature; **P**: rainfall; **HR:** relative humidity; **ETP:** evapotranspiration

Table 3: Analyses of physicochemical properties

Site	Sand %	Clay %	Silt %	N %	OC %	OM %	Exchangeable cations (mEq/100g of soil)				pH	pH_{KCl}	EC (1/5) ms/cm	P (ppm)	CEC pH7	C/N	SBE
							Ca	Mg	K	Na							
Satégui1	71	22	7	0.21	2.01	3.46	0.64	2.00	0,38	0.36	6.2	4.7	0.08	0.10	25.80	9.47	2.66
Satégui2	31	31	39	0.18	1.06	1.82	1.2	3.28	0,38	0.36	5.9	4.3	0.02	0.24	40.30	5.71	4.50
Satégui3	17	32	51	0.19	2.14	3.70	1.76	3.12	0,38	0.36	5.9	4.4	0.03	0.18	51.40	1.,48	4.90
Satégui4	54	23	23	0.21	2.21	3.81	3.04	2.24	0,38	0.36	6.0	4.8	0.06	0.20	58.60	1.,31	5.30
Satégui5	24	34	43	0.25	2.42	4.17	3.84	2.32	2,32	0.21	5.8	4.3	0.02	023	60.40	9.73	6.22
Mala1	40	27	23	0.18	1.53	2.64	0.64	4.64	4,33	0.36	5.9	4.5	0.02	0.14	65.60	8.68	5.43
Mala2	23	34	43	0.19	2.21	3.81	0.48	4.00	4,33	0.21	6.0	4.5	0.02	0.24	52.80	11.93	4.63
Mala3	19	36	45	0.25	2.89	4.99	0.96	1.52	4,33	0.21	6.1	4.6	0.05	0.16	72.48	11.60	2.61
Mala4	29	28	43	0.24	2.01	3.46	2.32	1.36	4,33	0.21	6.0	4.5	0.03	0.23	40.64	8.33	3.81
Mala5	22	31	37	0.24	2.14	3.70	4.16	4.96	4,33	0.21	5.9	4.5	0.07	0.22	88.56	8.88	9.25
Djongo1	27	32	41	0.23	2.35	4.05	1.36	3.44	4,33	0.36	5.8	4.4	0.02	0.25	70.24	10.29	4.95
Djongo2	20	35	45	0.23	2.89	4.99	0.56	3.52	4,33	0.36	6.0	4.7	0.05	0.18	60.00	12.84	4.23
Djongo3	24	29	47	0.17	2.01	3.46	0.96	4.08	4,33	0.36	6.0	4.4	0.02	0.23	51.60	11.59	5.19
Djongo4	19	32	49	0.25	2,69	4,64	1,36	3,04	4,33	0,36	5,9	4,6	0.03	0.24	63.52	10.87	4.55
Djongo5	15	31	54	0.19	2,42	4,17	0,48	4,00	4,33	0,36	5,4	4,3	0.03	0.20	48.24	12.88	4.63

OM: organic matter; **SBE:** Sum of exchangeable bases.

Pedoclimatic Assessment

The assessment is done through an assessment of climatic requirements and an assessment of other requirements (Table 4 and 5). The climatic assessment is done for the period from April to October. During this dry season, it appears that the climate is very suitable for the production of semi-irrigated rice with a climate index of 80 and a class S1. The soil used (Planosol) is unsuitable for rice cultivation, its sandy texture is the main limitation. To get around this situation, organic inputs are required combined with mineral fertilizer as proposed by Sedogo (1993) and Issiné (2023). If possible, the soil should be left fallow or other crops, especially legumes such as beans, should be introduced into the system (rotation). The soil unit used (Vertisol) is suitable for rice cultivation but the very clayey texture represents the main limitation. It is difficult to get around the situation but we can try to avoid the excessive use of heavy machinery such as tractors that further destroy certain parameters.

Table 4: Soil evaluation of semi-irrigated rice cultivation on a Vertisol

Features	**Values**	**Classes**	**Limitations**	**Parametric values**
Topography (t)				
Slope (%)	1%	S1 – 1	1	95
Humidity (w)				
Flooding	F0	S1 – 1	1	100
Drainage	Bon	S1 – 1	1	100
Physical characteristics of the soil (s)				
Texture/structure	SiCl	S2	2	85
Soil depth (cm)	160	S1-0	0	100
Coarse fragment (%)	0,2	S1-0	0	100
$CaCO_3$	0	S1-0	0	100
Gypsum (%)	0	S1-0	0	100
Soil fertility (f)				
Apparent clay CEC (mEq /100 g)	49	S1-0	0	100
V (%)	62,3	S1-1	1	91
SBE (Cmol/Kg)	3,7	S1-1	1	79
CO (%)	2,5	S1-0	0	100
pH_{eau}	5,8	S1-1	1	90
Salinity and sodicity (n)				
ECe (ds/m)	0,04	S1-0	0	100
ESP	0,6	S1-0	0	100
Calculated Earth Index		**S2**	**2**	**42,7**

Table 5: Soil evaluation of irrigated rice in semi-irrigated on a Planosol

Features	**Values**	**Classes**	**Limitations**	**Parametric values**
Climatic characteristics				
Precipitation (mm)	128+Irri	S1-0	0	100
Temperature (°C)	36,5	S1-1	1	85
Relative humidity (%)	72	S1-1	1	90
n/N	0,60	S1-1	1	80
Soil characteristics				
Topography (t)				
Slope (%)	1%	S1 – 1	1	95
Humidity (w)				
Flooding	F0	S1 – 1	1	100
Drainage	Bon	S1 – 1	1	100
Texture/structure	CL (SC)	S1 – 1	1	95
Soil depth (cm)	120	S1 – 0	0	100
Coarse fragment (%)	0	S1 – 0	0	100
$CaC0_3$ (%)	0	S1 – 0	0	100
Gypsum (%)	0	S1 – 0	0	100
Soil fertility (f)				
Apparent clay CEC (mEq/100 g)	85,25	S1 – 0	0	80
V (%)	27,69	S3	3	50
SBE (Cmol/Kg)				
CO (%)	2,06	S1-0	0	100
pH- H_2O	5,6	S1 – 1	1	93
Salinity and sodicity (n)				
CEe (mS/cm)	0.02	S1-0	0	100
ESP (%)	0,6	S1-0	0	100
Calculated Earth Index		**S1-0**		**65,5**

Conclusion

The study reveals that the soils are low in nutrients and are characterized by acids. The climate index shows that the climate is very suitable for producing rice in semi-irrigated systems between April and October. The assessment shows that Vertisols are suitable for growing rice in irrigated systems while Planosols are marginal. The main limitation in Planosols is the low level of nutrients. At the current state of knowledge, semi-irrigated cultivation on both land units is possible. To overcome the problem, it is necessary to improve the management of field fertility, rotate crops and train producers in integrated fertility management and provide them with credits and adequate agricultural equipment.

Authors' Contribution

Both authors contributed equally at all stages of research and manuscript preparation. Final form of manuscript was approved by both.

Conflict of Interest

Authors declare no conflict of interest with the present publication.

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