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Characterization and Integrated Assessment of the Chemical Fertility of Oasis Soils in Southeastern Niger

Cheick Mahamet [a*], Amadou Issoufou Abdourhimou [a],
Moussa Mamoudou Boubacar [a]
and Karema Ary Madou Kaoulé [a]

[a] *Faculty of Agricultural and Ecological Sciences, University of Diffa, PO Box: 78, Diffa, Niger.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

This study, conducted in the oasis basins of the Gouré, Goudoumaria, and Mainé Soroa departments (southeastern Niger), aims to characterize the soils in terms of morphological and physicochemical properties in order to assess their fertility. Nine (9) soil profiles were opened, and nine (9) soil samples were analyzed at the INRAN LASEVE laboratory using standardized methods. The results show a texture varying from sandy silt to silty clay depending on the depth for the Toumourwa, Balla, and Bassori basins, with a basic pH between 8.1 and 8.9 and moderate electrical conductivity indicating low salinity. The organic matter content (0.47 to 2.62%), available phosphorus (< 5 cmol+/kg), and cation exchange capacity (1.75 to 13.25 cmol+/kg) generally indicate low to medium fertility. The study reveals three groups of basins:

- High fertility basins: Tissouwa, Balla, and Toumourwa with organic matter (OM) > 1.5%, cation exchange capacity (CEC) > 8, and balanced pH;

**Corresponding author: E-mail: mahametcheick79@gmail.com;*

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- Medium fertility basins: Adébour, Bassori, Tchéballam, and Gotanga with average cation balance, low organic matter content, and good chemical reserve;
- Low fertility basins: Goudoumaria North and Kiria Mandaram with low CEC and OM, and degraded soil structure.

Fertility can be improved through the application of compost, mulching, crop rotation, and sustainable water management. These practices are essential for restoring the productivity of oasis soils and strengthening local food security.

Keywords: Oasis basins; fertility; organic matter; Southeast Niger.

1. Introduction

Rapid population growth in the Sahel over recent decades has generated a wide range of environmental pressures, notably inappropriate agricultural practices, overexploitation of soil and water resources, overgrazing, trampling, southward and urban-directed population migrations, and the widespread sedentarization of formerly nomadic populations (Ozer et al., 2010). In Niger, agriculture is predominantly practiced in the southern Sahelian zone, where it accounts for more than 40% of national GDP and constitutes the primary source of livelihood for over 80% of the population. Despite its socio-economic importance, agricultural production has been insufficient to meet food demand in recent years, resulting in chronic food insecurity (Habou et al., 2016, 2020).

In arid environments such as southeastern Niger, oasis basins represent key agricultural production systems (Ambouta et al., 2005). However, declining agricultural productivity driven by climate change and increasing climate variability has intensified pressure on these systems, prompting local populations to intensify farming activities in an effort to compensate for yield losses (Ozer et al., 2017). These oasis basins play a crucial role in sustaining rural livelihoods by supporting agricultural production and diversification in regions with limited agronomic potential (Tychon et al., 2009). In the absence of these systems, rural populations would likely be forced to migrate, a phenomenon that has become a major socio-environmental challenge in West Africa (Gemenne et al., 2017; FAO 2006; Saxton & Rawls 2006).

Agriculture in oasis basins is practiced throughout the year, and farmers actively seek to maintain soil fertility to ensure stable yields. However, such efforts often involve uncontrolled or unsustainable practices that may lead to long-term soil degradation (Zadi, 2016). Previous studies have focused on soil typology, mapping, and basin siltation processes (Ambouta et al., 2005; Karimou Barké et al., 2015; Krou et al., 2016; Assane et al., 2021). Nevertheless, these studies have not simultaneously addressed the characterization and comparative analysis of soils across the three departments of Gouré, Goudoumaria, and Mainé.

Against this backdrop, the present study undertakes a comprehensive characterization and physico-chemical analysis of soils in the oasis basins of southeastern Niger. The overarching objective is to develop an integrated soil quality index tailored to Sahelian conditions, enabling a diagnostic assessment of agricultural land in the Diffa region. Specifically, the study aims to: (i) characterize the physico-chemical properties of oasis basin soils, (ii) develop an integrated soil quality assessment methodology, (iii) identify the main soil fertility constraints, and (iv) propose sustainable soil management strategies to enhance agricultural productivity while preserving long-term soil fertility.

2. Materials and Methods

2.1 Study Area

The study was conducted in the departments of Gouré, Goudoumaria, and Mainé Soroa, located in southeastern Niger. Rainfall in Niger is highly seasonal, occurring mainly between May and September, with approximately 70–90% of annual precipitation recorded from June to August. Precipitation is characterized by strong interannual variability, typical of the Sahelian climate (Ozer et al., 2010). The study area experiences a dry tropical climate marked by a long dry season lasting 8 to 9 months and a short rainy season of 3 to 4 months. Temperatures are highest between March and May and relatively cooler from December to February (Ozer et al., 2010).

The landscape is dominated by a mosaic of mobile dunes in the northern part of the area and stabilized dunes in the south. Vegetation consists primarily of open steppe formations dominated by herbaceous species. The region is characterized by numerous basin-like landforms locally known as “N’gors”. These basins are interdunal depressions with highly variable cross-sections, generally resembling an inverted truncated cone (Ambouta et al., 2005).

Based on groundwater depth, three main types of basins are distinguished. Shallow water basins (SWC) have a water table depth of less than 1.5 m and typically exhibit four concentric rings, with the innermost zone often occupied by a permanent or seasonal pond. Intermediate water basins (IWC), with a water table depth ranging from 1.5 to 4 m, generally present three concentric rings, the central zone being predominantly bare. Deep water basins (DWC) are characterized by groundwater depths exceeding 4 m.

Within each basin type, land use allows the identification of three functional categories: agricultural basins, agropastoral basins, and pastoral basins (Ambouta et al., 2005). Although not systematically observed, a strong relationship exists between groundwater depth and land use. Basins with shallow and intermediate water tables are predominantly agricultural, supporting extensive arboriculture and market gardening, whereas deep water basins are mainly pastoral, with limited rainfed cropping and small-scale gardening.

Site selection was based on agro-ecological zoning, accessibility, security conditions, and basin typology. A total of nine (9) basins suitable for agropastoral use were selected, including three (3) shallow water basins (Adébour, Tchaballam, and Bassori) and six (6) intermediate water basins (Tissouwa, Balla, Gotanga, Tou Mourwa, Goudoumaria Nord, and Kiria Mandaram).

2.2 Description of Soil Profiles

Soil profiles were opened within the polyculture zones of each basin, corresponding to areas under active cultivation. For each basin, one soil pit representative of the polyculture zone was described, resulting in a total of nine (9) soil profiles.

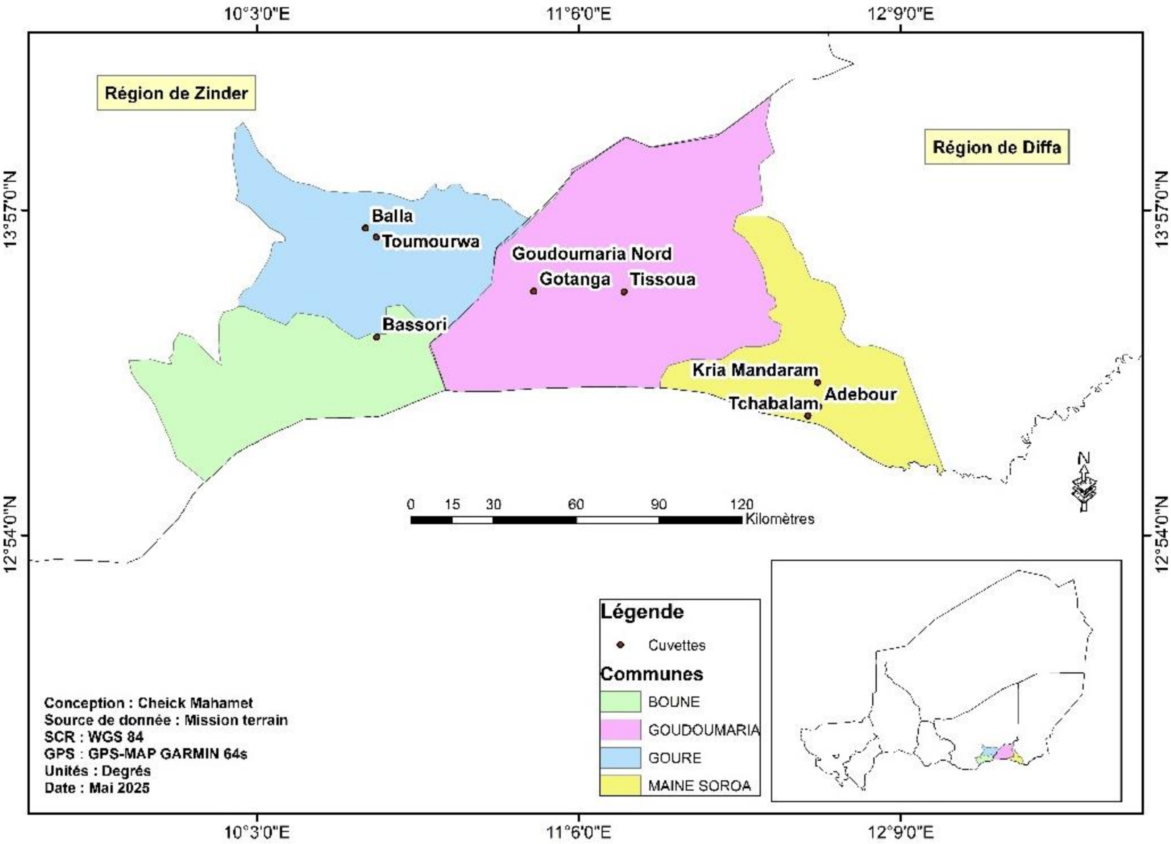


Fig. 1. Study area

The methodological approach was based on the conceptual framework of pedotransfer functions (PTFs), which establish quantitative relationships between easily measurable soil properties and soil water-holding characteristics. This approach, originally developed by Rawls et al. (1982) and subsequently refined by Saxton and Rawls (2006), is grounded in the principle that soil texture and structure are the primary determinants of water retention capacity, as demonstrated by Hillel (1998) and Dexter (2004). The originality of this study lies in the contextual adaptation of these general PTF principles to the specific properties of tropical and Sahelian soils, thereby addressing the limitations of standard models previously highlighted by Brabant (1991).

Data collection focused on forty-one (41) soil horizons distributed across the nine representative basins, with a standardized sampling depth ranging from 0 to 100 cm. Morphological descriptions were conducted in accordance with the guidelines of Baize and Jabiol (2011), including the identification of horizon boundaries and thicknesses, color determination using the Munsell Soil Color Charts (2000), and the characterization of soil texture and structure. Soil textures were classified into four main categories (clayey, silty, sandy, and organic), while soil structure was categorized into five types (massive, polyhedral, prismatic, particulate, and cubic block structures).

2.3 Water Potential Modeling

The soil water potential model developed in this study is based on the structure–function relationships described by Bruand and Tessier (2000). The model integrates texture-specific retention coefficients (C_texture) that reflect the intrinsic water-holding capacity of different soil textural classes, ranging from 0.12 for purely sandy soils to 0.48 for organo-clay soils. In addition, structural correction coefficients (C_structure) were applied to account for the influence of soil structure on water retention, with values varying from 0.90 for massive structures to 1.15 for prismatic structures.

The available water capacity (RU) for each soil horizon was calculated using the following equation:

$$RU = C\_texture \times C\_structure \times Thickness \times 10$$

where RU represents the available water capacity expressed in millimeters (mm), which is directly equivalent to the volume of water (liters) available per square meter of soil surface. This formulation allows for a standardized and comparable assessment of soil water availability across horizons and basin types.

2.4 Classification and Categorization

The classification of soil water potential was established in accordance with the recommendations of Zwart et al. (2021) for semi-arid environments. Six classes were defined, ranging from Very Low (available water reserves < 30 mm) to Exceptional (available water reserves > 150 mm). This classification framework provides a rapid and intuitive assessment of the soil's capacity to retain plant-available water, thereby supporting informed decision-making in agricultural planning and land management.

2.5 Methodological Limitations and Perspectives

With respect to morphological parameters, certain methodological limitations should be acknowledged, particularly the estimative nature of the coefficients employed and the limited consideration of intra-horizon variability. Nevertheless, as emphasized by Medinski et al. (2022), estimation-based approaches represent a pragmatic and robust solution in data-scarce environments. The methodology adopted in this study therefore provides an effective compromise between scientific rigor and field applicability, enabling the conversion of standard morphological observations into functional indicators. These indicators are directly applicable to the sustainable management of soil water resources in Sahelian basin agro-ecosystems.

2.6 Soil Sampling

Within each basin, three sampling points were randomly selected within the polyculture zone, with a minimum spacing of 300 m between points to ensure spatial independence. Soil samples were collected using an auger at a depth of 0–20 cm. For each basin, the collected samples were homogenized to form a composite sample representative of the polyculture zone.

2.7 Determination of the Physicochemical Characteristics of Soils

The analysis of soil chemical properties was conducted on composite soil samples. Laboratory analyses were performed following the standard procedures routinely applied at the Soil–Water–Vegetation and Fertilizer Laboratory (LASEVE) of the National Institute of Agronomic Research of Niger (INRAN). The set of analyses carried out is presented in Table 1. The parameters analyzed included soil pH measured in water, organic carbon content, exchangeable base cations (Ca^{2+}, Mg^{2+}, and K^{+}), total nitrogen, available phosphorus, electrical conductivity, and cation exchange capacity (CEC). Soil fertility status was subsequently evaluated based on the fertility classification criteria proposed by Amonmide et al. (2019).

2.8 Determination of the Soil Quality Index

Assessing soil quality is a critical issue for the sustainable management of agro-ecosystems in Sahelian environments. Given the complexity of pedoclimatic interactions, an integrated approach is required to evaluate soil fertility beyond isolated chemical analyses. Within this framework, a synthetic Soil Quality Index (SQI) was developed to provide a multidimensional assessment of soil fertility status.

The methodological approach follows the framework proposed by Andrews et al. (2002), which pioneered the development of soil quality indices, and was adapted to the specific conditions of arid and semi-arid environments in accordance with the recommendations of Masto et al. (2007), which are particularly relevant to the Sahelian context.

The underlying principle is based on the selection of indicators that are sensitive to the dominant pedological constraints of the Diffa region, combined with a weighting scheme that reflects their relative contribution to overall soil functioning. This integrated approach allows for a comprehensive and functional evaluation of soil quality, supporting informed decision-making for sustainable land and soil management.

2.8.1 Weighting and Justification of Indicators

Six major chemical indicators were selected based on their agronomic relevance and their sensitivity to environmental stresses characteristic of the study area. These indicators are:

- Soil organic matter (25%), which plays a fundamental role in regulating soil physicochemical and biological properties. It directly influences nutrient retention capacity and the resilience of agro-ecosystems to environmental constraints, particularly in arid and semi-arid regions (Andrews et al., 2002; Masto et al., 2007).
- Cation exchange capacity (CEC) (20%), which reflects the soil's nutrient reserve and its potential to retain essential plant nutrients.
- Soil pH (15%), a key controlling factor governing nutrient availability and overall soil chemical balance.
- Available phosphorus (15%), a nutrient that is frequently limiting in Sahelian cropping systems.
- Electrical conductivity (15%), a critical indicator of salinization risk under arid environmental conditions.
- Base saturation (10%), which reflects the chemical equilibrium of the soil exchange complex and overall soil fertility status.

The weighting scheme was designed to reflect the relative contribution of each indicator to overall soil functioning, with greater emphasis placed on parameters that exert a stronger control on soil productivity and resilience in Sahelian environments.

2.8.2 Calculation Method and Normalization

The Soil Quality Index (SQI) was calculated using a weighted additive model that integrates the normalized values of each selected indicator:

$$\mathbf{IQS} = \mathbf{0.25} \times \mathbf{MO_n} + \mathbf{0.20} \times \mathbf{ECE_n} + \mathbf{0.15} \times \mathbf{pH_n} + \mathbf{0.15} \times \mathbf{P_n} + \mathbf{0.15} \times \mathbf{CE_n} + \mathbf{0.10} \times \mathbf{SB_n}$$

Legend: where: $\mathrm{MO_n}$= normalized organic matter (0–1); $\mathrm{ECE_n}$ = normalized cation exchange capacity; $\mathrm{pH_n}$= normalized pH; $\mathrm{P_n}$= normalized available phosphorus; $\mathrm{CE_n}$= normalized electrical conductivity; $\mathrm{SB_n}$= normalized base saturation.

Each indicator was first transformed using a normalization function that scales raw values between 0 and 1, based on optimal threshold values reported in the literature.

Table 1. Laboratory analysis of samples

Parameters	Analysis Methods
pH-water	pH-water pH meter with a soil-to-water ratio of 1:2.5
Carbon	Walkley and Black
Assimal Phosphorus	Bray and Kurtz, 1945
Cation Exchange Capacity (CEC)	Kjeldahl Method
Organic Matter	Walkley and Black
Nitrogen	Kjeldahl Hillebrand,
Exchangeable Cations (Ca, Mg, Na, and K)	Atomic Absorption Spectrophotometry and Exchangeable Aluminum
Electrical Conductivity (EC)	Conductivity meter with a soil-to-water ratio of 1:5

Table 2. Basis for the calculation of the Soil Quality Index (SQI)

Parameter	Optimal threshold	Standardized indicator	Score range	Scientific reference	Justification
Organic Matter (OM)	4%	MOn = min (OM / 4.1)	0-1	Masto et al. (2007)	Threshold adapted to semi-arid zones, optimal for structural stability
Cation Exchange Capacity (CEC)	25 meq/100g	CECn = min (CEC / 25.1)	0-1	Karlen et al. (2003)	Excellent nutrient retention capacity in tropical soils
pH	7.0	pHn = 1 - (|pH - 7| / 3.5)	0-1	Andrews et al. (2002)	Optimum for nutrient availability, bell function
Assimilable phosphorus	10 mg/kg	Pn = min (P_assim / 10, 1)	0-1	Qi et al. (2009)	Satisfactory content for most annual crops
Electrical Conductivity (EC)	<0.8 ms/cm	CEn = (EC<0.8.1, max(1-(EC-0.8)/4.0))	0-1	Masto et al. (2007)	Tolerable salinity threshold for sensitive crops in arid areas
Base saturation	100%	SBn= min (Saturation / 100.1)	0-1	Andrews et al. (2002)	Optimal theoretical saturation of the absorbing complex

Table 3. Soil Quality Index (SQI) classes and interpretation

IQS Range	Quality	Interpretation
IQS ≥ 0.80	Excellent	Optimal operation without major constraints
0.60 ≤ IQS < 0.80	Good	Satisfactory fertility with minor constraints
0.40 ≤ IQS < 0.60	Average	Limited fertility requiring interventions
IQS < 0.40	Bad	Severe constraints requiring urgent amendments

The normalized indicators were then multiplied by their respective weighting coefficients and summed to obtain the final SQI value.

The product of the normalized indicator and its weighting coefficient represents the effective contribution of each parameter to the overall SQI, providing both a quantitative and qualitative assessment of integrated soil fertility. While normalized indicators reflect the current status of individual soil properties, the weighting factors express their relative importance in overall soil functioning. This approach acknowledges that certain constraints—such as low organic matter content—have a disproportionately greater impact on soil quality than others, thereby reflecting the hierarchy of pedological limitations typical of Sahelian environments.

2.8.3 Interpretation Scale and Validation

The final Soil Quality Index (SQI), which theoretically ranges from 0 to 1, was divided into four soil quality classes, as presented in Table 3. These classes provide a clear framework for interpreting the integrated soil fertility status and for supporting management decisions in Sahelian agro-ecosystems.

3. Results

3.1 Morphological Characteristics of Basin Soil Profiles

Fig. 2 illustrates the pedological profiles of the studied basins. The Tissouwa and Bassori basins exhibit a silty-clay texture in the subsurface, with prism-like and polyhedral soil structure. In contrast, the Tchaballam, Kiaria Mandaram, and Goudoumaria Nord basins display a sandy-silty texture, with distinctive structural arrangements including polyhedral forms in the deeper horizons.

3.2 Water Retention Potential of the Basins

Analysis of Fig. 3 indicates that the basins exhibit varying water retention potentials. Toumourwa and Adébour display high water retention, particularly within the 20–80 cm soil depth range. In contrast, Tissouwa and Tchaballam show relatively low water-holding capacity across the profile.

3.3 Chemical Characteristics of Soils

As shown in Table 4, the results indicate highly significant differences among the nine studied basins in carbonate, organic matter, and sulfur contents ($P < 0.05$). Significant differences were also observed in the concentrations of exchangeable cations (Na^+, Mg^{2+}, Ca^{2+}) and in cation exchange capacity (CEC) between basins. No significant differences were detected for potassium (K^+), pH, electrical conductivity (EC), exchangeable acidity (EA), or available phosphorus (P_{ass}).

3.4 Calcium-to-Magnesium Ratio

Fig. 4 illustrates the pronounced variability of the Ca/Mg ratio among the studied basins. Adébour, and to a lesser extent Bassori and Tchaballam, exhibit a satisfactory balance, with values close to the optimal range of 2–6.

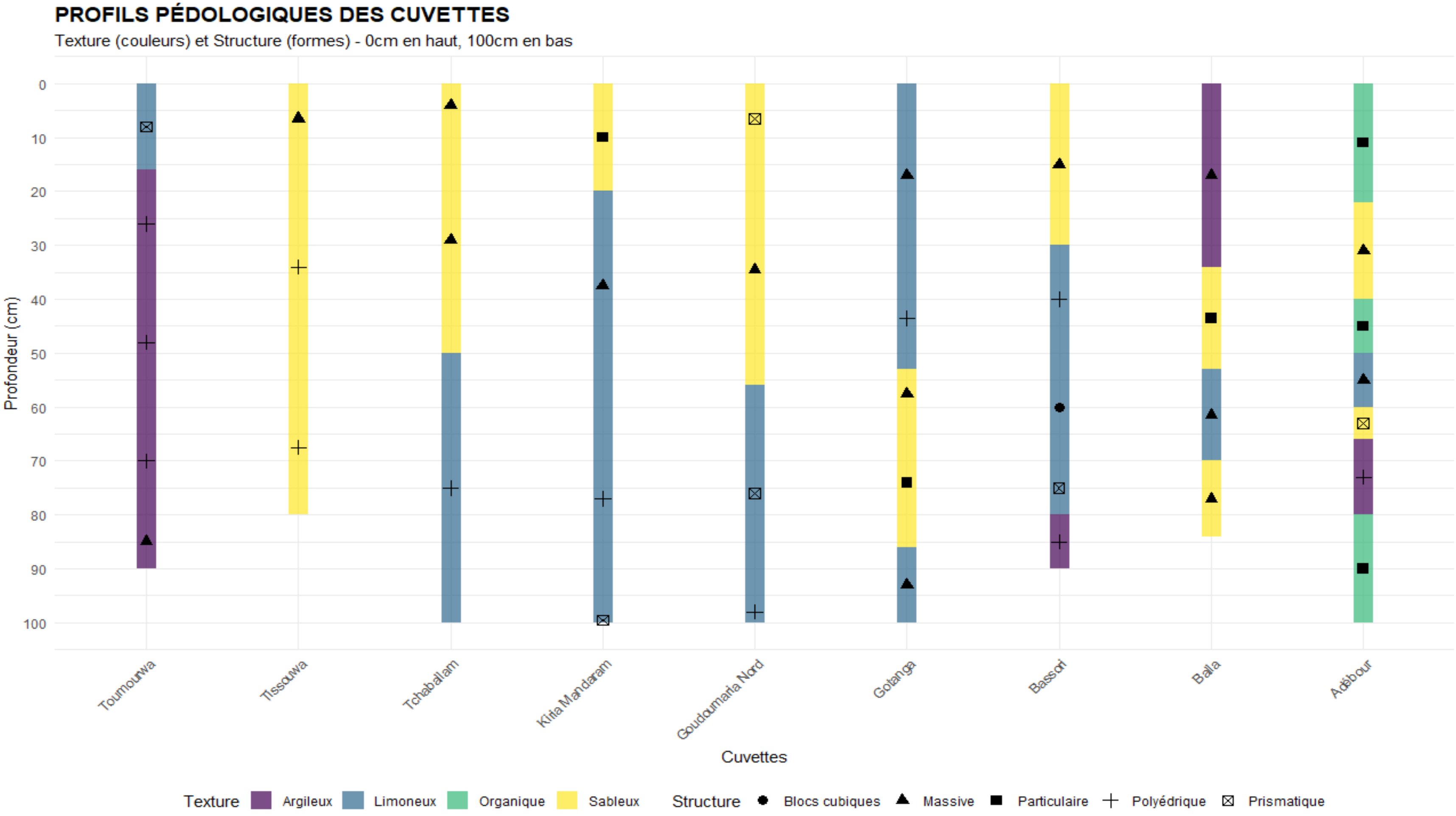
3.5 Soil Fertility Parameters

Fig. 5 shows that nearly all basin soils exhibit a basic pH. Fertility parameters are predominantly low to very low across the basins, except for Balla, which presents higher values (OM: 2.62%; CEC: 13.25 $cmol_c$/kg; SQI: 0.62), indicating relatively better soil fertility.

Table 4. Selected chemical properties of soils from the studied basins

Cuvettes	PH	CE	S	CEC	Pass	MO
Adebour	8.27a	0.77a	5.38bc	5.49bc	3.49a	0.69bc
Balla	8.28a	1.38a	13.19a	13.25a	4.45a	2.62a
Bassori	8.43a	0.48a	5.52bc	5.56bc	5.60a	0.61bc
Gotanga	8.13a	0.85a	7.49abc	7.54abc	1.70a	1.36abc
Goud nord	8.26a	0.06a	1.69c	1.75c	4.18a	0.47c
Kiria Mand	8.9a	0.79a	2.56bc	2.60bc	6.76a	1.08bc
Tchèballam	8.107a	0.19a	6.36bc	6.40bc	3.31a	0.66bc
Tissowa	8.133a	0.82a	9.1ab	9.14ab	1.83a	1.56abc
Toumr	8.34a	0.27a	8.31ab	8.36ab	1.79a	2.15ab
P-Value	0.156	0.296	0	0	0.05	0.001

Legend: CEC: cation exchange capacity; OM: organic matter; EC: electrical conductivity; P_{avail}: available phosphorus; pH: hydrogen potential; SB: sum of exchangeable bases



PROFILS PÉDOLOGIQUES DES CUVETTES

Texture (couleurs) et Structure (formes) - 0cm en haut, 100cm en bas

Fig. 2. Textural and structural representation of soil profiles in the studied basins

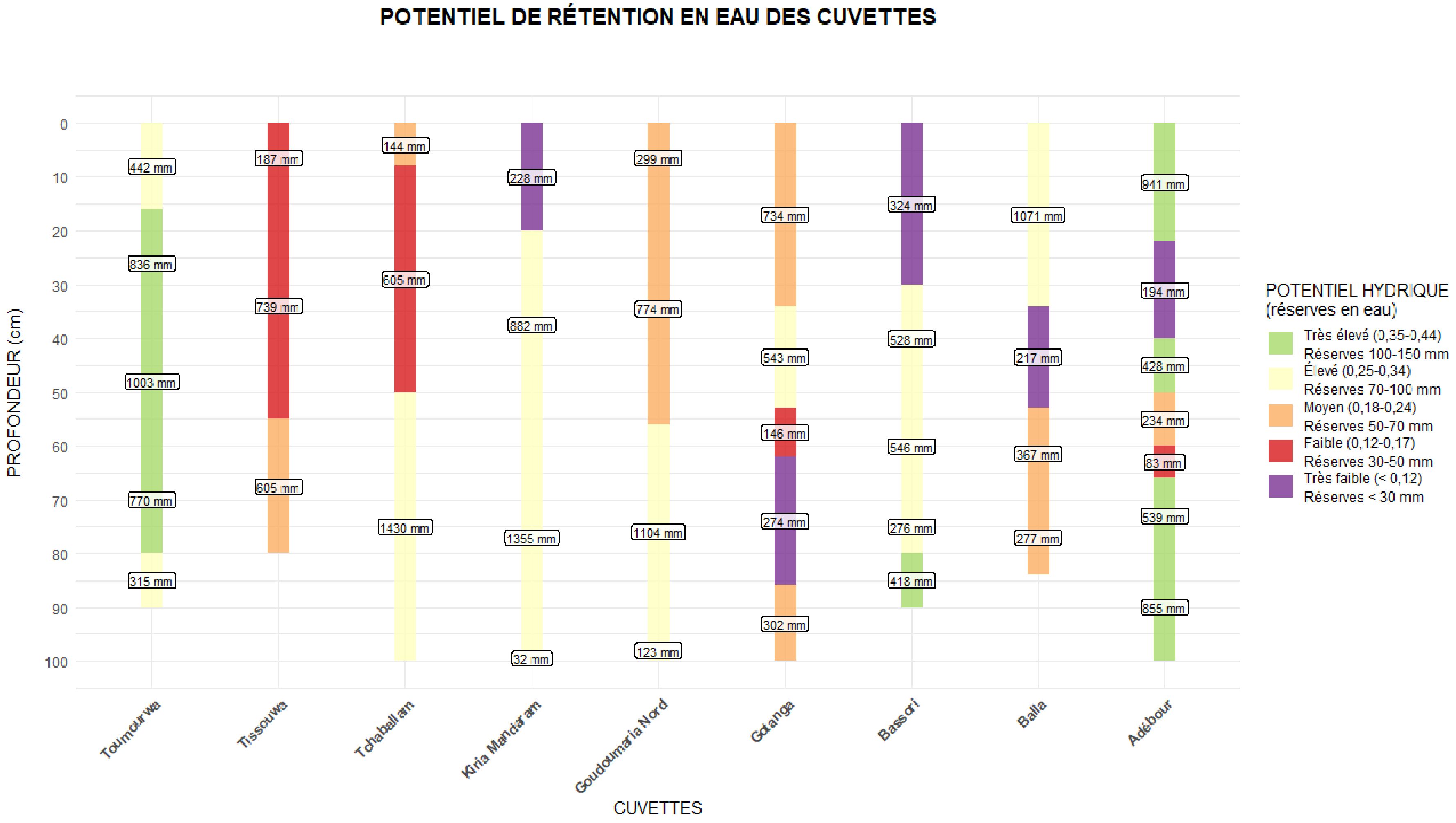


Fig. 3. Water retention capacity of the studied basins

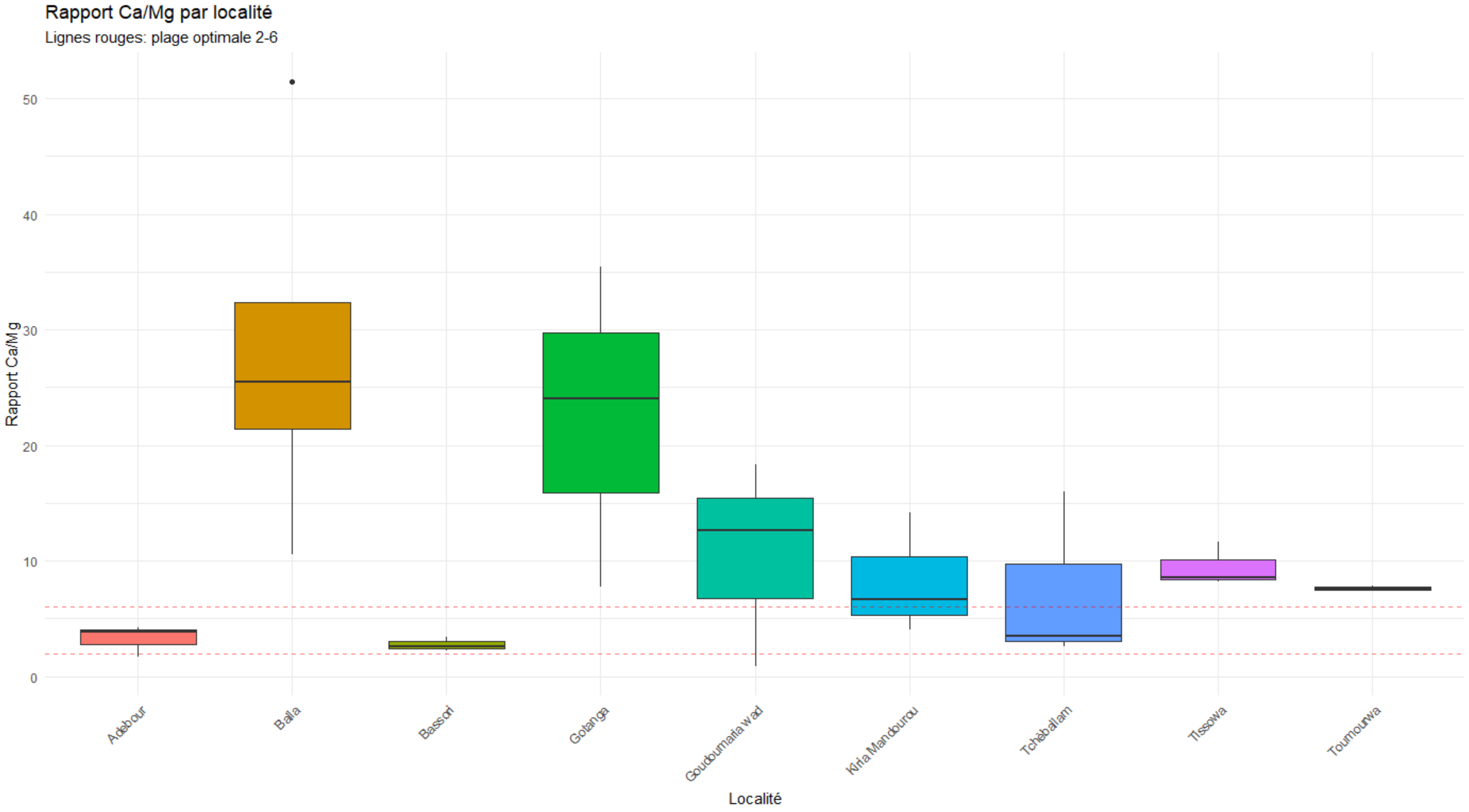


Fig. 4. Boxplot of the calcium-to-magnesium (Ca/Mg) ratio across the studied basins

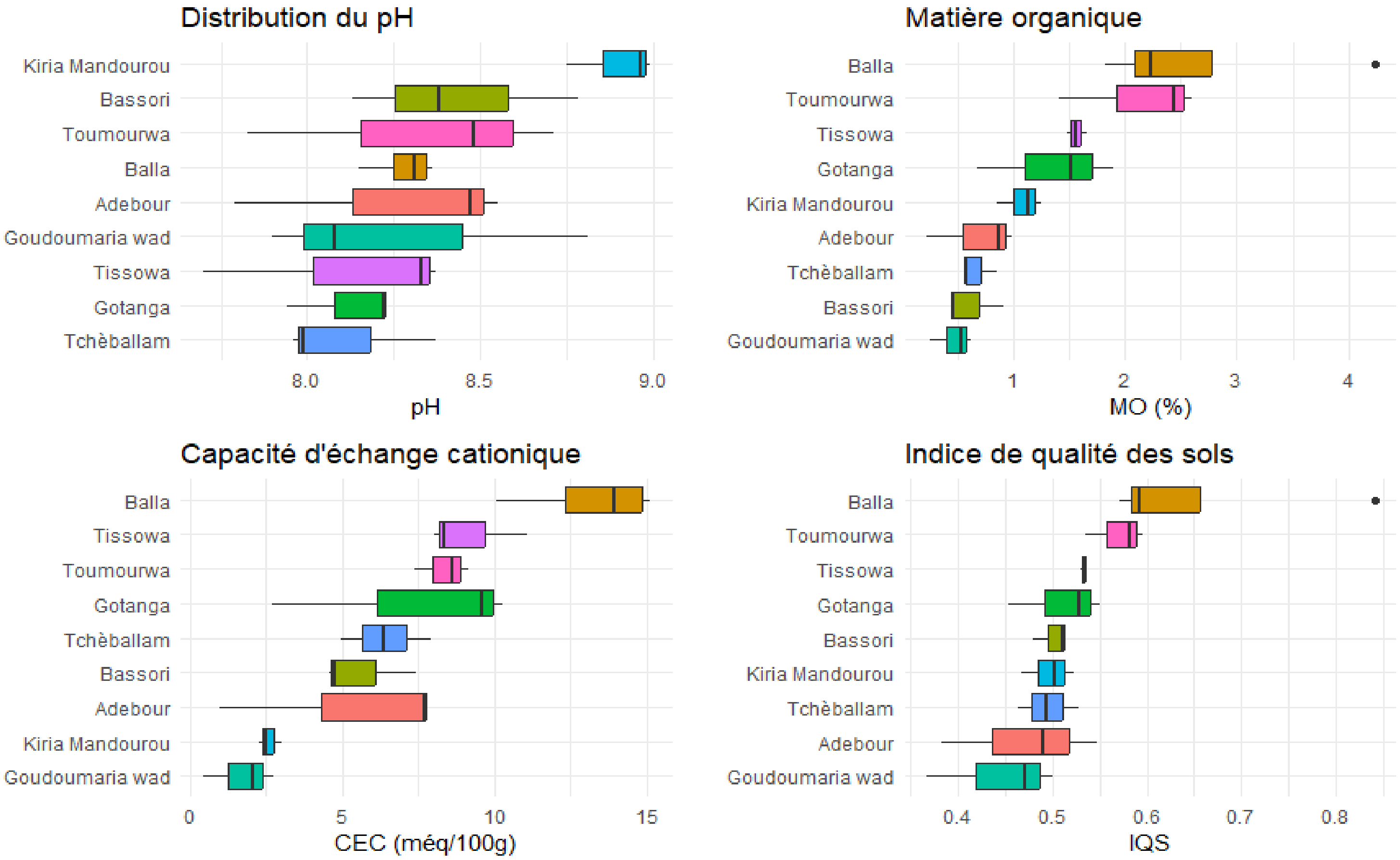


Fig. 5 illustrates the levels of soil fertility parameters across the studied basins

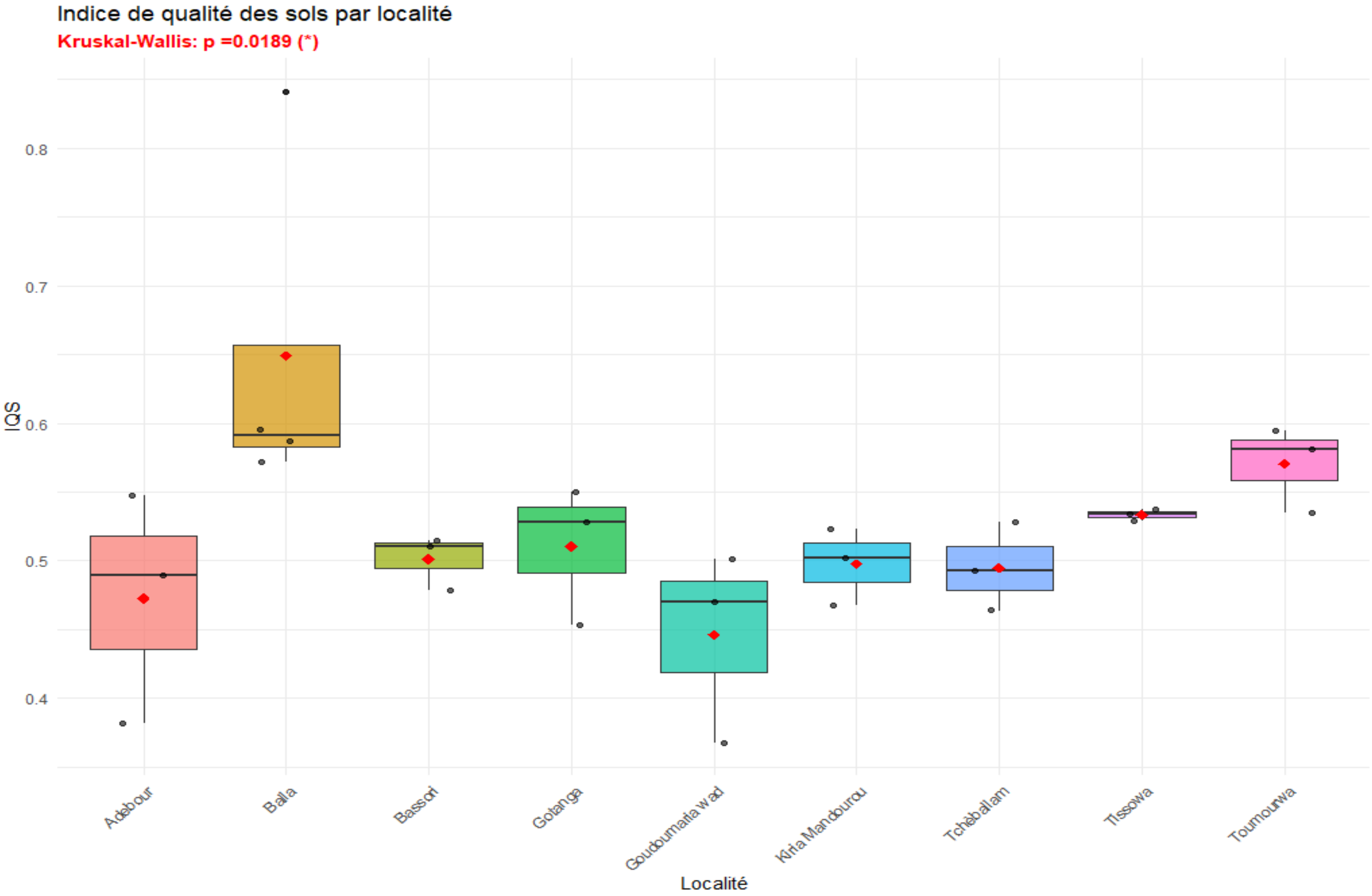


Fig. 6. Comparative boxplot of the Soil Quality Index (SQI) across the studied basins

3.6 Soil Quality Index of the Basins

Analysis of Fig. 6 indicates that, according to the Kruskal–Wallis test, there is a statistically significant difference in the Soil Quality Index (SQI) among the basins. The basins of Balla, Toumourwa, and Tissouwa exhibit relatively high SQI values, reflecting better overall soil quality.

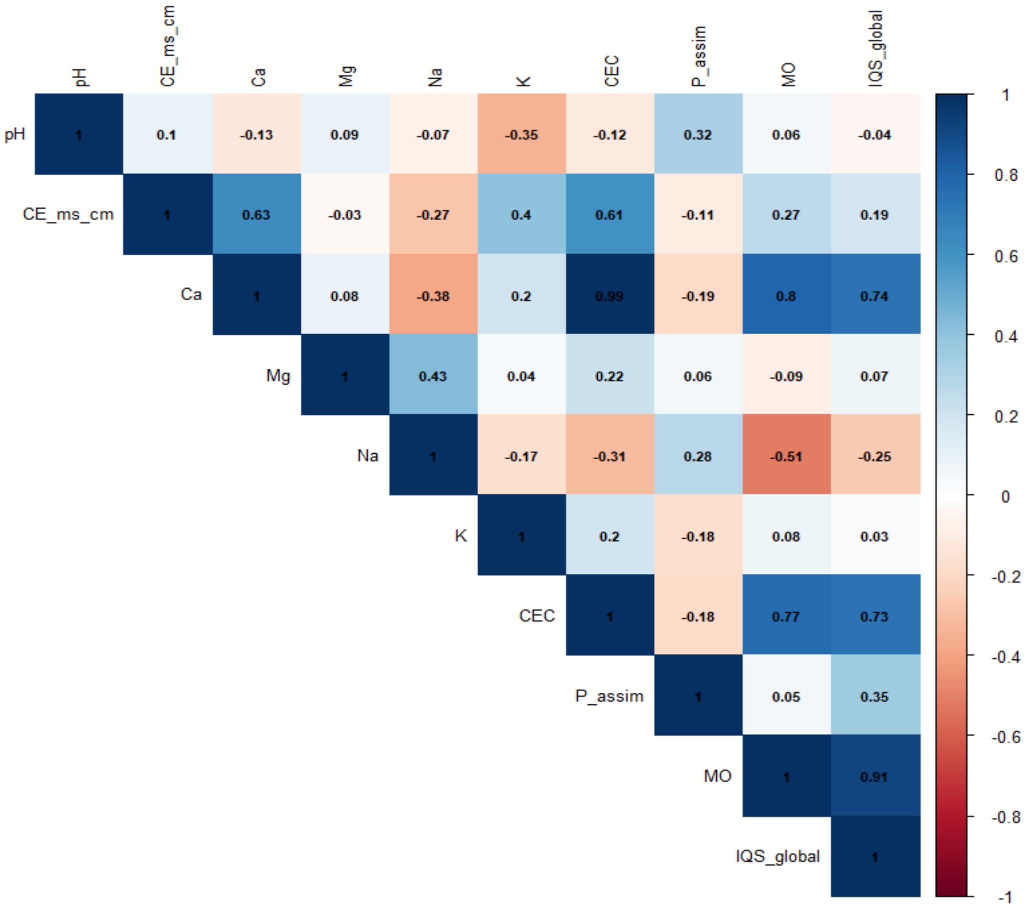
3.7 Correlation Analysis of Soil Fertility Parameters

Analysis of Fig. 7 highlights several strong correlations among soil fertility parameters. Positive correlations were observed between CEC and Ca (r = 0.99), CEC and OM (r = 0.77), CEC and SQI (r = 0.73), OM and SQI (r = 0.91), OM and Ca (r = 0.80), EC and Ca (r = 0.63), and EC and CEC (r = 0.61). Negative correlations were found between EC and Na (r = –0.27), Na and OM (r = –0.51), and Na and SQI (r = –0.25). These relationships suggest that organic matter and cation exchange capacity are key drivers of soil quality in the studied basins, while high sodium content may negatively impact soil fertility.

4. Discussion

4.1 Soil Morphological Characteristics

Morphologically, soils in the studied oasis basins (CEAs) exhibit a texture gradient from silty-clay in the subsurface to silty-sand in deeper horizons. In this semi-arid environment of Niger, the high clay content gives these soils a good water retention capacity. The work of (Abdelhafid et al., 2021) in the province of Biskra, in the Algerian Lower Sahara, corroborates this result. These morphological features are consistent with those described for saline soils with deep hydromorphic characteristics in the second aureole of the Bariram Koura CEA (Ambouta et al., 2005).



	pH	CE_ms_cm	Ca	Mg	Na	K	CEC	P_assim	MO	IQS_global
pH	1	0.1	-0.13	0.09	-0.07	-0.35	-0.12	0.32	0.06	-0.04
CE_ms_cm		1	0.63	-0.03	-0.27	0.4	0.61	-0.11	0.27	0.19
Ca			1	0.08	-0.38	0.2	0.99	-0.19	0.8	0.74
Mg				1	0.43	0.04	0.22	0.06	-0.09	0.07
Na					1	-0.17	-0.31	0.28	-0.51	-0.25
K						1	0.2	-0.18	0.08	0.03
CEC							1	-0.18	0.77	0.73
P_assim								1	0.05	0.35
MO									1	0.91
IQS_global										1

Fig. 7. Correlation matrix of soil chemical parameters in the studied basins

The lighter texture of the surface horizon allows the cultivation of vegetables such as pepper, potato, watermelon, lettuce, cabbage, onion, and maize on small plots. This observation aligns with the findings of Kekane et al. (2015), who highlighted that soil texture influences aeration, root penetration, and nutrient availability. Overall, soils in the studied basins are well-suited for irrigated agriculture, including cereals, vegetables, and fruit crops. Vegetable production can be intensified with moderate soil tillage and frequent low-dose irrigation. Kanembou et al. (2024) reported that short-cycle crops such as onion and cabbage were economically more profitable in the Guirsilik oasis basin. In 2024, agricultural exploitation of these basins provided an average income of 125,000 FCFA per farmer per campaign.

In contrast, soils from the CEI basins have a sandy-silty to sandy texture. Low organic matter content with rapid mineralization, combined with relatively low nutrient concentrations, necessitates regular inputs of manure and mineral fertilizers for cereal and vegetable crops. This observation is consistent with Tahirou et al. (2022), who demonstrated that low nitrogen content is a limiting factor for cereal yields. The significant soil depth also provides good potential for irrigated cereal and fruit production; however, the groundwater depth (~4 m) requires farmers to dig multiple wells and restrict vegetable cultivation to small plots of less than one hectare. These findings align with Ambouta et al. (2005), who reported similar characteristics for the Mariri basin in Niger.

4.2 Soil Chemical Characteristics

Overall, the studied soils are slightly alkaline and have low salinity, creating a relatively favorable environment for crop growth, though high pH may limit the availability of certain nutrients, particularly phosphorus. Soil pH is a critical factor for fertility, with an optimal range for most crops between 6 and 7.5 (Genot, 2009). Studies by Doucet (2006) and Borah et al. (2010), cited in Mahamat Nour Zakaria (2024), also emphasize that pH determines nutrient availability for plants and soil microorganisms. High pH can positively affect cation exchange capacity (CEC) (Julien & Tessier, 2021).

In this study, CEC varied from 1.75 cmol $_c$/kg in Goudoumaria Nord to 13.25 cmol $_c$/kg in Balla, indicating higher nutrient retention and fertility in Balla compared to the nutrient-poor Goudoumaria Nord basin. Limited variation in CEC in Goud Nord may reflect relatively low biological activity across the horizons. The importance of CEC for nutrient management has been highlighted by d'Aprile and Lorandi (2012).

Available phosphorus was variable and statistically significant (P = 0.05), with low values (< 2 mg/kg) in Gotanga, Tissowa, and Toumour, likely due to soil alkalinity, which favors phosphorus precipitation. Phosphorus availability can be improved through organic matter additions, as suggested by Zadi (2016), since organic residues release nutrients and improve soil properties. Organic carbon and matter content varied strongly between basins; fertile basins (Balla, Toumour, Tissowa) could support intensive production if salinization is prevented. Poorer basins (Goudoumaria Nord, Adébour) require organic amendments to improve fertility. Miningou et al. (2020) highlighted that low yields often result from nutrient depletion, biological pressure, and insufficient fertilizer use. Farmers in the study area employ both organic and mineral fertilizers; however, applying crop-specific fertilizer recommendations is critical to optimize effectiveness. Cheick et al. (2025) reported that local soil fertility management practices include manure application, mineral fertilizers, and crop associations.

5. Conclusion

Chemical analysis of the soils in the Gouré, Goudoumaria, and Mainé Soroa basins reveals significant textural heterogeneity, widespread alkalinity, and a deficiency in essential nutrients.

The study identifies three groups of basins:

- High fertility basins: Tissouwa, Balla, and Toumourwa with organic matter (OM) > 1.5%, cation exchange capacity (CEC) > 8, and balanced pH;
- Medium fertility basins: Adébour, Bassori, Tchéballam, and Gotanga with average cation balance, low organic matter content, and good chemical reserve;
- Low fertility basins: northern Goudoumaria and Kiria Mandaram with low CEC and OM, and degraded soil structure.

Soil fertility can be improved through the application of compost, mulching, crop rotation, and sustainable water management. These practices are essential for restoring the productivity of oasis soils and strengthening local food security.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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