(RESEARCH ARTICLE)

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Contribution to the assessment of the natural fertility level of Armoured soils in maize-based cropping systems in the department of Tengréla in northern Côte d'Ivoire

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Abstract

Assessing the natural fertility of hardened soils in sub-Saharan Africa is essential for understanding agricultural challenges. This complex subject requires a thorough understanding of the factors affecting soil fertility, including agricultural practices, soil chemical composition, and environmental impacts.

This study aims to evaluate the fertility level of hardened soils in maize-based cropping systems in the Tengréla department of northern Côte d'Ivoire, in order to contribute to their agricultural development. Agronomic experiments were conducted on maize plots (red-grained variety) on hardened soils (AS) and non-hardened soils (NAS) used as controls. The parameters measured included germination rate and grain yield. Soil samples were collected at different depths for physicochemical analyses. The data were statistically analysed using XLSTAT, including analyses of variance (ANOVA).

The hardened and control soils exhibited a sandy and sandy-loam texture with a shallow depth.

The studied soils showed low levels of carbon, cation exchange (CEC), exchange bases (EB), nitrogen (N), and organic matter (OM). Deficiencies in sodium (Na^+), nitrogen (N), and OM were observed specifically at site 2. The pH of the hardened soils was slightly less acidic (6.3) than that of the non-hardened soils (5.8). The hardened soils showed higher carbon (C) and nitrogen (N) content than the non-hardened soils, but remained low in organic matter. The lateritic soils showed a higher yield (1.08 t/ha at site 1 and 1.52 t/ha at site 2) compared to the control soils (0.65 t/ha at site 1 and 0.72 t/ha at site 2).

Keywords: Natural fertility, Armored Soil; Maize cultivation; Ivory Coast

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1. Introduction

Diagnosing the natural fertility of crusted soils in Africa is a complex subject that requires an in-depth understanding of the factors affecting soil fertility, including agricultural practices, the chemical and biological composition of soils, and environmental impacts.

Climate change, one of the factors contributing to the formation of crusted soils, has a significant impact on maize yields worldwide, particularly in vulnerable regions such as West Africa. Variations in temperature and precipitation, which are direct consequences of climate change, affect agricultural productivity, particularly that of maize. (Tchoho, 2023) [1].

The agronomic study of maize on hardpan soils in Africa requires a thorough understanding of the interactions between agricultural practices, soil fertility and the specific characteristics of hardpan soils. Crusty soils, often characterised by a hard layer that limits root penetration and water infiltration, present unique challenges for maize cultivation, which is a staple crop in many African regions, particularly in northern Côte d'Ivoire. Research shows that improving soil fertility is crucial to increasing maize productivity on these soils (Misonga *et al.,* 2017) [2].

Some authors argue that agricultural development has a positive impact on the living conditions of urban and rural households (Hall, 2018) [3]. In West Africa, agricultural practices have also evolved, with a focus on maximising production while minimising eco-climatic risk (Manzelli *et al.,* 2015) [4]. Soil management is therefore at the centre of debates on the sustainability of agricultural production systems (Akpo et al., 2016) [5]. Soil is an important resource for meeting this need to improve agricultural production (Chevallier *et al.,* 2020) [6], is exposed to strong anthropogenic pressures and increasingly unfavourable climatic conditions, which are likely to cause soil degradation in line with current practices (Kohio *et al.,* 2017) [7]. This situation weakens production systems and makes agricultural activity uncertain (Oumarou *et al.,* 2016) [8], with a reduction in the amount of arable land cultivated on the one hand and the appearance of crusts on the soil surface on the other.

In order to find methods for the agricultural development of crusted soils, it became necessary to conduct a study entitled: Contribution to the assessment of the fertility level of crusted soils in maize-based cropping systems in the department of Tengréla in northern Côte d'Ivoire.

It therefore seems important to gain a better understanding of these plinthitic soils with a view to improving their agronomic performance. The aim of this study is to contribute to the agricultural development of crusted soils.

Specifically, it will assess the physical and chemical properties of crusted soils under maize cultivation. It will then evaluate the yield of maize crops on crusted soil and non-crusted soil, which is considered to be control soil.

2. Materials and methods

2.1. Presentation of the study area

The work was carried out in the department of Tengrela, in northern Côte d'Ivoire, between longitudes 10° and 11° North and latitudes 6° and 7° West.

The relief of the area is monotonous, with altitudes varying on average between 300 and 400 m; however, granitic inselbergs sometimes reaching over 500 m in altitude exist in the landscape. The region also consists of lateritic plateaus sometimes reaching three metres in height, evidence of ancient peneplains. These plateaus have a very gentle and regular slope and average annual rainfall of around 1,200 mm. Forest galleries can be seen along the watercourses, consisting of wooded savannah and shrub vegetation (Brou, 2005) [9].

The geological formations in the area consist of a succession of bands of schistose rocks, migmatite rocks and plutonic rocks. These are mainly granites, granodiorites, undifferentiated schists and sericite schists (Yacé, 2002) [10].
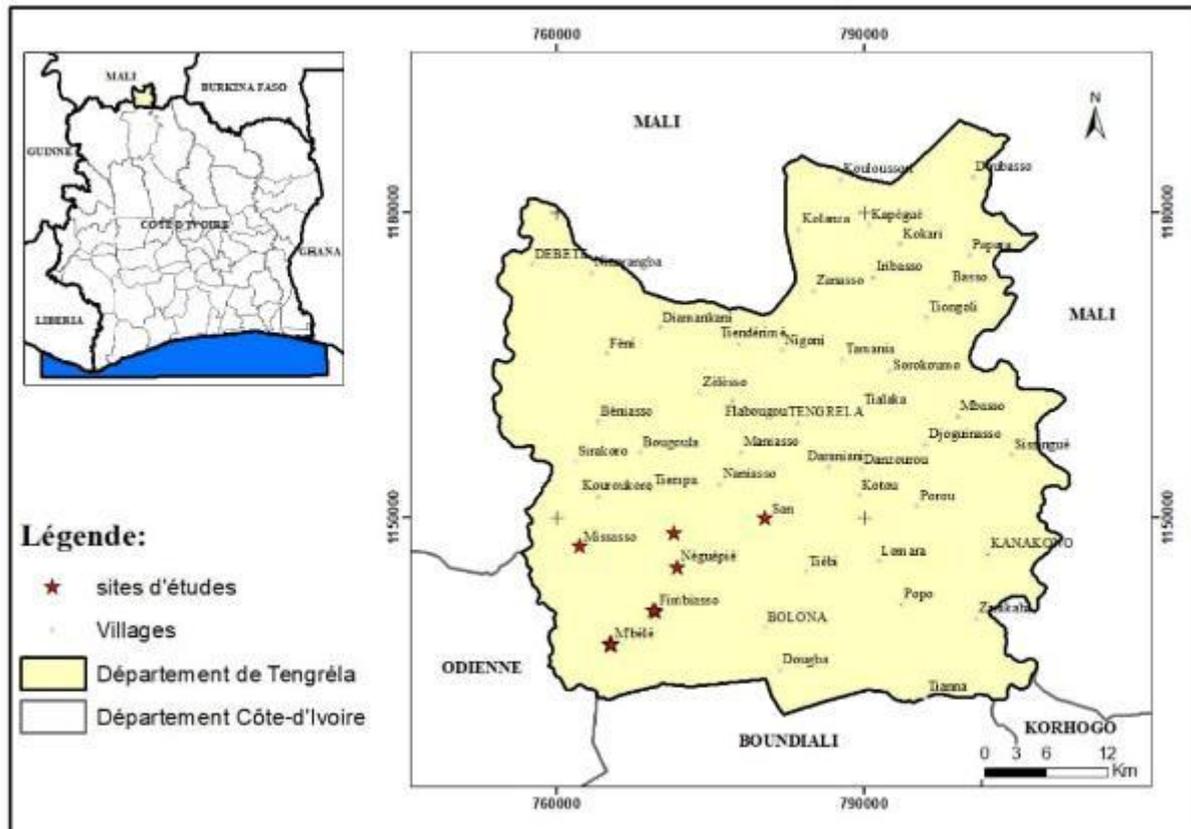
Figure 1 Presentation of the study area

2.2. Agricultural experiments in rural areas

2.2.1. Field trials

Objectives of the trials

Our trials focus mainly on maize crops, which are among the most widely grown seasonal crops in this department. They constitute the primary food source for the population.

The aim of the trials is to assess the agricultural potential of armoured soils under fallow based on the crops grown in this region.

Choice of experimental sites

The sites were chosen based on the presence of crusting in the developed area and the absence of crusting in the control area. Maize (*Zea mays P.*): The variety grown is red grain maize.

Table 1 Agricultural test parameters

Cultivation	Total number of plants per plot	Plot dimensions (L x W) in (m x m)	Sowing method	Variety used	Total number of replicates per trial	Sowing method	Experimental setup
Maize	150	6X 6	2 seeds per hole	Red grain maize	3	flat	Multi-local

2.3. Growth and agronomic parameters of the crops planted

The experiment was conducted over a period of four months, from July to September 2025, according to the plan presented in the diagram above.

The growth and agronomic parameters included height, number of leaves, and grain yield.

Plant height (cm) was measured using a ruler. This is the distance between the ground and the node where the last ligulate leaf is inserted.

-Grain yield was determined from quantitative parameters related to productivity

(the weight of 1,000 grains was assessed by counting the grains and weighing 1,000 grains).

Table 2 Chronology of crops during the activity trial

Activities	Maize variety	Plot preparation	Number and weight of maize grains	Grain yield
Maize	AC176 AC176 Local variety	1 month before sowing	Number of cobs per plant, Weight of 1,000 maize grains after harvest	

2.4. Agronomic parameters

2.4.1. Grain yield

One month after physiological maturity (i.e. at 120 DAP), harvesting is carried out.

Grain yields and the weight of 1,000 grains are assessed.

The formula below is used to calculate grain yield.

Yield = M × (100-Hc)/(100-Hs)

Yield = Yield in tons/hectare; M=Mass of seeds (tons) harvested per hectare; Hc = Field seed moisture content (%); Hs=Standard moisture content (the recommended moisture content for good grain storage, 14%). The weight of 1000 grains is estimated by counting the grains in each repetition and weighing 1000 grains. The results are expressed in g.

Soil samples were taken in July 2025 using the sampling method. Soil samples were taken from the [0-20] cm and [20-40] cm horizons using an auger. This selection of soil horizons took into account the depth of root development and their contribution of heat, water and nutrients. As a result, six plots (0.5 ha) were selected. Three soil samples were taken from each plot at different depths, giving a total of six samples, which were then mixed to produce a composite sample of 1 kg per depth. This gave a composite sample of 1 kg per depth. A total of 12 soil samples were taken for laboratory analysis.

2.5. Laboratory analysis of samples

The analysis was carried out using the method in force at the Soil Laboratory of the Houphouët Boigny National Polytechnic Institute in Yamoussoukro, Ivory Coast. This involved analysing the soil's physical and chemical parameters: nutritional parameters (CEC, Ca^{2+}, Mg^{2+}, Na^+, K^+), acidity (pHeau), agronomic parameters (C, N and physical parameters (grain size analysis).

2.6. Statistical data analysis

Regression analyses were performed using XLSTAT Version 216. The GML (General Linear Model) procedure was used for regression analyses of soil variables (C, N, C/N, OM, Pass, Ca^{2+}, Mg^{2+}, K^+ CEC).

The analyses were performed using XLSTAT Version 216 and Microsoft Office Excel, version 2018. The Newman-Keuls test was used to rank the means using analysis of variance (ANOVA) at a 5% threshold. A normality test was performed on each variable to validate the ANOVA results.

3. Results

3.1. Analysis of chemical parameters of soils at study site 1

This table compares the chemical properties between Maize-SC and Maize on NAS at site 1. Analysis of variance shows a highly significant difference ($p < 0.05$) in Mg^{2+} values and a significant difference in Na^+ values between Maize on AS and Maize on NAS with higher AS contents; other parameter values such as pHwater, C, N, CEC, C/N, MO, Ca^{2+} and K^+ show no significant differences between Maïs on AS and Maïs on NAS.

The pHwater values of the soils studied at site 1 are acidic on unarmoured soil (NAS) and slightly acidic on armoured soil (AS), with higher values on armoured soil (6.3) than on unarmoured soil (5.8).

However, the C content is normal in both soils, with higher C contents in the crusted soil (11.57 g.kg^{-1}) than in the non-crusted soil (8.42 g.kg^{-1}).

The N value is normal (1.12 g.kg^{-1}) in the crusted soil, while the N value is low (0.86 g.kg^{-1}) in the non-crusted soil.

The average C/N values are relatively normal for both types of soil studied at site 1, with values of 10.33 on the crusted soil and 9.80 on the non-crusted soil.

The soils are poor in organic matter in the crusted soils, where the value is 19.9 g.kg^{-1} compared to 14.43 g.kg^{-1} in the non-crusted soil.

The soils studied have very low levels of exchangeable cations, Na^+, Ca^{2+} and K^+, and very low to low levels of Mg^{2+} in the soils studied. Values of 0.073 are noted on armoured soil compared to 0.04 cmol+kg^{-1} for Na^+ and 0.041 on AS compared to 0.0191 cmol+kg^{-1} on NAS for K^+; 0.26 to 0.68 cmol+kg^{-1} for Mg^{2+}, and 0.422 and 0.984 cmol+kg^{-1} for Ca^{2+}.

he values obtained for Pass range from 39 mgkg^{-1} on SC to 54.33 mgkg^{-1} on NAS. These levels are relatively normal on armoured soil and high on non-armoured soil.

As for CEC, the values vary; they are very low in crusted soil (3.25 cmol+kg^{-1}) and in uncrusted soil (3.73 cmol+kg^{-1}), which has a low mineral reserve (Table III).

Table 3 Chemical parameters of the soils at site 1

Site 1	pHwater	C gkg^{-1}	N gkg^{-1}	C/N	MO gkg^{-1}	Pass mgkg^{-1}	CEC cmol+kg^{-1}	Ca^{2+} cmol+kg^{-1}	Mg^{2+} cmol+kg^{-1}	K$^+$ cmol+kg^{-1}	Na$^+$ cmol+kg^{-1}
Maize on AS	6.3 a	11.57 a	1.12 a	10,33 a	19.9 a	39 a	3.25 a	0.897 a	0.68 b	0.041 a	0.073 b
Maize on NAS	5.8 a	8.42 a	0.86 a	9,80 a	14.43 a	54.33 a	3.73 a	0.643 a	0.26 a	0,0191 a	0.04 a
Pr > F	0.275	0.575	0.647	0.842	0.571	0.199	0.714	0.236	0.005**	0.146	0.036*
Significant	No	No	No	No	No	No	No	No	Yes	No	Yes

Maize on AS: Maize on armoured soil; Maize on NAS: Maize on non-armoured soil

3.2. Analysis of chemical parameters of soils at study site 2

Average values determined for pHwater, C, N, MO, C/N, Na^+ and Ca^{2+}

The pHwater of the soil profiles studied at site 2 is slightly acidic on crusted soils and non-crusted soils, with values between 6.

The C content is normal for maize on armoured soil and non-armoured soil, with values of 1.39 cmol+kg^{-1} on SC and 1.42 cmol+kg^{-1} on SNC. However, the N value is very low on SC (0.143 cmol+kg^{-1}) and on SNC (0.11 cmol+kg^{-1}).

The soils are very poor in organic matter, with a value of 2.393 cmol+kg^{-1} in crusted soils and

The average C/N values are relatively normal (9.32) in crusted soils and high (12.42) in the uncrusted soil studied.

The AS soil is significantly richer in Pass (59.1 mg.kg^{-1}) than the NAS soil (42.67 mg.kg^{-1}). In addition, the CEC of the AS soil is exceptionally higher (35.07 cmol+kg^{-1}) than that of the NAS (3.67 cmol+kg^{-1}). AS soil contains a higher concentration of magnesium (1.952 cmol+kg^{-1}) than NAS soil (0.517 cmol+kg^{-1}).

Unlike other nutrients, the SNC soil is richer in K+ (0.169 cmol+/kg) than the SC soil (0.028 cmol+/kg).

Table 4 Chemical parameters of soils at site 2

Site 2	pHwater	C gkg^{-1}	N gkg^{-1}	C/N	MO gkg^{-1}	Pass mgkg^{-1}	CEC cmol+kg^{-1}	Ca2+ cmol+kg^{-1}	Mg2+ cmol+kg^{-1}	K+ cmol+kg^{-1}	Na+ cmol+kg^{-1}
Maize on AS	6.0 a	1,39 a	0,143 a	9,327 a	2,393 a	59,1 b	35,07 b	1,86 a	1,952b	0,028 a	0,042 a
Maize on NAS	6.0 a	1,42 a	0,11 a	12,42 a	2,44 a	42,67 a	3,67 a	1,18 a	0,517 a	0,169 b	0,053 a
Pr > F	1,000	0,969	0,552	0,056	0,972	0,049*	0,004**	0,208	0,004**	0,002***	0,594
Significant	No	No	No	Non	No	Yes	Yes	No	Yes	Yes	No

Maize on AS: Maize on armoured soil; Maize on NAS: Maize on non-armoured soil

3.3. Interpretation of data from the analysis of soil particle size distribution at the study sites

The distribution of soil particle sizes in the soil layers and the soil profile is shown in Table V. The results show no significant difference in clay, sand and silt between armoured and non-armoured soils at site 1.

The most representative granulometric elements in the soils at site 1 are sand, with contents varying from 48.56% in armoured soil to 44.6% in non-armoured soil.

Clay content varies between 18% in armoured soil and 15.5% in non-armoured soil, while silt content varies between 31.45% in AS and 36.32% in sandy-clay soil, both for armoured and non-armoured soil at site 1.

At site 2, the clay content is significant, while the silt and sand contents are insignificant. The sand content is 54.25% on armoured soil, compared to 45.47% on non-armoured soil.

The clay content is 12.25% on armoured soil and 30.86% on non-armoured soil. However, the silt content is 29% on AS compared to 22.47%.

The soil texture is sandy on armoured soil and sandy-clay-loam on non-armoured soil at site 2.

Table 5 Granulometric parameters of the study site

Site1	Sand (%)	Silt (%)	Clay (%)	Texture	Site 2	Sand (%)	Silt (%)	Clay (%)	Texture
Maize on AS	48.56 a	31.45 a	18 a	sandy-clay	Maize-SC	54.25 a	29 a	12.25 a	sandy
Maize on NAS	44.6 a	36.32 a	15.5 a	sandy-clay	Maize-SNC	45.47 a	22.47 a	30.86 b	sandy-clay-loamy
Pr > F	0.417	0.368	0.635		Pr > F	0.111	0.312	0.001***	
Significant	No	No	No		Significant	No	No	Yes	

Maize on AS: Maize on armoured soil; Maize on NAS: Maize on non-armoured soil

3.4. Grain Yield of Corn Crops on Hardened Soil Compared to Control at Two Sites

The grain yield of corn on hardened soil and its control at Site 1 was not significant, unlike the grain yield of corn on hardened soil and its control at Site 2, where the difference in grain yield was highly significant. Furthermore, the correlation coefficient between the grain yield of the two soils at Site 1 was 0.713, with a negative statistical test value of -4.849 (Table).

The average yield was 1.08 t/ha on hardened soil compared to 0.65 t/ha on non-hardened soil at Site 1 (Table). However, the average grain yield of corn on hardened soil was 1.52 t/ha, while the average grain yield on non-hardened soil was 0.72 t/ha. The Pearson correlation coefficient between the two yields is 0.529, and the statistical test result is -14.36 (Table IV).

Table 6 Comparative study of grain yield of maize at sites 1 and 2

Treatment	Site 1 Grain Yield on Maize (t/ha)	Site 2 Grain Yield on Maize (t/ha)
AS	1.08 a a	1.52 a a
NAS	0.65 a a	0.72 b b
Statistical Test	-4.849	-14.36
Pr > F	0.100	0.001**
Significant	Non	Oui

AS: armoured soil; NAS: non-armoured soil

3.5. C Correlation physico-chemical parameters between and maize yield at the study sites

The results show that several parameters have a perfect correlation (1.0 or -1.0) with maize yield. This is a direct consequence of the small number of observations (two soil types). A correlation of 1.0 indicates that when the parameter increases, the yield also increases. A correlation of -1.0 indicates that when the parameter increases, the yield decreases.

Parameters such as nitrogen (N), silt, sodium (Na^+), potassium (K^+), pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), organic matter (OM), carbon (C) and the C/N ratio are perfectly positively correlated with yield. This suggests that higher levels of these elements or characteristics are associated with better maize yield between armoured and non-armoured soil.

Conversely, sand, clay, available phosphorus (Pass) and cation exchange capacity (CEC) are perfectly negatively correlated with yield. This implies that higher levels of these parameters are associated with lower maize yield at site 1.
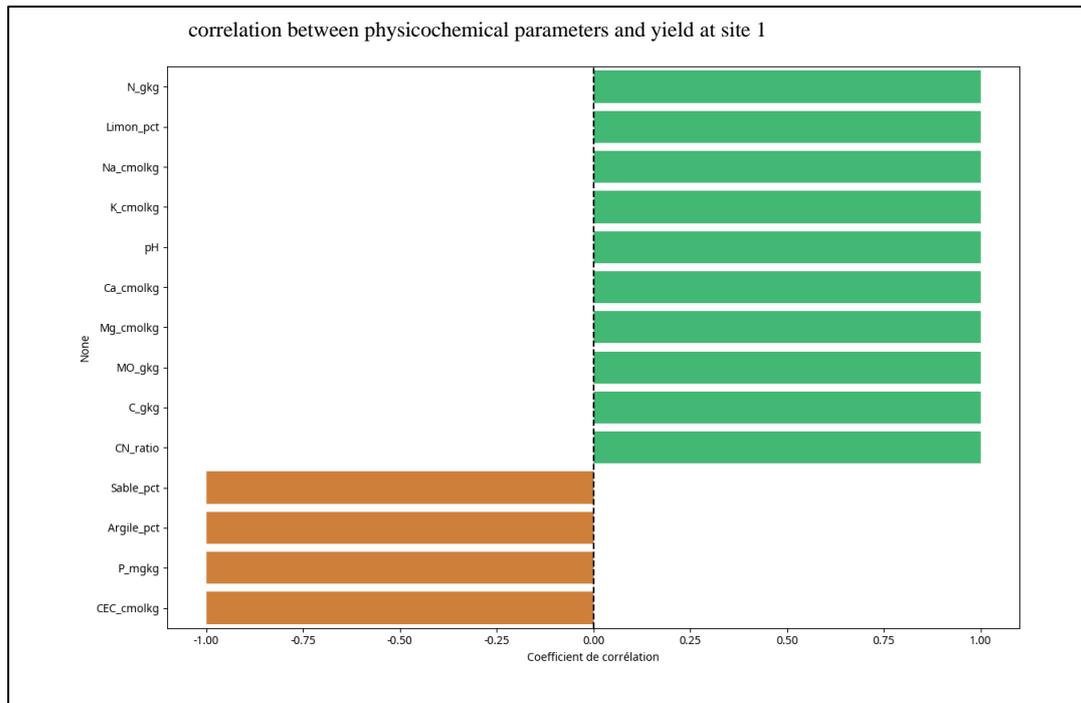
Figure 2 Correlation between physicochemical parameters and maize yield at site 1

Parameters such as silt, CEC, sand, nitrogen (N), calcium (Ca^{2+}) and phosphorus (Pass) show a positive correlation with maize yield. Conversely, carbon (C), C/N ratio, clay and organic matter (OM) show a negative correlation at site 2.
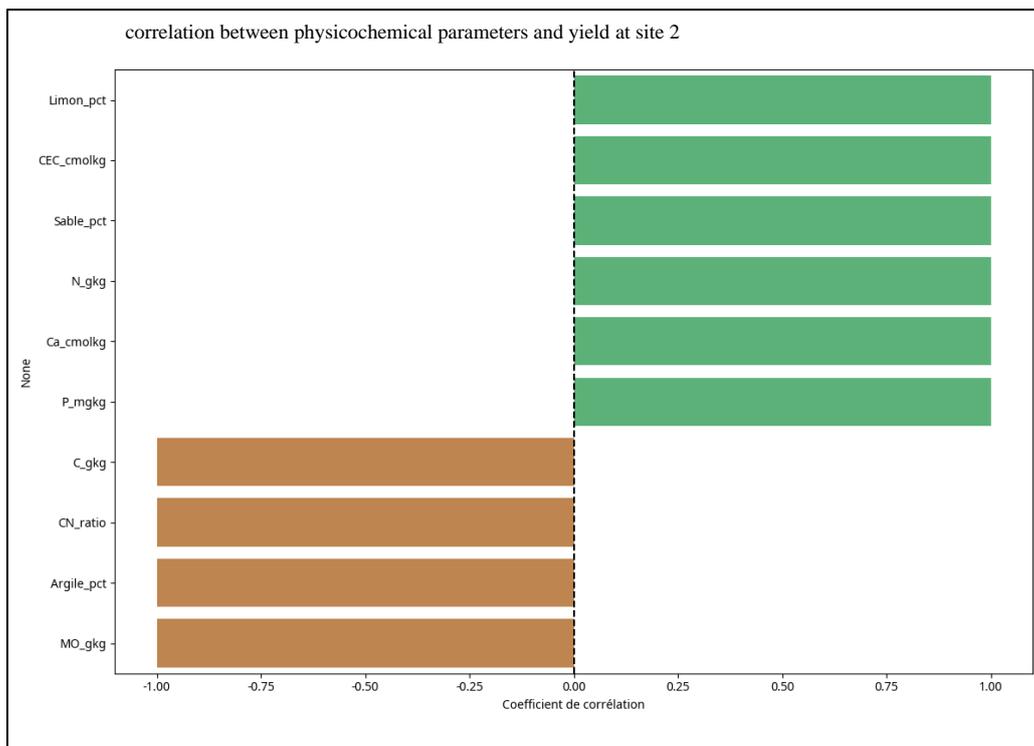

Figure 3 Correlation between physicochemical parameters and maize yield at site 2

4. Discussion

4.1. Analysis of Site 1 and Yield-Chemistry Correlations

First, on Site 1, the Mg^{2+} and Na^+ contents are significantly higher in hardened soils (AS) than in non-hardened soils (NAS). Furthermore, other parameters such as carbon (C), nitrogen (N), organic matter (OM), calcium (Ca^{2+}), and potassium (K^+) are also higher in AS, although these differences are not statistically significant. Conversely, phosphorus (Pass), cation exchange capacity (CEC), and the percentages of sand and clay are slightly higher in NAS. Consequently, the average yield in AS (1.08 t/ha) is higher than that in NAS (0.65 t/ha), suggesting better overall fertility in AS soils.

4.2. Analysis of Site 2 and Yield-Chemistry Correlations

Next, at Site 2, the cross-interpretation of yield data and chemical parameters reveals a consistent explanation for the productivity differences. Indeed, the excellent maize yield on the AS soil (1.52 t/ha) is strongly correlated with its significantly higher richness in essential nutrients and a much higher cation exchange capacity (CEC) compared to the NAS soil. More specifically, the increased availability of assimilable phosphorus (Pass) and magnesium, combined with a higher CEC in the AS soil, creates a more fertile soil environment. Thus, these factors likely promote better root development, increased nutrient uptake, and more efficient photosynthesis, resulting in a significantly higher grain yield. Although the NAS soil is richer in potassium, the positive impact of the other nutrients and the CEC in AS appears to be predominant, hence the dramatic and statistically significant yield difference.

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Furthermore, physicochemical analyses show that organic matter (OM) levels are very low at both sites, for both AS and NAS soils. Indeed, hardened soils often exhibit relatively low OM levels, which limits their fertility. Similarly, in NAS soils, this low OM content results from intensified cultivation without the application of organic fertilizers, explaining the excessive decrease in the organo-mineral horizon. Given the low C/N ratio, OM mineralization is rapid (Henintsoa, 2013) [11]. Consequently, OM allows both plant nutrition by releasing mineral elements and their storage, while preventing leaching through improved colloid adsorption. Thus, it constitutes a key driver for improving fertility and yields (Akanza *et al.,* 2002) [12]. Finally, the regular application of organic fertilizer remains a viable solution: it reduces acidification, increases saturation and CEC (Trigalet *et al.,* 2017) [13].

Moreover, the pH of the studied soils, moderately acidic to acidic (favourable for crops; Giguère, 2002), determines nutrient availability. However, a deficiency in OM, N, K^+, Na^+, and Ca^{2+} is observed, especially in the subsoil of the Tengréla department and northern Côte d'Ivoire, due to overexploitation linked to population growth (Akplo *et al.,* 2020; Saïdou *et al.,* 2012) [14] [15]. For example, Pass stimulates flowering and fruiting, while K^+ participates in metabolic processes for fruit yield and quality; nitrogen promotes growth, and Ca^{2+} prevents physiological diseases. Nevertheless, the excess of Mg^{2+} in the subsoil of Site 2 could negatively impact plant nutrition (Akassimadou and Yao-Kouamé, 2014) [16]. Germination Conditions and Microclimate

Moreover, particle size analyses indicate that the AS soils have a sandy to silty-sandy texture, while the NAS soils are sandy to sandy-loamy (Site 1) or sandy-clay (Site 2), textures favourable to corn. Therefore, a good yield is possible if nutrients are adequately supplied. Overall, average yields on conservation agriculture (CA) are 1.08 t/ha (Site 1) and 1.52 t/ha (Site 2), compared to 0.65 and 0.72 t/ha on conventional soils (CS), close to reported values (1.55-1.95 t/ha; Guibert et al., 2016) [17]. However, they remain below the global average (4.4 t/ha; Badu-Apraku, 2006) [18].

5. Conclusion

Evaluating the physicochemical parameters of hardened soils is essential for optimizing maize cultivation. The challenges identified in this study include shallow soil depth, deficiencies in certain exchangeable base (EB) elements, and low organic matter content. These factors limit maize yields on these soils and necessitate adapted management strategies, including soil amendment, the selection of appropriate maize varieties, and the adoption of sustainable farming practices. An integrated approach combining in-depth soil analyses with appropriate management techniques is needed to help improve agricultural productivity in regions where hardened soils are predominant.

However, further studies are necessary to fully understand the production environment required for sustainable, high-yielding maize production and to improve the income of maize farmers.

Research Directions

Further research could be undertaken to further explore farmers' perceptions of soil fertility in the context of climate variability and change. This will highlight the role of climate change and variability on the properties and agricultural suitability of lateritic soils, as perceived by farmers.

The practice of Assisted Natural Regeneration (ANR) for agroforestry on lateritic soils.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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