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Soil Quality in Central-Western and South-Western Burkina Faso - West Africa

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ABSTRACT

The study on the characterisation of the physico-chemical parameters of the soils of Poura, Fara and Ramongo aims to contribute to the improvement of soil quality in these mining areas. Observations of the physical and chemical characteristics were made on the three sites at the 0-30 cm and 30-60 cm horizons. The results indicate that EC, TDS, NH_4^+, NH_3^- and NO_3^- on the Poura site in the dry season were significant between horizons. EC (75 µs/cm) and TDS (75 mg/l) were high in the 0-30 cm horizon, while NH_4^+ (48.4 mg/l), NH_3^- (5.7 mg/l) and NO_3^- (629 mg/l) were high in the 30-60 cm horizon. In the wet season, only EC (48 µs/cm) and TDS (49 mg/l) increased significantly in the 0-30 cm horizon. For the Fara site, EC, TDS, NH_4^+, NH_3^-, NO_3^-, N^- NO_3^-, phosphorus, $P_2O_5^-$ and PO_4^{3-} were significant. The 0-30 cm horizon showed high values for EC (85 µs/cm), TDS (84 mg/l), phosphorus (1.86 mg/l), $P_2O_5^-$ (4.3 mg/l) and PO_4^{3-} (5.7 mg/l). The 30-60 cm horizon shows high values of NH_4^+ (24.3 mg/l), NH_3^- (23 mg/l), NO_3^- (548 mg/l), and N^- NO_3^- (124 mg/l). For the Ramongo site, the highest values were observed in the 0-30 cm horizon for EC (26 µs/cm), TDS (27 mg/l), NH_4^+ (23.2 mg/l), NH_3^- (22 mg/l), NO_3^- (150 mg/l), $P_2O_5^-$ (3.54 mg/l) and PO_4^{3-} (4.72 mg/l) with significant values. The high EC values, compared with the national standard (2 µs/cm), are significantly higher in mining areas than at the Ramongo site, indicating a soil pollution.

Keywords: parameters, physico-chemical, soils of the mine site, pollution, Burkina Faso

INTRODUCTION

Agriculture in Burkina Faso in its current form is dependent on soil quality and rainfall. A soil is the result of the decomposition of a source rock under the effect of physical factors (climate), plant and animal debris and biological activity [1], [2]. The soil is made up of more or less organic and mineral elements that promote plant growth. However, soils in Burkina Faso are subject to various forms of physico-chemical and biological degradation. Population pressure, the destruction of vegetation cover, mining and agricultural activities contribute to intensifying water erosion, with the consequent decline in soil quality. The deterioration of soil fertility results in a reduction in agricultural yields [3], even though agriculture is the main activity of the Burkinabe population, most of whom are rural. However, mining in Burkina Faso is an activity that contributes to reducing poverty in rural areas by injecting monetary income and has experienced significant development over the last ten (10) years. Of the potential in mining resources, gold is currently the most exploited resource and the leading export product. Three types of gold mining are practiced: industrial mining, semi-mechanized mining and artisanal mining, called "gold panning" which employs more than a million people according to estimates by the Ministry in charge of mines. However, this sector creates a lot of environmental problems. Without being exhaustive, this activity causes deforestation, deforestation, soil degradation, air, soil and water pollution, loss of biodiversity and shaping of the landscape [4], [5], [6], [7]. Artisanal gold mining is generally accompanied by the opening of trenches, wells, scraping and turning of the soil, with the corollary of the weakening of the soil and the progressive destruction of arable land. Gold panning contributes to the destruction of plant cover and predisposes the soil to often intense erosion processes [8]. In addition, the use of chemical substances (mercury, cyanide, acids) and other non-biodegradable solid wastes can reduce soil fertility [9]. As soil is an important support for ecosystems, particularly terrestrial ecosystems, a deterioration in its physical, chemical and biological properties induces subsidiarity in the consequences generated, in this case on agrosilvopastoral activities. The current concern boils down to maintaining, over time, the productivity and fertility of cultivated soils. The general objective of this study is to assess the quality of the soil in our study area, which is plagued by mining activity. It will be a question of evaluating the texture of the soils through the characterization of the particle size of three (3) fractions, of characterizing the chemical behavior of the soils based on the physicochemical parameters, of determining the pedo-agronomic characteristics of these soils studied and finally of evaluating the fertility based on the variation in carbon (C), nitrogen (N) and the C/N ratio as a function of the soil texture.

METHODOLOGY

The study area includes three sites, the first two of which are the localities of Poura and Fara located 180 km southwest of Ouagadougou, the capital of Burkina Faso. They are located in the province of the "Balés", region of the Boucle du Mouhoun, located between latitudes 11°20 North and 11°50 North and longitudes 2°40 West and 2°55 West (Figure 1). The vegetation is characterized by a shrubby and wooded savannah and a gallery forest along the Mouhoun River with Vitellaria paradoxa, Lannea microcarpa, Balanites aegyptiaca, Piliostigma thonningii, and Eucalyptus camaldulensis and a great forage potential represented mainly by mimosaceae [10], [11]. It is a locality with strong agricultural potential, where the peasant world is made up of agricultural cooperatives. The third site, Ramongo, is located 80 km from Ouagadougou and has geographical coordinates of latitude 12° 13′ 0" North and longitude 2° 13′ 60" West and altitude 299 m. It is characterized by a Sudano-Sahelian climate. The vegetation of Ramongo is characterized by wooded parks dominated by protected species such as Parkia biglobosa, Vitellaria paradoxa, Faidherbia albida, Lannea microcarpa, Tamarindus indica L and Khaya senegalensis. Piliostigma reticulatum [12].

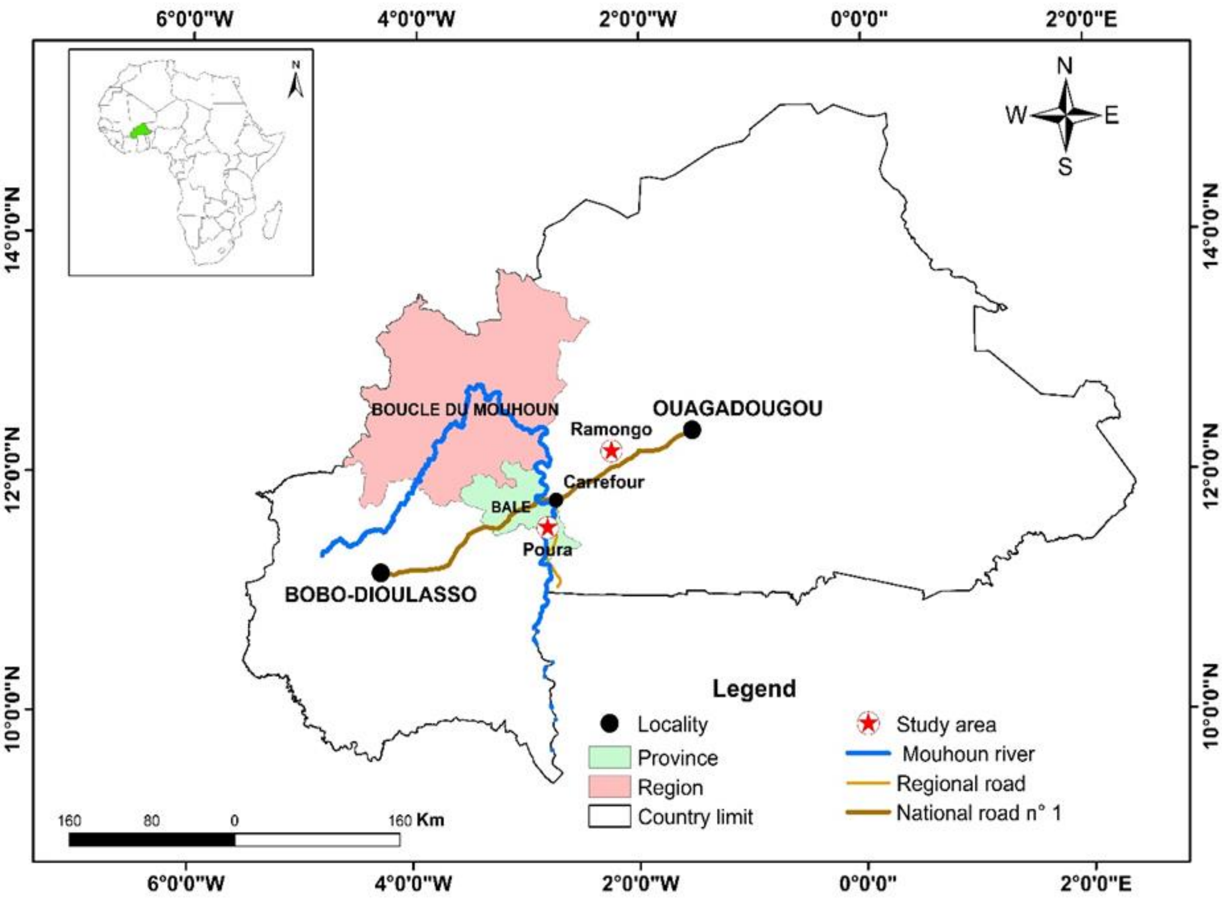

Figure 1: Location of study sites

The sampling concerned only the soils. It was made using a 20 cm diameter manual auger. Two depths were considered for the sampling. A first sampling takes place in a horizon called "topsoil", defined as 0 to 30 cm deep, and a second sampling takes place at a depth of 30 to 60 cm in another horizon, called "subsoil". At all sites, we carried out random sampling. Composite samples were formed from five samples taken from the same site at 20-metre intervals. A GPS, from Garmin 62S, was used to record the geographical coordinates. All samples were packaged in plastic bags and labelled before being sent to the laboratory of the Bureau of Mines and Geology of Burkina Faso (BUMIGEB) for physical preparation. To avoid contamination from one horizon to another, or from one sample to another, the equipment used is decontaminated by rubbing it at least three times with the type of soil to be sampled before it is packaged. The samples were packaged in sterile bags of sizes: 20X30 cm (250µm); 30X40 cm (200µm and 250µm); 45X50cm (200µm); 80X50cm (200µm) and sent to the laboratory. Physico-chemical parameters such as pH, temperature, total dissolved salts (TDS), electrical conductivity (EC), exchangeable bases, soil nutrients, cation exchange capacity and saturation rate, were carried out in the LEHSA laboratory of 2IE and in the CID laboratory using standard methods [13]. Other complementary analyses, such as the three-fraction particle size, using the sedimentometry method (densimetry) were carried out at the Soil-Water-Plant laboratory of INERA using methods from the National Soil Bureau of Burkina Faso [14]. The texture of the soils was determined with the texture triangle by the GIZ and FAO method version 1.4 [15]. The soil quality in the Poura-Fara gold zone was conducted through the evaluation of the physico-chemical parameters addressed, as well as a comparative study with a non-mining area such as the Ramongo site. Samples were taken both in the wet and dry seasons for the Poura site, and exclusively in the winter and dry seasons, respectively for Fara and Ramongo, for reasons of accessibility related to the insecurity that Burkina Faso is experiencing during the period.

Figure 2: Particle size measurement by densimetry (a: sedimentation, b: densimetric measurement)

RESULTS

Particle size

The particle size and textural distribution of soils in the two horizons of the different study sites is contained in Table 1.

Poura site

During the dry season, the soils of the Poura site showed no significant variation between the two horizons in terms of sand content. However, the clay content has evolved at the level of the 30-60 cm horizon with a value of 20.71%. In addition, the silt rate varied significantly but in the opposite direction to that of clay with a rate of 25.37% in the 0-30 cm horizon of the soil. It can be seen that the topsoil or surface layer has a sandy silt (LS) texture, while the subsoil has a sandy-clay silt (LSA) texture. It is noted that during the wet season, no significant variation was observed in sand, silt or clay.

Fara site

During the winter season, no significant variation was observed in the soils of the Fara site with regard to the sand content. On the other hand, for the clay and silt levels, significant differences were observed. Thus, the clay content is higher in the "subsoil" horizon with 17.00% and that of silt in the "topsoil" horizon with 19.23%. The lowest clay content is recorded in the "topsoil" horizon with 13.72% and that of silt in the "subsoil" horizon with 16.48%. Texturally, the respective proportions of clay, silt and sand in the topsoil (13.72%; 19.23% and 67.05%) indicate a sandy silt texture. At the subsoil level, these proportions (17.00%; 16.48% and 66.52%) also have a sandy loam texture.

Ramongo site

As far as the Ramongo site is concerned, no significant difference is observable between the horizons in terms of silt. Unlike clay and sand which show significant differences between the two horizons. Thus, we notice that the level of clay is higher than the level of the "subsoil" horizon with 25.49% and the lowest rate is noted in the "topsoil" with 19.61%. As for the sand rate, it is higher in the surface horizon with 66.67% and the lowest rate is recorded in the deeper horizon with 59.8%. The superficial and deep horizons each indicate a sandy-clayey silt texture.

Table 1: Particle size composition of the soil

Nature of the site	Horizon	Clay content (%)	Silt content (%)	Sand content (%)	
POSL	0-30 cm	16.30b±3.43	25.37a±1.99	58.33±4.29	LS
	30-60 cm	20.71a±6.90	21.69b±4.40	57.60±4.68	LSA
	Probability	***0.048***	***0.048***	***0.749***	
	Signification	***S***	***S***	***NS***	
SLP	0-30 cm	20.99±3.77	19.80±2.63	59.21±3.22	LSA
	30-60 cm	21.37±3.56	20.59±3.92	58.04±6.88	LSA
	Probability	***0.870***	***0.720***	***0.738***	
	Signification	***NS***	***NS***	***NS***	
SLF	0-30 cm	13.72±1.40	19.23±6.64	67.05±10.78	LS
	30-60 cm	17.00±2.32	16.48±5.07	66.52±10.96	LS
	Probability	***0.049***	***0.047***	***0.903***	
	Signification	***S***	***S***	***NS***	
RA	0-30 cm	19.61±8.40	13.72±8.40	66.67±8.40	LSA
	30-60 cm	25.49±8.40	14.71±8.40	59.8±8.40	LSA
	Probability	***0.049***	***0.754***	***0.048***	
	Signification	***S***	***NS***	***S***	

POSL: Poura soil in the dry season, SLP: Poura soil in the winter season, SLF: Fara soil, RA: Ramongo soil. N: significant, NS: non-significant.

Physico-chemical parameters

Table 2 presents the physicochemical parameters of the soils

Poura site

During the dry season, the soils of the Poura site showed no significant differences in pH, temperature, N^- NO_3^-, phosphorus (P), $P_2O_5^-$ and PO_4^{3-}, at any horizon. However, significant variations were observed with EC, TDS, NH_4^+, NH_3^- and NO_3^- between the horizons. Thus, we note a high EC and TDS at the level of the 0-30 cm horizon with values of 75 µs/cm and 75 mg/l respectively. In contrast to NH_4^+, NH_3^- and NO_3^- where high values at depth (30-60 cm) are recorded with respective values of 48.4 mg/l; 45.7 mg/l and 629 mg/l. During the wet season, the soils of the Poura site do not reveal any significant variation between the horizons, with regard to pH, temperature, NH_4^+, NH_3^-, NO_3^-, N^- NO_3^-, Phosphorus (P), $P_2O_5^-$ and PO_4^{3-}. On the other hand, there is a significant difference with the EC and the TDS. Thus, in the 0-30 cm horizon, there is an increase in EC and TDS with averages of 48 µs/cm and 49 mg/l respectively. The lowest values were recorded at the 30-60 cm horizon with an average of 12 µs/cm and 12 mg/l respectively.

Fara site

During the winter season, the soils of the Fara site showed no significant variation between the horizons, in terms of pH and temperature. On the other hand, there were significant variations in EC, TDS, NH_4^+, NH_3^-, NO_3^-, $N^-NO_3^-$, Phosphorus (P), $P_2O_5^-$ and PO_4^{3-}. Thus, at the level of the 0-30 cm horizon, there are high values of EC, TDS, Phosphorus (P), $P_2O_5^-$ and PO_4^{3-} with respective averages of 85 µs/cm, 84 mg/l; 1.86 mg/l; 4.3 mg/l and 5.7 mg/l. At the 30-60 cm horizon, high values are recorded with NH_4^+ (24.3 mg/l), NH_3^- (23.00 mg/l), NO_3^- (548 mg/l), $N^-NO_3^-$ (124 mg/l).

Ramongo site

The soils of the Ramongo site show no significant variation in pH, temperature, $N^-NO_3^-$ and phosphorus (Table 2). On the other hand, there are significant variations with EC, TDS, NH_4^+, NH_3^-, NO_3^-, $P_2O_5^-$ and PO_4^{3-}. Thus, the highest values were recorded at the 0-30 cm horizon for EC (26 µs/cm), TDS (27 mg/l), NH_4^+ (23.2 mg/l), NH_3^- (22 mg/l), NO_3^- (150 mg/l), $P_2O_5^-$ (3.54 mg/l) and PO_4^{3-} (4.72 mg/l).

Table 2: Soil Chemistry

Nature du site	**Horizon**	**pH eau**	**T (°C)**	**CE (µs/cm)**	**TDS (mg/l)**	**NH_4^+ (mg/l)**	**NH_3^- (mg/l)**	**NO_3^- (mg/l)**	**$N^-NO_3^-$ (mg/l)**	**P (mg/l)**	**P_2O_5 (mg/l)**	**PO_4^{3-} (mg/l)**
POSL	0-30 cm	6.88±0.39	27.05±2.23	75a±9.59	75a±5.51	23.1b±2.02	21.8b±2.52	500b±33.88	113±15.44	4.41±0.91	10.1±1.96	13.6±2.00
	30-60 cm	6.54±0.46	26.38±2.50	39b±5.43	39b±3.43	48.4a±8.51	45.7a±6.92	629a±64.41	142±16.88	3.58±0.27	8.2±1.49	11.0±1.03
	Probability	***0.133***	***0.607***	***0.035***	***0.035***	***0.043***	***0.043***	***0.049***	***0.723***	***0.632***	***0.620***	***0.618***
	Signification	***NS***	***NS***	***S***	***S***	***S***	***S***	***S***	***NS***	***NS***	***NS***	***NS***
SLP	0-30 cm	6.86±0.28	28.76±1.36	48a±3.38	49a±3.49	25.9±2.44	24.4±2.86	425±41.87	96±5.75	1.12±0.09	2.56±0.07	3.42±0.62
	30-60 cm	6.30±1.10	30.10±1.54	12b±1.20	12b±1.40	21.4±1.05	20.3±1.21	452±25.70	102±8.60	0.68±0.05	1.55±0.05	2.08±0.68
	Probability	***0.302***	***0.183***	***0.013***	***0.013***	***0.760***	***0.762***	***0.933***	***0.932***	***0.467***	***0.471***	***0.473***
	Signification	***NS***	***NS***	***S***	***S***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
SLF	0-30 cm	7.14±0.42	28.36±0.73	85a±7.93	84a±6.91	15.1b±3.07	14.3b±2.68	349b±34.31	79b±6.78	1.86a±0.08	4.3a±0.09	5.7a±0.09
	30-60 cm	7.09±0.88	29.76±0.90	51b±6.61	51b±7.68	24.3a±2.80	23.0a±3.98	548a±54.26	124a±9.72	0.7b±0.04	1,7b±0.07	2.2b±0.02
	Probability	***0.873***	***0.101***	***0.047***	***0.047***	***0.049***	***0.049***	***0.044***	***0.040***	***0.032***	***0.031***	***0.032***
	Signification	***NS***	***NS***	***S***	***S***	***S***	***S***	***S***	***S***	***S***	***S***	***S***
RA	0-30 cm	7.01±0.13	27.6±4.91	26a±7.93	27a±7.93	23.2a±7.93	22a±7.93	150a±7.93	260±7.93	0.23±0.03	3.54±0.03	4.72a±0.07
	30-60 cm	7.45±1.04	30.2±4.93	18b±7.93	19b±7.93	15.3b±7.93	15b±7.93	107b±7.93	262±7.93	0.21±0.03	1.7b±0.02	2.6b±0.04
	Probability	***0.910***	***0.878***	***0.048***	***0.042***	***0.049***	***0.049***	***0.047***	***0.978***	***0.816***	***0.038***	***0.048***
	Signification	***NS***	***NS***	***S***	***S***	***S***	***S***	***S***	***NS***	***NS***	***S***	***S***

Soil and agronomic characteristics

Table 3 presents the soil and agronomic parameters of the soils studied. The variables used to characterize the pedo-agronomic qualities of our sites under study are the variation of exchangeable bases, the variation of the sum of exchangeable bases, the cation exchange capacity and the soil saturation rate.

Poura site

During the dry season, the soils of the Poura site did not reveal any significant differences between the horizons with regard to all the parameters determined. However, there are some differences in grades between the horizons. High concentrations of Ca2+ (1.67 cmolc.kg-1), Mg2+ (1.04 cmolc.kg-1), sum of bases (3.01 cmolc.kg-1), CEC (4.48 cmolc.kg-1) and saturation rate (66.50%) were recorded at the 0-30 cm horizon. As for K+ and Na+, they have high concentrations in the 30-60 cm horizon, respectively 0.22 cmolc.kg-1 and 0.21 cmolc.kg-1. During the wet season phase, the soils of the Poura site showed no significant variation between horizons in terms of the variation of exchangeable bases, the sum of exchangeable bases, cation exchange capacity and soil saturation rate.

However, some numerical differences were observed between the horizons. There were high levels of Ca2+ (1.67 cmolc.kg-1), Mg2+ (1.03 cmolc.kg-1), basal (3.08 cmolc.kg-1) and CEC (4.92 cmolc.kg-1) at the 0-30 cm horizon. As for the K+; of Na+ and saturation rate, they were raised with the horizon 30-60 cm respectively by (0.46 cmolc.kg-1; 0.08 cmolc.kg-1 and 65%).

Fara site

The soils of the Fara site do not show any significant variation between horizons in general. Nevertheless, there are some numerical differences. The highest results were observed with the 0-30 cm horizon, for Ca2+ (1.92 cmolc.kg-1), Mg2+ (1.11 cmolc.kg-1), K+ (0.58 cmolc.kg-1), sum of bases (3.77 cmolc.kg-1), CEC (5.35 cmolc.kg-1) and saturation rate (70.40%). As for Na+ (0.21 cmolc.kg-1), it was raised with the horizon 30-60 cm.

Ramongo site

No significant differences were observed in the soils of the Ramongo site between the horizons. However, there are some numerical variations between the horizons. The highest numerical values for Ca2+ (1.76 cmolc.kg-1), Mg2+ (1.13 cmolc.kg-1), sum of bases (3.11 cmolc.kg-1) and CEC (4.9 cmolc.kg-1) were recorded by the 0-30 cm horizon. On the other hand, the Na+ (0.12 cmolc.kg-1) and the saturation rate (68%) were higher than the level of the 30-60 cm horizon.

Table 3: Soil and agronomic characteristics

Nature du site	Horizon	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Somme des bases	CEC	Taux de saturation
POSL	0-30 cm	1.67±0.03	1.04±0.08	0.21±0.04	0.08±0.09	3.01±0.74	4.48±0.68	66.50±7.90
	30-60 cm	1.41±0.07	0.93±0.04	0.22±0.06	0.21±0.08	2.76±0.45	4.40±0.83	63.00±3.96
	Probability	***0.169***	***0.320***	***0.985***	***0.092***	***0.430***	***0.836***	***0.327***
	Signification	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
SLP	0-30 cm	1.67±0.01	1.03±0.03	0.38±0.03	0.07±0.03	3.08±0.88	4.92±0.54	63.40±4.84
	30-60 cm	1.40±0.06	0.73±0.01	0.46±0.08	0.08±0.03	2.45±0.61	3.78±0.92	65.00±6.75
	Probability	***0.424***	***0.292***	***0.329***	***0.524***	***0.229***	***0.424***	***0.719***
	Signification	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
SLF	0-30 cm	1.92±0.02	1.11±0.01	0.58±0.05	0.15±0.05	3.77±1.11	5.35±1.26	70.40±8.55
	30-60 cm	1.65±0.03	1.05±0.04	0.40±0.01	0.21±0.04	3.31±1.12	4.72±1.27	69.10±6.62
	Probability	***0.255***	***0.642***	***0.125***	***0.310***	***0.298***	***0.199***	***0.700***
	Signification	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
RA	0-30 cm	1.76±0.07	1.13±0.08	0.13±0.01	0.09±0.02	3.11±0.28	4.9±0.92	63±7.11
	30-60 cm	1.65±0.04	1.07±0.09	0.13±0.02	0.12±0.03	2.97±0.60	4.4±0.82	68±5.12
	Probability	***0.872***	***0.928***	***0.992***	***0.916***	***0.467***	***0.991***	***0.875***
	Signification	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Variation du carbone, de l'azote et du rapport C/N en fonction de la texture des sols

Table 4 presents the chemical properties of the soils studied.

Poura site

During the dry season, the soils of the Poura site showed no significant differences between the different horizons for all parameters. However, there are some numerical differences. The carbon and nitrogen contents are higher at the 30 to 60 cm horizon with values of 0.47% and 0.07% respectively. In contrast to the C/N ratio, which notes a high value at the 30 to 60 cm horizon with 7.02. During the wet season, there is no significant variation in carbon between textures. On the other hand, there are significant variations in both nitrogen and C/N ratio. Thus, the highest nitrogen content came from the LAS texture with 0.06% compared to the LS texture which recorded the lowest nitrogen content (0.04%). The C/N ratio was higher than the LS texture at 7.09 and the lowest C/N ratio was recorded by the LAS texture (6.79).

Fara site

During the winter season, the soils of the Fara site show no significant difference between the different horizons with regard to carbon, nitrogen and C/N ratio. However, there are some numerical differences in carbon and C/N ratio. Thus, there is a higher value with carbon at the LS texture level (0.45%) and a low value at the LAS texture level (0.43%). As for the C/N ratio, the highest value was noted by the LS texture with 10.75 and the lowest value was noted by the LAS texture with 10.02.

Ramongo site

For the Ramongo site, the results did not reveal any significant difference between the different horizons. However, there were some numerical variations. Thus, the carbon, nitrogen and C/N ratio contents were higher than the LAS texture level with values of (0.33%, 0.05% and 7.11, respectively). The lowest values for carbon, nitrogen and C/N ratio were observed at the LS texture of (0.23%, 0.04% and 6.82), respectively.

Table 4: Variation in carbon, nitrogen and C/N ratio as a function of soil texture

Nature of the site	Texture	C%	N%	C/N
POSL	LS	0.44±0.10	0.06±0.02	7.02±0.46
	LSA	0.47±0.06	0.07±0.01	6.97±0.21
	Probability	***0.503***	***0.814***	***0.805***
	Signification	***NS***	***NS***	***NS***
SLP	LSA	0.31±0.06	0.04b±0.01	7.09a±0.25
	LSA	0.40±0.09	0.06a±0.01	6.79b±0.12
	Probability	***0.070***	***0.043***	***0.045***
	Signification	***NS***	***S***	***S***
SLF	LS	0.45±0.06	0.04±0.01	10.75±1.07
	LS	0.43±0.05	0.04±0.01	10.02±1.01
	Probability	***0.504***	***0.906***	***0.886***
	Signification	***NS***	***NS***	***NS***
RA	LSA	0.23±0.05	0.04±0.01	6.82±0.08
	LSA	0.33±0.07	0.05±0.01	7.11±0.09
	Probability	***0.094***	***0.774***	***0.672***
	Signification	***NS***	***NS***	***NS***

Variation in electrical conductivity

With regard to the typology of sites, it can be seen that the sites hosting mining activities (Poura and Fara) have a particularly high electrical conductivity (EC) compared to the Ramongo site with no mining activity.

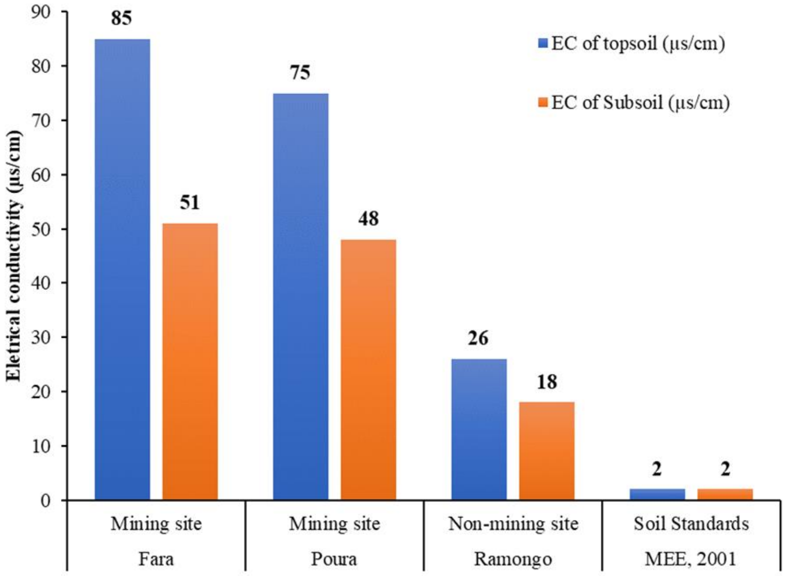

Figure 3: Variation of the electrical conductivity (EC) of the different sites as a function of the horizons

DISCUSSION

Particle size composition of the soil

Regardless of the type of farming, during the dry season, the soils of the Poura site were not positively influenced by the different horizons, apart from the texture in the 0-30 cm horizon. This could be explained by the contribution of organic manure which may have enriched the topsoil with organic matter, thus promoting an increase in clay, silt and sand contents. The texture observed in the 30-60 cm horizon would be justified by the lack of organic matter in the subsoil.

During the wet season, no significant variation was observed in texture for the Poura site. However, there is a high clay and silt content in the subsoil. This could be linked to a high organic matter content in this profile due to the burial of organic manure in the deep soil layer. The Arabian layer high in sand would be due to the low rate of organic matter but also to erosion. As for the Fara site, during the winter season, the soils of the site were significant in clay and silt. This would translate into a richness of the site's soils in organic matter in the different layers. As for the soils of the Ramongo site, they were significant in clay and sand. There is a high clay content in the subsoil (30-60 cm) and this is due to the burial of organic manure in the soil. The high sand content in the topsoil (0-30 cm) is explained by the low level of organic matter in this layer, but also by tillage and the effects of erosion. Our results are similar to those of [19] who proved that the high proportion of sand found in the surface horizon of cultivated soils is due to the destructive effects of ploughing, especially carried out with tractors.

Chemical characterization of soil

During the dry season, the soils of the Poura site showed no significant variation in pH, temperature, $N^-NO_3^-$, phosphorus (P), $P_2O_5^-$ and $P0_4^{3-}$ regardless of the type of farm. On the other hand, EC, TDS, NH_4^+, NH_3^- and NO_3^- were significant. Thus, the high EC and TDS at the 0-30 cm horizon with values of 75 µs/cm and 75 mg/l respectively, could be explained by the richness in organic matter and the presence of intense microbial activity in the surface layer of the soil, thus favouring the concentration of mineral elements and an increase in soil temperature. Unlike NH_4^+, NH_3^- and NO_3^- they were higher in the 30-60 cm horizon, which here reflects a leaching of these elements into the subsoil. The modification of the physical and chemical composition by the upwelling of materials taken from the depths of the soil and the incorporation of organic matter into epigeal nests during their construction and/or repair, and the redistribution of these elements in the adjacent soil, confirm the role of termites as soil engineers [16]. As far as the wet season is concerned, the different horizons as well as the different fertilization inputs could not positively influence pH, $N^-NO_3^-$, phosphorus (P), $P_2O_5^-$, PO_4^{3-}, NH_4^+, NH_3^- and NO_3^- with the exception of EC and TDS, which were significant. There is also an increase in EC and TDS in the 0-30 cm horizon. This situation would be justified by the supply of organic matter in this superficial part of the soil which constitutes the topsoil. The increase in TDS would be due to the transformation of organic matter by microorganisms, thus leading to an increase in heat, and therefore a release of ions. However, the low EC and TDS values noted in the 30-60 cm horizon would result in the low level of organic matter and microbial flora in this profile. [17], report that the total exchange capacity of the soil depends more on organic colloids than on clays, often in smaller quantities and of the kaolinite type, with low exchange capacity. The soils of the Fara site in the winter season have a non-significant pH and temperature. In contrast to other parameters such as, EC, TDS, NH_4^+, NH_3^-, NO_3^-, $N^-NO_3^-$, Phosphorus (P), $P_2O_5^-$ and PO_4^{3-} which varied significantly and increased in the 0-30 cm profile with the exception of NH_4^+, NH_3^-, NO_3^-, and $N^-NO_3^-$ which were higher in the 30-60 cm horizon. The increase in these parameters in the 0-30 cm horizon could be explained by the contribution of the various fertilisers which may have enriched the topsoil with fertilising elements. By the simulation method, [18] have shown that the presence of straw increases the N content in bare soil by 1.1 times. The presence of mineral elements in the subsoil would be justified by their runoff or leaching in this profile. For the soils of the Ramongo site, the parameters observed varied significantly. Except pH, temperature, $N^-NO_3^-$ and Phosphorus (P). Thus, the different parameters had high values in the 0-30 cm horizon and this could be explained by the richness of these elements in this topsoil following the addition of fertilizers and organic matter. The low content of these elements in the 30-60 cm horizon would result in a poverty of fertilizing elements and organic matter in the subsoil. With regard to the typology of sites, it can be seen that the sites hosting mining activities (Poura and Fara) have a particularly high CE compared to the Ramongo site with no mining activity. These high EC values, which express the ionic state of the chemical elements present, constitute a signature of environmental pollution, likely to affect agricultural production and in general the ecosystem through salinization or aluminum pollution, or even trace metal elements [13]. A comparative study of pollution results across the EC could be attributable to mining activities.

Soil and agronomic characterization of sites

During the dry and wet season, the soils of the site did not vary in chemical elements (exchangeable bases, sum of exchangeable bases, cation exchange capacity and soil saturation rate) between the horizons regardless of the type of exploitation and fertilization applied. This situation could be linked to the low rate of soil cover of leaf biomass and microorganisms. But also, this could be explained by a low rate of organic matter in the different soil horizons of the site. The same observation was made with the soils of the Fara sites in the winter season and Ramongo. According to [20], this poverty of the soil's reserves of exchangeable bases is also explained by very low levels of organic matter; Organic matter is the main determining factor in the retention of cations on the adsorbent complex.

Characterization of soil fertility at different sites

The soils of Poura and Ramongo in the dry season, and those of Fara in the winter, are low in carbon, nitrogen and C/N ratio regardless of soil texture and farm types, as no evidence of significance during all these periods has been found. This is thought to be due to the decline in leaf biomass and low soil organic matter at these sites. According to [21], this decrease in organic matter content on cultivated soils is due to the practice of producers, which does not compensate for the losses of organic matter. Our results are in agreement with those of [22] which attest that this situation is caused by tillage which leads to a loss of carbon through mineralization and water erosion. On the other hand, during the wet season, the soils of the Poura site showed a significant presence of nitrogen and C/N ratios in the different textures. Indeed, the nitrogen content was higher in the silty-clay-sandy soils and this could be justified by the presence of clay likely to maintain the mineral elements on its surface. The reference [23] reports that the positive effect of organo-mineral fertilization on crops results from the improvement of the organo-mineral status of the soil and its probable interaction on the physical properties of the soil, including the water status. The C/N ratio increased in sandy loam soils. This would be linked to the addition of organic fertiliser in the soil, which was able to release mineral elements such as carbon in large quantities. External fertilizers (cow dung and chemical fertilizers, household manure) increase the organic matter content of the soil compared to the control field on the 0-10 cm and 10-25 cm horizons [24].

Characterization of soil pollution

The chemical characterization of the soils of the different sites under study indicates that the EC values are above the standards of Burkina Faso in terms of environmental impacts on the soil (Figure 3). It can be seen that the Fara and Poura sites hosting artisanal and industrial mining sites have EC values that are 3 times higher on average than those of the Ramongo site, which has zero mining activity. These values correspond to 43 times higher than the normative values in force in Burkina Faso for the Fara site, 38 times for the Poura site and 13 times for the Ramongo site. As the Ramongo site is exclusively agricultural, it could be deduced that its pollution would probably be linked to agricultural activities and to a lesser extent to the geological context, i.e. the nature of the rocks [13]. By considering the pollution of the Ramongo site as being the contributing part of agricultural and natural activities, it could be deduced that the share of responsibility of mining activities in the pollution is highly considerable in view of these high EC values of the two horizons studied (Fara site: 85 and 51 µs/cm, Poura site: 75 and 48 µs/cm). This pollution could be linked to salinization or contaminating trace metal elements in the environment [25], [26], [27], despite the sequestration of the latter by organic matter and microbial activities [28], [29], [30]. This is confirmed by Figure 3, which shows low values at the subsurface horizon (30-60 cm) compared to the surface horizon (0-30 cm) in all the sites studied and regardless of the season.

CONCLUSION

In this study, soil chemistry, soil particle size composition, changeable base change, sum of exchangeable bases, cation exchange capacity, soil saturation rate, and variation in carbon, nitrogen and C/N ratio as a function of soil horizons were observed. These observations mainly focused on three sites: the Poura site in the dry and wet season, the Fara site in the winter season and the Ramongo site in the dry season, at the 0-30 cm and 30-60 cm horizons. It appears from these results that the soil parameters of the different sites varied more or less overall, except with the pH and the highest parameters in value were mainly observed in the topsoil. As far as the particle size is concerned, no significant variation has been observed at the Poura site. On the other hand, significant differences were observed for the Fara site in clay and silt between the different layers as well as for the Ramongo site which recorded a significant variation with clay and sand. The clay content was higher in the subsoil, unlike the sand, which was higher in the topsoil. However, for the different sites visited, no significant variation was found between textures, exchangeable bases, sum of exchangeable bases, cation exchange capacity and soil saturation rate. The same is true for carbon, nitrogen and C/N ratio with the exception of the Poura site in the wet season, where significance was recorded with nitrogen and C/N ratio. Nitrogen content was higher in silty-clay-sandy soils and C/N ratio increased in silty-sandy soils. The obtaining of high EC values in the soil horizons of mining sites compared to the non-mining site, provides very significant information on the involvement of anthropogenic activities, particularly mining, in soil pollution.

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