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Assessment of the Quality of Agricultural Soils in Manica Province (Mozambique)

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Abstract: Agriculture is the main economic activity of Mozambique and there is lack of information about the quality of agricultural soils. In this paper, five soils from the Manica and Sussudenga districts (Manica province) were sampled in the years 2021/2022 and 2022/2023 (before and after the rainy seasons), were subjected to an agronomical and environmental chemical analysis to assess its quality, either from the fertility and environmental contamination point of view. Standard analytical methodologies from external certified laboratories and local X-ray fluorescence measurements were used. All the studied soils are acidic (pH ranging from 4.5 and 5.4), have no salinity problems (conductivity ranging from 4.2 to 11.8 mS/m), have low amount of soil organic matter (0.90% to 1.81%), and soils from the Sussudenga district have a very low cation exchange capacity (CEC) (average of 3.33 cmolc/kg), while those from Manica district ranges from very low to average CEC (3.59 to 13.11 cmolc/kg). Also, Sussudenga soils have a phosphorous deficiency (values ranging from <20 to 38.5 mg/kg) and there are deficiencies and/or excesses of some macro and micronutrients in all soil samples. Manica soils are contaminated, apparently from geogenic origin, with Cr (280 to 1400 mg/kg), Co (80 mg/kg), Ni (78 to 680 mg/kg) and V (86 mg/kg). Agricultural soils monitoring must be fostered in Mozambique in order to improve food quality and quantity to assure economic and environmental sustainability.

Keywords: agricultural soils; chemical soil properties; soil fertility; metallic soil pollutants.

1. Introduction

The quality of agricultural soils is a critical factor for the environmental and socio-economic sustainability of a rural region. Environmental agricultural soils quality should follow regulations defined by governmental agencies to assure the ecological equilibrium and reduce human health risks, without compromising the yield of food production. Moreover, in this context, countries and organizations must stay tuned with the United Nations Objectives for Sustainable Development 2 (zero hunger), 12 (responsible consumption and production) and 15 (life on land). This is particularly important for Mozambique, which is one of the poorest countries of the world, where the majority of the population depends on subsistence farming, and sustainable management of soil is mandatory for the future generations to continue to rely on the soil for food production.

Toxic heavy metals soil contamination has been the subject of much research, and it is an increasing concern [1]. It is a severe problem in many regions of the world [2], especially in terms of environmental health safety [2-5], because of the potential threat to food contamination and its harmful effects on humans and animals [5]. These substances are considered pollutants due to their resistance to biodegradation, their toxic effects and because they persist for long periods in soil [1-5]. Heavy metals are introduced into soils by natural sources [6,7] and also by anthropogenic sources [6,7], which have increased their levels [8]. Activities such as agriculture with intensive use of chemical products [6-8], irrigation using polluted water [6-8], industrial activities such as mining, are good examples of environmental stressors for the agricultural soils.

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Agriculture is practiced by the majority of the Mozambican population [9,10], with the country having approximately 36 million hectares of arable land, but only 9 million are actually in use, most of which are occupied by family farming [10]. Nevertheless, the existing information about the soils of Mozambique is very scarce, although there is a consensus on the poor fertility of these soils [11-14].

In this paper, the results of the analysis of five soils from five farms of the province of Manica, and in the Manica and Sussudenga districts (Mozambique), will be presented and discussed. Firstly, the agronomical chemical characteristics of the soils will be discussed, based on the following parameters: extractable K, Mg, Ca, Fe, Mn, Zn, Cu and B; exchangeable Na, K, Ca, Mg and Al; cation exchange capacity (CEC); pH; extractable P; soil organic carbon and organic matter; nitrogen Kjeldahl and inorganic; conductivity, and, texture. Secondly, the environmental quality of the soils will be discussed, and some elements were analyzed by inductively-coupled plasma mass spectrometry (ICP-MS) (As, Sb, Ba, Be, Cd, Cr, Co, Cu, Hg, Pb, Mo, Ni, Se, Sn, V and Zn), and another set of elements were analyzed by a portable X-ray fluorescence (XRF) (K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Rb, Sr, Zr, Ba, Ta and Pb). The agronomical and environmental assessment of the soils under investigation will be done.

2. Materials and Methods

2.1. Study area

The area of study focuses in two districts of the Manica province (center of Mozambique), namely the Manica and Sussudenga districts (Figure 1).

Manica district [15] is characterized by a dry-winter subtropical climate (Cw of the Koppen classification) with two well-defined seasons (rainy and dry) – the rainy season begins in November and it ends in the month of April. The annual average temperature is 21.2 ºC with extreme maximum values in October (30.9 ºC) (summer) and July (24.4 ºC) (winter) and with extreme minimum values in February (18.5 ºC) (summer) and in July (7.3 ºC) (winter). The Manica region is drained by the Revué river and its effluents.

Sussudenga district [16] is characterized by a tropical rainy savanna climate (Aw of the Koppen classification) with two well-defined seasons (rainy and dry), similar to Manica district. The annual average temperature is 23.0 ºC, with an average maximum and minimum values 29.5 and 17.6 ºC, respectively. The Sussudenga district has four main rivers: Revué, Munhinga, Mussapa and Lucite.

Manica district is characterized by its oxic red or reddish brown clay soils [15]. The Sussudenga district has different soil groups such as red clay soils, red sandy soils and medium-textured red soils [16].

2.2. Soil sampling

Soils were sampled in agricultural farms in the Manica province, namely two samples in the Manica district (Fields **C1** and **C2**) and three samples in the Sussudenga district (Field **C3**, **C4** and **C5**) (Figure 1). The areas of the five farms and their agricultural productions are:

C1 - 7 ha: corn, green beans, banana, lettuce, cucumber, strawberries and okra;
C2 - 2 ha; corn, tomatoes and beans;
C3 - 1.5 ha: corn and sesame;
C4 - 1 ha: corn and beans;
C5 - 1 ha: corn and beans.

Fertilizers and pesticides are used in these farms to improve the fertility of the soil and control pests.

Samples were collected in two campaigns (2021/2022 and 2022/2023), and in each of them samples were obtained before and after the rainy season, in the following periods (Table S1): 2021/2022 campaign - September and October 2021 (before the rainy season) and April 2022 (after the rainy season; 2022/2023 campaign - September 2022 (before the rainy season) and April 2023 (after the rainy season).

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For each agricultural field, a sample was collected that was made up of a determined number of subsamples, which varied between 15 and 20. The collection of the subsamples for each field was done randomly and in a zigzag manner, in order to cover the entire area. The depth considered for the soil sampling was from 0 and down to 20 cm, and involved the use of a manual auger, two plastic buckets and some plastic bags. Table S1 shows the date of the samplings and the coordinates of all the sub-samples. After collecting the subsamples, they were mixed manually to homogenize, and about 1 kg of the mixture was kept in a plastic bag, placed inside a cooler to be transported and conserved in a freezer.

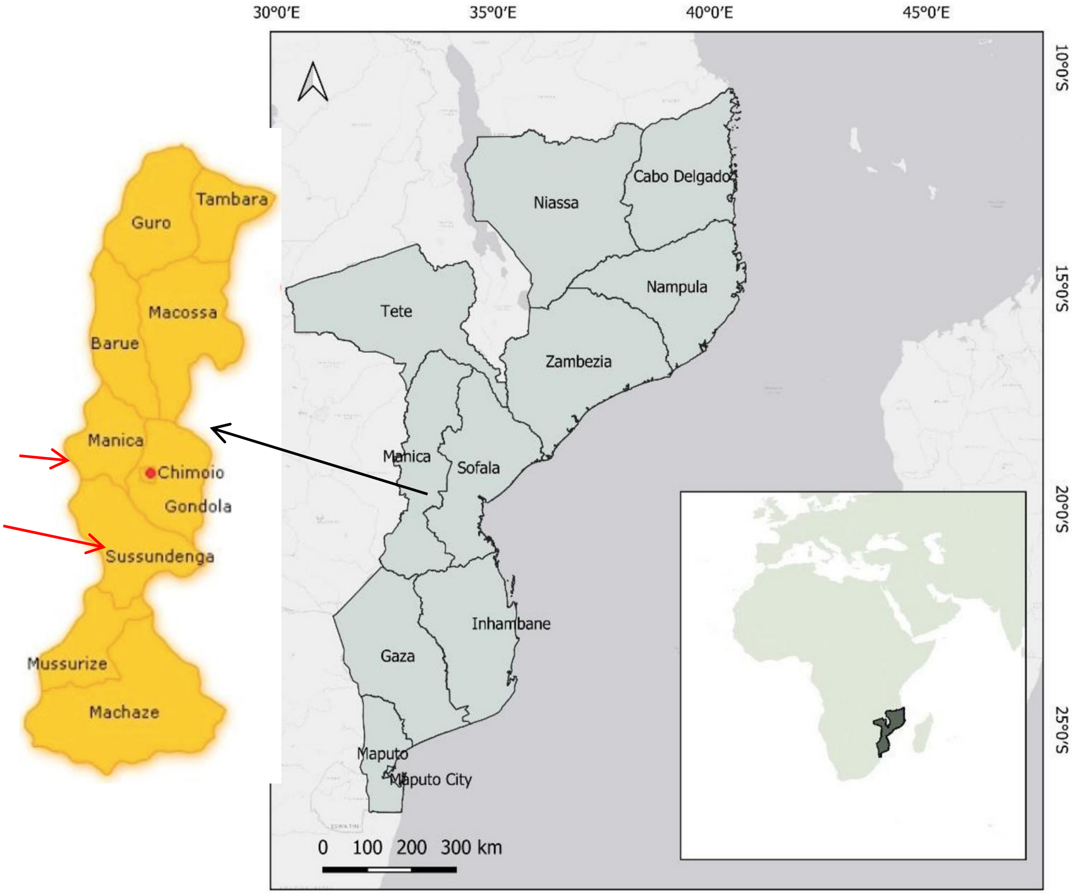

Figure 1. Mozambique map with its provinces, with the Manica province amplified and with its districts. Red arrows indicate the areas under soil analysis. With permission from reference [17].

2.3. Soil samples preparation

The preparation of the soils consisted of the following procedure: (i) soils were dried at room temperature; (ii) fine soil fraction, for further analysis, was separated from coarser elements using a 2 mm sieve; and, (iii) fine soil fractions were kept inside glass beakers, in desiccators, until sent to analysis.

For the agronomical chemical analysis, ten soil samples were prepared, one from each farm in the two campaigns, 2021/2022 and 2022/2023 – the samples collected before and after the rainy season were mixed. For the environmental chemical analysis by ICP-MS, only the samples from the 2022/2023 campaign were subject of analysis, and five soil samples were prepared, one from each farm, by mixing the soils collected before and after the rainy season. For the XRF soil analysis, the ten samples collected in the 2022/2023 campaign, one from each farm and before and after the rainy season, were analyzed.

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2.4. Analysis of the soils

Agronomical chemical analysis was done at Eurofins Agro Testing (Lagra, Beja, Portugal), according to the IPac Accreditation L0728 ISO/IEC 17025. The following methods were used: Extractable K (K_2O) – Egner-Rienm method; Extractable Mg and Ca – extracted with ammonium acetate; Extractable Fe, Mn, Zn and Cu – Lakanen method; Extractable Boron – extracted with boiling water; Exchangeable Na, K, Ca and Mg - extracted with ammonium acetate; Exchangeable Al – extracted with KCl; Extracted phosphorous (P_2O_5) – Egner-Riehm method; Organic carbon and organic matter – Walkley-Black method; Inorganic nitrogen – extraction with $CuSO_4$; Sand (USDA) – sieving; Clay (USDA) – pipet method/gravimetry.

Metals were analyzed by inductively coupled plasma-mass spectrometry (ICP-MS) at Eurofins Analytico B.V., according to the reference method NEN-EN-ISO 17294-2.

A handheld energy dispersive X-ray fluorescence (XRF) X-MET 7000 (Oxford Instruments) was used for chemical elemental soil quantification. Soil samples were individually packed into cylindrical plastic boxes and coupled to the XRF for measurements. For each soil sample, three consecutive readings were registered and the average and standard deviations calculated.

3. Results and Discussion

3.1. Agronomical chemical analysis of the soils

Table 1 shows the results of the agronomical chemical analysis of the five soils sampled in the campaigns 2021/2022 and 2022/2023. The analysis of this table shows that all the soils are extremely to strongly acidic (pH ranging from 4.5 and 5.4, with an average of 5.0±0.3) and have no salinity problems (conductivity ranging from 4.2 to 11.8 mS/m). The difference in pH values determined in water and in KCl 1M was about 0.8, suggesting that these soils have negative charge and are cation exchangers [7]. All soils are characterized by a low amount of soil organic matter (SOM) ranging from 0.90% to 1.81%. The soils from the Sussudenga district (**C3** to **C5**) have a very low CEC (average and standard deviation of 3.33±0.99 $cmol_c$/kg) while those from Manica district (**C1** and **C2**) ranges from low to average CEC (**C1**, 7.30 and 13.11 $cmol_c$/kg) and very low to low CEC (**C2**, 3.59 to 9.74 $cmol_c$/kg). This analysis shows that these soils need liming, for pH correction, and incorporation of organic correctives to increase organic matter and improve CEC, in order to improve fertility. Also, the Sussudenga district soils have a phosphorous deficiency (values ranging from <20 to 38.5 mg/kg) while the Manica district soils usually have a high amount of phosphorous (with a concentration ranging from 106 to 174 mg/kg), with the exception of the sample **C1** from the year 2022 (44.8 mg/kg). This results show that the samples of the Sussudenga district soils have marked fertility problems.

A study about the Mozambique soil fertility published in 2006 concluded that, in general, they can be classified as having low to moderate fertility [11]. Indeed, the median CEC was low, with an average of 5.0 $cmol_c$/kg, ranging from 0.4 to 14.5 $cmol_c$/kg, and 75% of the samples had less than 7.5 $cmol_c$/kg, which is considered the minimum adequate CEC [11]. The soils under analysis from Sussudenga have a particularly very low CEC value (3.33±0.99 $cmol_c$/kg). Mozambique soils have a median pH of 6.0±0.53, and ranged between 4.4 and 7.8, and a SOM ranging from 0.4% to 5.0%, with a median of 2.1% [11]. The Manica and Sussudenga soils under analysis fall within these pH and SOM intervals, but are close to the lower values, i.e. more acidic and poor in organic matter.

Mozambique soils are poorer in the macronutrient phosphorous, and the following study cases demonstrates this problem:

(i) Cassava is the second most produced crop in Mozambique [9,10]. Cassava is produced mainly by small-scaled, resource-poor farmers, on nutrient-depleted soils [1]. Indeed, cassava can achieve reasonable yields in poor soils, where other crops would not thrive [18]. In Mozambique, about 75% of the economically active population is engaged in agriculture, and the majority in small farms with an average land of 1.78 ha [18]. A soil of Milha-14 in the coastal Dondo district (Sofala province, Mozambique) was analyzed with the following results [18]: pH = 4.9; P, 6 mg/kg; K, 149 mg/kg; Ca, 215 mg/kg; Mg, 60 mg/kg; Na, 16 mg/kg; and, SOM, 1.03%. The cassava tuber yield of this soil was

14.7±2.6 ton/ha. The fertilization of this soil with 60 kg/ha N and with 60 kg/ha P_2O_5 yielded 27.7 tons/ha [18].

(ii) Maize is the highest crop in Mozambique [9,10]. Besides the well-known nitrogen fertilization in maize production, the availability of phosphorous is a critical factor for crop productivity, especially under Africa acid soils conditions [19]. In a study on the Nacala corridor (Mozambique), it was suggested the fertilization with 32-74 kg P_2O_5 ha^{-1} [19].

(iii) Soybean production is small, but it is growing in Mozambique, with a yield in the year 2020 of 1.67 t/ha [20]. Besides being used in human and animal nutrition, it is a legume crop that improves soil fertility [20]. The average soybean yield in the world was 67.8% higher than that of Mozambique [20]. Fertilization with 20 to 30 kg P ha^{-1}, potassium and starter nitrogen, and inoculants, improved soybean yields [20].

The soils under analysis have somewhat different textures because the Manica soils have higher percentage of clays, when compared with the Sussudenga soils, with higher percentages of sand: Manica **C1** soil has a sandy clay loam/ clay loam texture; Manica **C2** soil has a sandy-loam/sandy clay loam textures; **C3**, **C4** and **C5** Sussudenga soils have loamy sand/sandy clay loam/sandy loam texture.

The Manica and Sussudenga soils have a similar texture to other Mozambique soils, that fall in the loamy sand, sandy loam and sandy clay loam classes [11]. Typical mineral present in these soils are the kaolinite, illite, and the hydroxides, oxohydroxides, and oxides of Fe and Al [11].

The following observations can be drawn about the macro and micronutrients in the Manica and Sussudenga soil samples:

(i) all the soils under analysis are deficient in boron, with an average concentration of the extractable boron lower than 0.2 mg/kg;
(ii) soils **C4** and **C5** from the Sussudenga district have calcium, magnesium and potassium deficiencies;
(iii) soil **C3** from the Sussudenga district have calcium and zinc deficiencies;
(iv) soil **C4** from Sussudenga district have copper and zinc deficiencies;
(v) soil **C1** from Manica district have an excess of magnesium, manganese and iron;
(vi) soils **C2** from Manica district, and **C3** from Sussudenga district, have excess of manganese and iron.

Table 1. Characteristics of the five soil samples in campaigns 2021/2022 (first row) and 2022/2023 (second row).

Property	C1	C2	C3	C4	C5
Extractable K (K_2O), mg/kg	157	251	157	40.1	49.3
	149	124	110	45.0	37.9
Extractable Mg, mg/kg	268	386	128	46.4	75.8
	622	102	121	47	40.1
Extractable Ca, mg/kg	916	1191	512	448	424
	1474	458	641	516	270
Extractable Fe, mg/kg	183	230	117	49.3	107
	88.9	170	81	50.9	74.3
Extractable Mn, mg/kg	263	307	180	45.6	22.6
	301	163	153	51.8	14.2
Extractable Zn, mg/kg	1.9	1.9	0.95	2.0	3.0
	1.4	1.6	0.86	1.3	2.7
Extractable Cu, mg/kg	3.5	3.6	2.0	0.45	0.60
	2.2	3.2	1.4	0.42	0.38
Extractable B, mg/kg	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Exchangeable Na, cmol(+)/kg	0.10	0.15	0.11	0.04	0.05
	0.17	0.04	0.07	0.05	0.04
Exchangeable K, cmol(+)/kg	0.33	0.44	0.39	0.14	0.16
	0.39	0.31	0.33	0.15	0.12

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Exchangeable Ca, cmol(+)/kg	4.6	5.9	2.6	2.2	2.1
	7.4	2.3	3.2	2.6	1.3
Exchangeable Mg, cmol(+)/kg	2.2	3.2	1.0	0.38	0.62
	5.1	0.84	0.99	0.39	0.33
Exchangeable Al, cmol(+)/kg	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
	< 0.025	< 0.025	< 0.025	< 0.025	< 0.03
CEC, cmol(+)/kg	7.30	9.74	4.22	2.83	3.08
	13.11	3.59	4.67	3.26	1.91
pH(KCl) 1:5	5.2	5.4	4.8	5.2	4.6
	5.2	4.5	5.1	5.3	4.5
pH(H_2O) 1:5	6.0	6.1	5.7	5.8	5.4
	6.2	5.4	6.0	5.9	5.2
Extractable P (P_2O_5), mg/kg	132	106	36.4	37.1	37.9
	44.8	174	<20	38.5	37.3
Organic Carbon (%)	0.63	0.77	1.0	0.60	0.78
	1.0	0.52	0.76	0.64	0.66
Organic Matter (%)	1.09	1.33	1.81	1.04	1.34
	1.77	0.90	1.31	1.10	1.14
Nitrogen Kjeldahl, g/kg	0.94	1.23	1.10	0.59	0.80
	1.24	0.78	0.68	0.66	0.68
Inorganic nitrogen, mg/kg	18.5	23.2	7.0	12.0	16.9
	19.8	14.5	4.7	14.3	20.1
Conductivity, mS/m	10.1	11.8	7.8	6.6	6.9
	6.3	5.7	4.2	4.9	5.3
Sand, Clay, Silt (USDA) (%)	62.7. 21.7. 15.6	55.2. 26.3. 18.5	67.9, 20.3, 11.8	77.4, 10.2, 12.4	79.4, 13.0, 7.6
	34.0. 32.3. 33.7	71.0. 17.0. 12.0	66.4, 19.2, 14.4	85.9, 9.7, 4.4	78.5, 10.5, 11.0
Texture (USDA)	sandy clay loam	sandy clay loam	sandy clay loam	sandy loam	sandy loam
	clay loam	sandy loam	sandy loam	loamy sand	sandy loam

These results show that corrections are required in the concentration of the soil macro/micro nutrients to achieve increased yields of Mozambique crops. However, before defining a correction scheme, soils must be analyzed to confirm its main deficiencies to allow a sustainable agro-environmental management of the food production.

3.2. ICP-MS elemental concentrations

Table 2 shows the concentrations of the elements present in the five mixtures of the soils sampled before and after the rainy season in the 2022/2023 campaign. The following elements were not detected: As; Sb; Be; Cd; Hg; Mo; Se; and, Sn.

The reference values for agriculture soils accordingly to the Portuguese Environmental Agency [21] are included in Table 2. The comparison of the results with the reference values show that soil samples **C1** and **C2** from the Manica district have severe contamination problems for the following elements: **C1**, Cr (1400 mg/kg), Co (80 mg/kg), Ni (680 mg/kg) and V (86 mg/kg); **C2**, Cr (280 mg/kg) and Ni (78 mg/kg). The soils from the Sussudenga district show no contamination with the measured chemical elements.

The presence of the elements Cr, Co, V and Ni in the agricultural soils is of geogenic origin [97]. In a study of the top soils from the Beira city (Mozambique) the concentration of these elements ranged [22]: Cr, 11.0 to 3930 mg/kg (with an average of 89 mg/kg); Co, below the detection limit to 56.0 mg/kg (with an average of 3.00 mg/kg); and Ni, 1 to 120 mg/kg (with an average of 7.00 mg/kg); and, V, 2.00 to 87.0 mg/kg (with an average of 17.0 mg/kg). Soil pollution with an anthopogenic origin, namely of Cu, Pb and Zn, were not detected. Moreover, taking into consideration that the Manica district area under investigation has illegal artisanal gold mining [23-25], no Hg contamination was detected in the studied soils.

Comparing the contamination of the **C1** and **C2** Manica soils with other agricultural soils al over the world we can conclude that these are considered outliers, due to the relative high concentration levels of pollutants. For example, it compares with Iranian agricultural soils that have an average (minimum/maximum) concentration of Cr, Co, Ni and V, respectively, 101 (5.67/633), 27.9 (6.80/519), 68.0 (2.79/770) and 101 (20.3/1202) mg/kg [26]. In a review from Indian agricultural soils values for metals Co, Cr Ni and V usually are lower that the values found in this work [27]. Also, the analysis of the agricultural soils from the Shanghai region has an average Cr value of 41.00 mg/kg [28] and show that although this region is highly industrialize, the heavy metal levels in agricultural soils are within the safe ranges according to the Chinese environmental regulations.

Due to the absolute and relative abnormal concentrations of some elements in samples **C1** and **C2**, these two soils were subject to a detailed chemical analysis of organic pollutants, and the following were detected: **C1** - p-isopropyltoluene (0.06 mg/kg), ethyl chlorpyrifos (0.03 mg/kg), diethylhexyl phthalate (0.3 mg/kg) and total petroleum hydrocarbons (C30-C35) (7.6 mg/kg); **C2** - diethylhexyl phthalate (0.4 mg/kg). The presence of these organic pollutants suggests that, besides the geogenic origin of the pollutants in these two soils, there is an unknown anthropogenic contribution to that pollution that will be the subject of further research.

Table 2. ICP-MS results (in mg/kg) of the analysis of the five soil samples collected in the 2022/2023 campaign.

Element	C1	C2	C3	C4	C5	Reference Value[1]
As	-	-	-	-	-	
Sb	-	-	-	-	-	
Ba	67	32	51	19	17	210
Be	-	-	-	-	-	
Cd	-	-	-	-	-	
Cr	**1400**	**280**	34	-	4.1	67
Co	**80**	17	7	-	-	19
Cu	32	13	9.1	-	-	62
Hg	-	-	-	-	-	
Pb	8.8	6.4	13	4.3	5.1	45
Mo	-	-	-	-	-	
Ni	**680**	**78**	11	-	-	37
Se	-	-	-	-	-	
Sn	-	-	-	-	-	
V	**86**	36	30	3.0	5.1	86
Zn	30	17	15	-	13	290

[1] Reference values for agriculture soils according to the Portuguese Environmental Agency [21].

3.3. XRF elemental concentrations

Table 3 shows the concentrations of the elements present in the soils under analysis for the year 2022 and 2023. This table only shows the elements that were detected by XRF.

The analysis of Table 3 confirms the results obtained by ICP-MS, showing that the soil sample **C1** from the Manica district are severely contaminated with V, Cr, Co and Ni and that the contamination is observed both in the samples collected before and after the rainy season. Also, sample **C2** is also contaminated with V, Cr and Ni. Also, comparing the results obtained before and after the rainy season, it shows that the elemental concentration remains in the same order of magnitude, and it demonstrates that the rain that washed the soil in the summer months had no effect in the attenuation of the contamination. A probable cause for this observation is the geogenic origin of the most concentrated elements, and whose minerals are not soluble in water.

The comparison of the ICP-MS and XRF concentration estimations shows that the results obtained by XRF are usually higher than those obtained by ICP-MS for the elements Ba and Cr, which were the elements with the highest concentrations in the soils under analysis. For the others, the XRF estimates were in the same order of magnitude of ICP-MS – the plot of the two sets of results, resulted in linear plot with a slope 1.1 and an intercept of 7. This result supports that the use of portable XRF equipment can be use for screening on-site straightforward estimation of the concentration of chemical elements in the soils, allowing the identification of potential contaminations that are above the regulated threshold values.

Table 3. XRF results (mg/kg) of the analysis of the five soil samples in the campaign 2022/2023, before (first row) and after (second row) the rainy season (averages and standard deviation of three independent measurements).

Element	C1	C2	C3	C4	C5	Reference Value[1]
K	5591(101)	14013(696)	15344(2062)	40165(3925)	22545(1113)	
	6841(161)	13877(620)	15772(524)	23067(3136)	22609(511)	
Ca	7186(1327)	6432(478)	2170(167)	3703(659)	4360(258)	
	8335(1046)	6585(113)	2450(1131)	3057(403)	3034(146)	
Ti	3833(72)	5814(849)	5243(779)	2242(690)	2073(65)	
	3798(159)	5284(228)	4840(308)	1353(29)	2018(217)	
V	**132(20)**	**97(27)**	-	-	-	86
	112(10)	24(42)	-	-	-	
Cr	**2675(308)**	**803(67)**	60(13)	-	-	67
	2543(119)	**700(8)**	52(54)	-	-	
Mn	1429(238)	783(174)	690(111)	318(34)	167(18)	
	1423(159)	799(23)	686(115)	268(60)	126(5)	
Fe	83114(6083)	29774(2118)	22247(2373)	4412(530)	5109(95)	
	75161(2541)	28393(960)	25610(3308)	4048(553)	4871(141)	
Co	**44(38)**	11(18)	-	-	-	19
	49(46)	-	11(20)	-	-	
Ni	**823(70)**	**154(13)**	23(6)	4(8)	4(7)	37
	684(42)	**158(2)**	25(5)	-	-	
Cu	26(4)	14(1)	-	-	-	62
	25(6)	17(3)	4(8)	-	-	
Zn	39(3)	19(2)	16(1)	-	4(6)	290
	36(5)	22(3)	20(6)	-	-	
Rb	47(8)	53(8)	91(4)	202(30)	101(2)	
	45(1)	53(2)	84(3)	106(20)	98(5)	
Sr	48(9)	59(5)	49(2)	91(14)	88(3)	
	55(4)	63(4)	38(5)	49(8)	96(2)	
Zr	164(24)	261(52)	393(53)	169(34)	196(65)	
	199(66)	294(23)	292(18)	158(2)	165(8)	
Ba	-	**256(3)**	**-**	**414(71)**	**299(25)**	210
	-	**256(22)**	**-**	**294(19)**	**293(30)**	
Ta	29(4)	-	-	-	-	
	10(18)	7(13)	12(11)	-	-	
Pb	3(6)	7(6)	22(3)	30(10)	18(2)	45
	3(6)	5(5)	19(2)	17(2)	19(2)	

[1] Reference values for agriculture soils according to the Portuguese Environmental Agency [21].

4. Conclusions

The Manica and Sussudenga districts soils under analysis in this paper confirmed the low fertility of Mozambique soils mainly due to some macro and/or micronutrient deficiencies, low CEC and low SOM. These results emphasize the need to implement local soil analysis facilities in Mozambique, to support the management of agricultural production in a sustainable manner and with increased agricultural yields. Moreover, technical support to farmers and infrastructures to easy access to markets are also mandatory.

Besides the fertilization issues of the Mozambique soils, their environmental chemical quality must be assessed. The soils of the Manica district revealed a worrying situation because the contamination of agriculture soils, where food is produced, is high for some toxic metals, like chromium, cobalt, nickel and vanadium. This situation raises human health risks and deserves further investigation. In the case of the Sussudenga district soils, no chemical contamination with toxic substances was detected.

Mozambique is experience some economic growth and projections foreseen a rise in the gross domestic product (GDP), pushed, among other economic activities, by agriculture. This scenario opens the opportunity for the implementation of sustainable agricultural practices, implementing an agro-environmental management that assures that the quality of the agricultural soils is improved and future generations will be able to continue to rely on agricultural production to stimulate the economy.

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