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Screening of Soybean, Common Bean and Maize on Nickeliferous Soils from Mafic Rocks

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Authors' contributions

This work was carried out in collaboration among all authors. Authors OCN, GEFG, ZO and NCO designed the study, wrote the protocol of soil and rocks samples collection and wrote the first draft of the manuscript. Author OCN performed the statistical analysis and authors GEFG and ZO analyzed the macroscopic aspect of the rock. Author KEM monitor the experiment. All authors managed the literature searches read and approved the final manuscript.

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ABSTRACT

In this study, nickeliferous soils' effects on grain legume and cereal growth as well as their potential to accumulate nickel and related micronutrients were examined. A completely randomized block design with six repetitions was set up. Samples were collected from eight points and the experiment was conducted for six weeks at the University of Man. In order to fill a plastic container, eight soil samples were used. The soil humidity was controlled with SONKIR MS02 multimeter. Common bean (*Phaseolus vulgaris*), soybean (*Glycine max*), and maize (*Zea mays*) were the test plants. Each soil sample was air dried and sieved with a 2 µm mesh. The X-ray fluorescence (XRF) technique was used to carry out a chemical analysis. Statistica 7.1 was used to conduct statistical analysis like the ANOVA and correlation test. At Moyango, the soil was developed on dunite. The soil had a colour varying from 7.5YR6/2 to 10YR5/6.). The dominant oxides found were Fe_2O_3, SiO_2, and P_2O_5 with wt% > 7. The soil Ni was negatively correlated with K, Ca and, V. The soils had significant effect on soybean, common bean, and maize growth. However, the negative effect was more on common bean. The lowest soybean plant's heights were observed on plant grown on soil from the mining site. The soil had a significant effect on soybean Ni, V, Mn, and Co content. Soybean plant Ni contents were 9.20 and 7.31 wt%, respectively from plants grown on soils M1 and M2. The content of Ni in soil had significant effect on plant growth, specifically it has

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reduced the height of grain legumes. From the results observed, maize should be the one most suitable for cultivation in the vicinity of the Ni mining region of Foungouesso-Moyango. Further investigation is needed with more test plants to prevent population health.

Keywords: Nickel; soybean; maize; common bean; trace elements; phytoavailability.

1. INTRODUCTION

Soil, arising from different parental materials under different environmental conditions, is a complex, heterogeneous mixture of organic and inorganic materials that determine its physical, chemical, and biological properties. Based on those properties, soils are classified into 12 groups [1].

In Africa, lateritic soils frequently form and are rich in industrial and precious metals, including Au, Fe, Al, and Ni. Apart from Au, many of these metals are regarded as heavy metals or trace elements [2]. Some of these elements are referred to as microelements in plant nutrition since plants only require very small amounts of them [3,4]. In reality, it is known that at least 16 microelements are essential to maintaining human life [5,6]. Even one of these nutrients, if consumed insufficiently, could impede metabolic changes that cause illness, ill health, and disruptions in children's development. However, the harmful effect becomes apparent when the plant consumes them in large quantities. As a result, the transfer of heavy metals from soil to edible plant parts, including pods, leaves, and grains, may have a negative effect on human health [5,6].

Several common trace metals, including nickel (Ni), are released into the environment from both natural and anthropogenic sources. According to their conditions of formation, Ni deposits are of two types: sulfide deposits of hypogene origin and lateritic deposits of supergene origin. Nickeliferous laterites constitute a thick weathering cover of ultramafic rocks in tropical areas [7]. The distribution of Ni is uniform through the soil profile, but Ni could accumulate at the surface from deposition by industrial and agricultural activities. Its content in soil ranges from 3 to 1000 mg kg^{-1}, with some conditions reaching 24,000 mg kg^{-1} [8].

In addition to being a component of the enzyme urease, which is necessary for nitrogen metabolism in higher plants, nickel is a crucial element for plant growth [8]. However, agricultural exploitation of Ni-enriched soils constitutes a worry because of the strong phytotoxicity of Ni at high concentration. The most common symptoms of Ni toxicity in plants are inhibition of growth, photosynthesis, seed germination, sugar transport, and induction of chlorosis, nacrosis, and wilting [8]. Additionally, Ni phytotoxicity varies from crop to crop due to differences in the physiological mechanisms governing the accumulation of elements in edible parts [9,10]. Moreover, the occurrence of Ni is accompanied by several other micronutrient metals [3]. Therefore, soil with high Ni content could be correlated with some micronutrient metals.

In addition important, Ni-enriched zones can be found in the western and northern lateritic soils of Ivory Coast, where mining operations are still active. Smallholder farming (family agriculture) is frequently practiced by smallholder farmers around the mining sites. The main crops for people living in the northern part of Ivory Coast include grains legumes, cereals, and vegetables [11].

The Foungouesso-Moyango nickel deposit, which has been found for more than 50 years, is one of the world's largest and richest lateritic deposits. The feasibility study indicates with a dry mass of more than 49.9 million tons, an excellent nickel content, or 2 % nickel content, was reported [12].

Uncontrolled farming operations could result in excessive intakes of Ni and some of the micronutrient metals stored in edible parts due to Ni dispersion in the soil profile and its phytotoxicity. Additionally, open mining pits are commonly used in nickel mines to bring deep minerals to the soil's surface. This study examined the origin of nickeliferous soils and their effects on grain legume and cereal growth as well as the possibility of nickel and related micronutrient build-up in these plants.

2. MATERIALS AND METHODS

2.1 Sites for Soil Sampling

For the purpose of this study, soil samples were taken from eight sampling sites that could be divided into two (2) categories: on and off mining zones. With the aid of an auger, the sample was collected between 0 and 15 cm and stored in well-labelled disposable bags.

Four soil samples were taken from the Foungouesso-Moyango mining zone's surroundings (RM, HM, FG and RFM) and three from the Moyango mining site itself. Soil samples M1, M2, and M3 were taken at the mining site, going down from up. Lastly, a single sample (UM) was taken far from the Ni deposit zone, within the University of Man (Table 1). The soils constituted the eight treatments of the experiment.

The settlement of Moyango (Souatiesso) is situated in the department of Touba, in the Bafing area, northwest of the Ivory Coast, and in the sub-prefecture of Foungouesso, which is in that department.

The University of Man is located in the hilly west of the Ivory Coast, next to Kassiapleu hamlet, on the Man-Danané axis, 6 km from Man city, and is the administrative center of the Tonkpi department and area. To serve as a control, the sample was collected far from the Ni deposit zone.

Table 1. Sampling locations

Locations	Latitude	Longitude
M1	7°58'2.60"	-7°31'34.31"
M2	7°58'2.50"	-7°31'31.50"
M3	7°58'10.33"	-7°31'31.71"
RM	7°58'09.30"	-7°31'31.00"
HM	7°57'57.42"	-7°31'32.46"
FG	7°55'57.63"	-7°39'4.47"
RFM	7°57'26.86"	-7°36'51.18"
UM	7°20'41.97"	-7°36'58.36"

M1. 2 and 3: soil samples from Moyango mining sites; RM and HM: soil samples from out of Moyango mining site; FG: soil sample from out of Foungouesso mining site; RFM: soil sample from between Moyango and Foungouesso mining site; UM: soil sample from University of Man site

2.2 Test Plants

Out of the crops grown by farmers in western Ivory Coast, common bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* L.), and maize (*Zea mays* L.), one cereal, were chosen as test plants. Utilized were the commercial varieties of "Maïs jaune de FERKE" yellow corn, "Contender" common beans, and "canarana" yellow soybeans from CNRA (National Agronomic Research Centre of Ivory Coast). They are all readily available cultivars that local farmers raise. They are cultivated on tropical soil and have different soil adaptations. In the Ivory Coast, Touba is known as a soybean farming area. Farmers also grow common beans as a cash crop and for their own consumption.

2.3 Experimental Setup and Management

The study was designed as a pot trial. Two kilograms of each soil sample were used to fill plastic pots after stones and obvious plant remains were taken out. In order to prevent soil contamination, filled pots were carefully arranged thereafter.

The soil samples were moistened to a specific degree of humidity before being removed. The next day, the sowing was completed. The pots were irrigated following the sowing. Using the SONKIR MS02 multimeter, irrigation was then carried out in accordance with a humidity level of 7-8. Six weeks after sowing, the trial was stopped.

2.4 Data Collection and Analysis

2.4.1 Macroscopic description

The macroscopic petrographic descriptions were carried out on the vertical faces of the various pit beds of the Foungouesso and Moyango mine. They consisted of the description with the naked eye and/or with a magnifying glass of the different lithologies observed. The Munsell colour chart was used to determine the colour of the soil.

2.4.2 Soil acidity determination

By measuring pH_{H2O}, the acidity of the soil was determined. To prepare the solution, 10 g of the soil sample was mixed with 25 mL of distilled water. The solution was covered and placed on the bench for one hour after being stirred with a stirrer magnet for 30 minutes. An electronic pH meter was used to measure the pH [13].

2.4.3 Soil chemical analysis

Soil samples were air dried, 2 µm screen sieved, and ground in an agate mortar for further geochemical XRF analysis. The investigation involved employing X-ray fluorescence (XRF) technology to identify chemical components and soil oxides [14,15].

2.4.4 Plant analysis

Plants were severed at the base six weeks after seeding in order to detach the shoot from the root. The roots were gently removed, and they were then cleaned with running water. For 48 hours, all plant samples were dried at 60 °C. The analyses were carried out in the University of Man's central laboratory in Côte d'Ivoire. The HORIBA MESA-50 was the instrument utilized to analyse both soil and plant samples [16].

2.5 Statistical Analysis

A completely randomized block with six repetitions made up the experimental setup. The acquired data was subjected to a variance analysis. With the Fischer test, the means that showed significant differences were separated. Furthermore, Pearson correlation was used to estimate the link between the components. The analyses were performed using Statistica 7.1.

3. RESULTS

3.1 Soil Origin, Acidity, Colour and Major Elements' Content

At Moyango, the observation revealed that the soil was developed on a dunite. The upper horizon was dark red, very little plastic and disaggregated. It is partly made up of goethite and hematite, kaolinite, manganese oxides and silica, presenting little indurated nodules and ferruginous pisolites. The structure of the source rock is no longer preserved there.

At Foungouesso, in the upper part there are pisolithic laterite and brownish-red lateritic cuirass below which has developed a clayey to limonitic horizon, yellowish red, semi-plastic, composed of goethite and hematite, kaolinite, manganese oxides and silica. This profile was developed on harzburgites and dunites.

In University of Man vicinity, the soil observed in the superficial part is composed of pisolithic laterite and leached brownish-red lateritic cuirass, little or no consolidated, composed of hematite, kaolinite, manganese oxides and silica.

The results of the soil pH and the four macronutrients analysed (P, S, K, and Ca) are shown in Table 2. The pH of the soils varied from 4.9 to 6.1, with the soil sample collected from Foungouesso having the least pH of 4.9. Thus, the soil was very acid to moderately acid. The soil colour varied from 7.5YR6/2 (pinkish gray) to 10YR5/6 (yellowish brown).

Table 2. Total macronutrients and secondary elements of soils identified by XRF (0-15 cm)

Samples	Colour	pH	P	S	K	Ca
				(wt%)		
M1	10YR5/3	5.3	0.929	0.000	0.661	0.687
M2	10YR5/6	5.5	1.250	0.000	0.520	0.590
M3	10YR5/4	6.3	0.000	0.775	0.626	0.484
RM	10YR5/4	5.9	0.293	0.000	0.640	1.458
HM	7.5YR6/4	6.1	0.000	0.000	4.472	1.183
FG	10YR5/8	4.9	0.000	0.071	0.376	0.186
RFM	7.5YR6/3	6.0	0.000	0.000	11.930	2.154
UM	7.5YR6/2	5.5	1.668	0.000	1.746	1.048

M1, 2 and 3: soil samples from Moyango mining sites; RM and HM: soil samples from out of Moyango mining site; FG: soil sample from out of Foungouesso mining site; RFM: soil sample from between Moyango and Foungouesso mining site; UM: soil sample from University of Man site.

Table 3. Level of microelements across sampling points (wt%)

Samples	Cl	Mn	Fe	Co	Ni	Cu	Zn	Mo	I	V
M1	0.000	1.037	71.015	0.000	7.435	0.035	0.081	0.356	0.006	0.022
M2	0.000	0.802	63.119	0.568	5.381	0.027	0.053	0.282	0.006	0.022
M3	0.000	0.976	59.648	0.568	3.516	0.021	0.063	0.249	0.006	0.032
RM	0.000	1.133	65.107	0.491	2.864	0.014	0.081	0.354	0.005	0.024
HM	0.001	0.671	39.954	0.000	0.900	0.064	0.063	0.925	0.003	0.082
FG	0.036	0.514	85.422	0.000	0.868	0.029	0.034	0.458	0.011	0.052
RFM	0.084	1.133	31.278	0.000	0.539	0.027	0.060	0.797	0.000	0.121
UM	0.000	0.103	15.604	0.091	0.024	0.019	0.038	0.485	0.001	0.119

M1. 2 and 3: soil samples from Moyango mining sites; RM and HM: soil samples from out of mining site of Moyango; FG: soil sample from out of Foungouesso mining site; RFM: soil sample from between Moyango and Foungouesso mining site; UM: soil sample from University of Man site

Table 4. Relationship between soil chemical elements

	P	S	Cl	K	Ca	V	Mn	Fe	Co	Ni	Cu	Zn	Mo
S	0.02												
Cl	-0.05	-0.48											
K	0.42	-0.04	0.39										
Ca	0.07	0.27	-0.14	<u>**0.66**</u>									
V	0.04	0.20	0.14	0.40	<u>**0.52**</u>								
Mn	0.27	-0.07	0.06	0.19	0.07	0.29							
Fe	-0.13	-0.12	-0.28	<u>**-0.84**</u>	<u>**-0.83**</u>	<u>**-0.67**</u>	-0.15						
Co	-0.13	-0.33	0.04	-0.43	<u>**-0.57**</u>	<u>**-0.61**</u>	0.15	<u>**0.62**</u>					
Ni	-0.07	-0.28	0.05	<u>**-0.53**</u>	<u>**-0.59**</u>	<u>**-0.63**</u>	-0.12	<u>**0.69**</u>	<u>**0.87**</u>				
Cu	0.02	-0.27	0.08	-0.03	-0.07	0.07	-0.04	-0.11	0.24	0.34			
Zn	0.30	0.38	-0.31	0.39	<u>**0.65**</u>	0.18	-0.17	-0.47	-0.13	-0.08	0.21		
Mo	**0.68**	0.15	-0.21	**0.60**	**0.51**	-0.04	0.00	-0.39	-0.08	-0.07	0.10	**0.80**	
I	-0.05	0.30	-0.13	**-0.57**	**-0.57**	-0.24	0.10	**0.60**	**0.60**	**0.60**	0.31	-0.13	-0.18

Underlined are significant correlation

Table 5. Soil major and minor oxides contents (wt%)

Samples	K_2O	NiO	I_2O_5	CaO	TiO_2	Mn_2O_3	Fe_2O_3	CoO	SiO_2	Al_2O_3	P_2O_5	MoO_3	SO_3
M1	0.37	1.15	0.00	0.44	0.37	0.36	23.61	0.10	23.56	48.40	0.00	0.06	0.00
M2	0.29	1.26	0.00	0.34	0.49	0.34	26.84	0.11	13.83	52.26	1.52	0.07	0.94
M3	0.37	0.94	0.00	0.31	0.58	0.44	27.16	0.12	11.08	55.16	1.83	0.08	0.00
RM	0.28	0.41	0.00	0.74	0.33	0.40	20.12	0.08	30.81	43.78	0.89	0.06	0.73
HM	1.58	0.10	0.00	0.44	1.06	0.16	9.32	0.03	64.23	21.71	0.00	0.13	0.56
FG	0.20	0.12	0.00	0.13	1.19	0.17	30.12	0.10	8.83	56.83	1.30	0.09	0.00
RFM	4.73	0.07	0.00	0.81	1.97	0.30	7.80	0.04	73.96	9.28	0.00	0.11	0.00
UM	1.69	0.02	0.00	1.39	8.11	0.09	22.71	0.00	0.00	59.95	0.00	1.47	0.00

M1. 2 and 3: soil samples from Moyango mining sites; RM and HM: soil samples from out of mining site of Moyango; FG: soil sample from out of Foungouesso mining site; RFM: soil sample from between Moyango and Foungouesso mining site; UM: soil sample from University of Man site

Table 6. Relationship between soils oxides and chemical elements

	Si	P	S	Cl	K	Ca	V	Mn	Fe	Co	Ni	Cu	Zn	Mo
K_2O	0.51	-0.18	-0.24	**0.79**	**0.97**	**0.82**	**0.83**	0.11	-0.69	-0.46	-0.52	0.12	-0.09	**0.71**
NiO	-0.50	0.28	0.31	-0.46	-0.48	-0.46	**-0.78**	0.43	0.49	0.57	**0.94**	-0.15	0.43	-0.70
I_2O_5	0.54	0.61	0.08	-0.28	-0.35	-0.28	0.35	**-0.81**	-0.39	-0.07	-0.33	-0.41	-0.59	-0.27
CaO	**0.83**	0.53	-0.31	0.04	0.28	0.57	0.66	-0.38	**-0.83**	-0.17	-0.42	-0.32	-0.12	0.19
TiO_2	**0.82**	0.59	-0.19	-0.01	0.09	0.16	**0.72**	**-0.78**	**-0.74**	-0.30	-0.54	-0.23	-0.57	0.15
V_2O_5	**0.81**	0.52	-0.20	0.05	0.13	0.15	**0.76**	**-0.81**	**-0.74**	-0.37	-0.62	-0.17	-0.63	0.22
Mn_2O_3	-0.54	-0.26	0.47	-0.09	-0.12	0.01	-0.68	**0.87**	0.46	0.65	0.67	-0.36	**0.72**	-0.54
Fe_2O_3	-0.46	0.32	0.35	-0.44	**-0.84**	**-0.87**	-0.61	-0.26	0.61	0.42	0.40	-0.49	-0.30	**-0.87**
CoO	**-0.85**	-0.20	0.46	-0.25	-0.54	-0.61	**-0.91**	0.50	**0.87**	0.59	**0.71**	-0.23	0.29	**-0.72**
CuO	**0.89**	0.24	-0.29	-0.07	0.32	0.34	**0.77**	-0.64	**-0.83**	-0.47	-0.62	0.45	-0.32	0.67
SiO_2	0.13	-0.54	-0.29	0.55	**0.83**	**0.77**	0.40	0.48	-0.31	-0.37	-0.25	0.54	0.38	**0.82**
Al_2O_3	-0.19	0.51	0.29	-0.61	**-0.89**	**-0.80**	-0.47	-0.45	0.38	0.38	0.30	-0.49	-0.31	**-0.82**
P_2O_5	-0.51	-0.19	0.62	-0.22	-0.52	-0.60	-0.63	0.14	0.60	**0.76**	0.23	-0.40	-0.17	-0.67
MoO_3	**0.80**	0.67	-0.16	-0.18	-0.06	0.06	0.60	**-0.80**	-0.70	-0.21	-0.44	-0.24	-0.51	0.04
SO_3	-0.10	0.13	-0.31	-0.39	-0.21	0.06	-0.40	0.18	0.14	0.54	0.22	0.14	0.26	-0.07

Table 7. Soybean height and chemical content as influenced by soils

Soil	Height (cm)	Ni	V	Mn	Fe	Co	Cu	Zn	I	Mo
						(wt%)				
UM	15.67	0.21	0.0640	0.48	21.93	0.11	0.063	0.238	0.002	0.88
M1	14.75	**9.20***	**0.0028***	0.98	60.90	**0.58***	0.069	0.187	0.007	0.93
M2	12.42	**7.31***	**0.0007***	0.80	47.39	0.43	0.064	0.224	0.004	1.09
M3	11.63	5.89	**0.006 ***	0.91	48.55	0.39	0.070	0.181	0.003	1.08
HM	**25.33***	0.93	0.0570	1.31	33.32	0.25	0.080	0.169	0.004	0.90
RM	14.36	2.95	**0.0057***	1.13	49.9	0.42	0.047	0.170	0.002	0.75
RFM	**20.92***	0.54	0.0930	**2.06***	24.41	0.19	0.056	0.222	0.002	1.06
FG	16.93	0.52	0.0200	0.71	50.9	0.09	0.048	0.091	0.002	0.62

M1, 2 and 3: soil samples from Moyango mining sites; RM and HM: soil samples from out of mining site of Moyango; FG: soil sample from out of Foungouesso mining site; RFM: soil sample from between Moyango and Foungouesso mining site; UM: soil sample from University of Man site,
Means with (*) are significantly different from the control level mean according to Dunnett Multiple Comparisons at P <0.05

Table 8. Relationship between soil and soybean plant chemical components

		Plant chemicals components													
		P	**S**	**Cl**	**K**	**Ca**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Mo**	**I**
Soil chemicals component	**P**	-0.16	-0.21	0.33	0.06	0.05	-0.1	-0.46	-0.1	0.12	0.25	0.09	0.31	0.07	0.16
	S	0.32	-0.22	0.13	-0.07	-0.23	-0.29	-0.11	0.18	0.13	0.23	0.19	-0.06	0.15	-0.04
	Cl	0.2	0.32	-0.12	0.22	0.44	**0.61**	**0.57**	-0.33	-0.42	-0.42	-0.34	-0.02	0.02	-0.32
	K	0.25	0.23	0.08	0.43	0.47	**0.81**	**0.71**	**-0.56**	-0.32	-0.42	0.01	0.17	0.14	-0.2
	Ca	0.05	0.3	0.09	0.41	0.44	**0.68**	**0.64**	**-0.52**	-0.13	-0.38	-0.1	0.25	0.09	-0.25
	V	0.08	0.01	0.25	**0.55**	**0.63**	**0.93**	0.28	**-0.79**	**-0.68**	**-0.7**	0.05	0.19	0.02	-0.31
	Mn	0.15	0.26	-0.21	-0.19	-0.23	-0.24	**0.52**	0.36	**0.57**	0.42	-0.09	0	0.14	0.12
	Fe	-0.11	0.09	-0.45	**-0.59**	**-0.5**	**-0.77**	-0.19	**0.77**	0.37	0.44	-0.26	-0.37	-0.16	0.19
	Co	0.19	0.07	0.12	-0.12	-0.3	**-0.58**	-0.2	0.27	0.4	0.41	-0.06	0.1	0.15	-0.12
	Ni	-0.02	-0.13	-0.06	-0.42	**-0.53**	**-0.72**	-0.14	**0.65**	**0.82**	**0.89**	0.17	0.05	0.14	**0.54**
	Cu	0.05	-0.15	-0.07	0.07	-0.1	0.24	0.2	-0.08	-0.04	-0.09	**0.54**	-0.1	0.01	0.36
	Zn	-0.08	0.06	-0.12	-0.19	-0.32	-0.31	0.32	0.36	**0.72**	0.49	0.14	0.06	0.09	0.32
	Mo	0.06	0.09	-0.01	0.39	0.37	**0.79**	**0.51**	**-0.55**	-0.44	**-0.59**	0.21	0.01	-0.01	-0.07
	I	-0.13	-0.01	-0.38	**-0.53**	-0.44	**-0.73**	-0.42	**0.66**	0.13	0.28	-0.24	-0.4	-0.21	0.11

The total phosphorus content was very low, under the limit of detection, for the soil samples from M3, HM, FG, and RFM. Besides, soil from M1, M2, RM, HM, RFM, and UM had very low levels of sulphur. However, K and Ca were found in all samples.

3.2 Correlation Analysis of Microelements

The microelements assessed were Cl, Mn, Fe, Co, Ni, Cu, Zn, Mo, I, and V. The highest Ni content was observed in soil M1 with 7.43 wt% on the mining site of Moyango, while the lowest was 0.024 wt%, found in soil collected from the University of Man. The highest mean value of 1.133 wt% of Mn was found in RM and RFM, respectively (Table 3).

A positive and significant correlation was observed between Ni and Fe (0.69), Co (0.87), and I (0.60). Contrarily, Ni was negatively correlated with K (-0.53), Ca (-0.59), and V (-0.63). Furthermore, Mo was positively correlated with P (0.68), K (0.60), Ca (0.51), and Zn (0.80) (Table 4).

3.3 Soil Oxides Content

The dominant oxides found were Fe_2O_3, SiO_2, and P_2O_5, with wt % > 7, but SiO_2 content in UM soils was below the detection limit. On the mining site, the means of NiO, from M1 to M3, were 1.15, 1.26, and 0.94 wt %, giving an overall mean of 1.12 wt % (Table 5). It was also observed the very low NiO content of UM's soil.

Ni content was positively and significantly correlated with NiO and CoO. Al_2O_3. Fe_2O_3 was negatively and significantly correlated with K, Ca, and Mo. On the other hand, a positive and significant correlation was observed between SiO_2 and K, Ca, and Mo (Table 6).

3.4 Effects of Soil Chemical Components on Soybean Height

There was a significant effect of soil on soybean growth (P 0.0001). The highest plant height of 25.33 cm was observed on soil from HM, collected from Moyango out of the mining site; the plant height mean was 25.33 cm. The Dunnett grouping analysis showed that the mean height of the plants in soil HM (25.33 cm) and RFM (20.92 cm) was significantly higher than the plants from the control soil UM (15.67 cm).

The soil had a significant effect on soybean Ni, V, Mn, and Co content (Table 7). The Ni content of soybean plant grown on M1 and M2 soils were 9.20 and 7.31 wt%, respectively. These mean values were significantly higher than UM's 0.21 wt%. Furthermore, the soils RFM and M1 had higher mean values for soybean Mn and CO content. Soybean plants grown on M1, M2, M3, and RM soils had lower V content when compared to the control soil. The contents of Cu, Zn, I, and Mo in soybean did not differ significantly.

According to the correlation analysis in Table 8, some soil chemicals, such as I, Mo, Zn, Co, Ca, K, Cl, S, and P, are not significantly correlated with those found in plants. V, Mn, Fe, Ni, and Cu, on the other hand, were significantly and positively correlated with those in soybean, with correlation coefficients estimated to be 0.93, 0.52, 0.77, 0.89, and 0.54, respectively. Furthermore, a positive and significant relationship between soil Ni and Fe, Co, and I was observed on the one hand, and a significant negative relationship with Ca and V on the other.

3.5 Soil Effect on Common Bean Height and Chemical Components

Table 9 displays the results of common bean height and total chemical content. Plant height was significantly affected by soil samples (P = 0.006). The plants grown on HM had the highest mean level of plant height (17 cm), followed by those grown on RM (16.14 cm).

The origin of the soil had a significant influence on the Ni content of common beans (P = 0.009). M2 yielded the highest mean value of plant Ni content (7.34 wt%). Soils had a significant effect on common bean V accumulation as well (P = 0.000). The highest V content was found in common beans grown on UM soil, at 0.093% by weight. Only the soil sample RFM had a different mean for Mn content than the control soil UM.

The soil samples increased the common bean Fe content significantly (P = 0,002): the highest mean values were 60.85, 59.63, and 55.27 wt%. Soil samples had a significant influence on Co (P = 0.011). Plants grown in M1, M2, M3, HM, and FG soil had Co contents of 0.39, 0.54, 0.45, 0.26, and 0.36 wt%, respectively. The Cu content of common beans differed significantly (P 0.039). Plants grown in HM soil yielded the highest value of 0.089 wt%. The soil factor had no effect on the Zn, I, or Mo content.

Table 9. Common bean height and chemical content as influenced by soils

	Height (cm)	Ni	V	Mn	Fe	Co	Cu	Zn	I	Mo
						(wt%)				
UM	15.33	0.20b	0.093	0.21	26.36	0.11	0.036	0.097	0.0008	0.58
M1	9.64	**6.90a***	0.006*	0.74	45.82	**0.39***	0.058	0.115	0.0018	0.77
M2	12.40	**7.34a***	0.001*	0.85	**60.85***	**0.54***	0.060	0.117	0.0025	0.64
M3	10.75	5.21a	0.020*	0.75	**55.27***	**0.45***	0.052	0.112	0.0014	0.41
HM	17.00	1.04b	0.049*	0.77	35.69	**0.26***	0.089*	0.190	0.0014	0.86
RM	16.14	1.04b	0.005*	0.63	28.76	0.23	0.032	0.096	0.0003	0.40
RFM	10.25	0.52b	0.086	0.96*	26.68	0.19	0.041	0.116	0.0007	0.56
FG	9.50	0.75b	0.031*	0.58	**59.63***	**0.36***	0.049	0.077	0.0030	0.41

M1, 2 and 3: soil samples from mining Moyango sites; RM and HM: soil samples from out of mining site of Moyango; FG: soil sample from out of Foungouesso mining site; RFM: soil sample from between Moyango and Foungouesso mining site; UM: soil sample from University of Man site,
Means with (*) are significantly different from the control level mean according to Dunnett Multiple Comparisons at P <0.05

Table 10. Relationship between soil and common bean plant chemical components

		Common bean plant chemical content													
		P	**S**	**Cl**	**K**	**Ca**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Mo**	**I**
Soil chemicals components	**P**	-0.20	-0.23	0.08	-0.09	-0.13	0.07	-0.44	-0.06	-0.04	0.28	-0.18	-0.16	0.17	0.01
	S	-0.14	0.49	-0.06	-0.03	-0.33	-0.18	0.09	0.37	0.37	0.26	-0.01	-0.06	-0.29	0.01
	Cl	0.00	-0.22	-0.08	-0.07	0.42	**0.50**	0.33	-0.21	-0.27	-0.39	-0.24	-0.13	-0.13	-0.03
	K	-0.08	-0.33	-0.06	0.14	**0.59**	**0.65**	0.38	**-0.52**	-0.44	-0.39	0.00	0.23	0.12	-0.23
	Ca	-0.25	-0.24	0.01	0.19	**0.60**	**0.52**	0.21	**-0.80**	**-0.62**	-0.45	-0.20	0.19	0.07	-0.46
	V	-0.02	-0.47	0.02	0.05	**0.60**	**0.97**	-0.21	**-0.62**	**-0.71**	**-0.65**	-0.09	0.12	0.10	-0.21
	Mn	-0.22	0.35	-0.05	0.17	-0.03	-0.47	**0.66**	0.01	0.27	0.32	-0.03	0.07	-0.06	-0.15
	Fe	0.20	0.40	-0.03	-0.13	-0.48	**-0.82**	0.22	**0.69**	**0.64**	0.41	0.05	-0.25	-0.18	0.35
	Co	-0.19	0.31	-0.10	-0.19	-0.47	**-0.56**	0.11	0.32	0.47	0.43	-0.18	-0.13	-0.29	-0.04
	Ni	-0.16	0.33	0.03	0.10	-0.45	**-0.77**	0.29	0.45	**0.64**	**0.85**	0.14	-0.02	0.15	0.15
	Cu	0.42	-0.27	-0.01	0.30	0.19	0.07	0.25	0.02	0.03	-0.03	**0.82**	**0.65**	**0.51**	0.14
	Zn	-0.27	0.37	0.07	0.35	0.00	-0.49	0.38	-0.21	0.09	0.33	0.09	0.22	0.14	-0.27
	Mo	0.24	-0.44	-0.01	0.23	**0.60**	**0.63**	0.16	**-0.51**	**-0.52**	**-0.56**	0.38	0.48	0.32	-0.14
	I	0.30	0.30	-0.04	-0.24	**-0.53**	**-0.68**	-0.02	**0.77**	**0.60**	0.30	0.06	-0.30	-0.22	0.44

Table 11. Maize h eight and chemical content as influenced by soils

Soil	Height (cm)	Ni	V	Mn	Fe	Co	Cu	Zn	I	Mo
						(wt%)				
UM	26.92	0.08	0.089	0.53	20.8	0.11	0.079	0.199	0.0043	1.15
M1	25.83	0.81	0.021	0.55	47.5	0.30	0.037	0.147	0.0012	0.53
M2	25.94	4.52	0.004	0.67	38.6	0.29	0.033	0.102	0.0016	0.48
M3	29.83	4.22	0.007	0.88	44.8	0.36	0.044	0.134	0.0010	0.74
HM	22.75	0.39	0.042	0.65	19.9	0.13	0.035	0.081	0.0015	0.61
RM	26.69	2.51	0.008	1.1	41.4	0.33	0.040	0.119	0.0015	0.54
RFM	**13.83***	1.42	0.008	1.1	26.7	0.23	0.032	0.130	0.0000	0.55
FG	16.75	4.73	0.000	0.68	36.4	0.29	0.044	0.127	0.0016	0.64

Table 12. Relationship between soil and maize plant chemical components

		Maize plant chemicals content													
		P	**S**	**Cl**	**K**	**Ca**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Mo**	**I**
Soil chemicals content	**P**	-0.14	0.11	0.32	-0.10	0.20	0.49	-0.48	-0.04	-0.16	-0.17	0.37	0.44	0.32	0.44
	S	0.29	-0.03	-0.16	-0.09	-0.14	-0.19	0.16	0.22	0.26	0.29	0.02	0.04	0.12	-0.12
	Cl	0.16	0.01	-0.32	0.16	0.22	-0.26	0.39	-0.15	-0.03	0.01	-0.18	-0.02	-0.15	-0.30
	K	0.24	-0.37	-0.29	0.36	0.19	0.00	0.37	-0.30	-0.19	-0.26	-0.17	-0.08	-0.09	-0.26
	Ca	0.09	**-0.58**	-0.13	0.28	0.20	0.11	0.49	-0.26	-0.17	-0.37	-0.08	-0.02	-0.06	-0.15
	V	0.02	-0.19	-0.23	0.48	0.46	**0.50**	0.00	-0.49	-0.42	-0.38	0.28	0.28	0.39	0.16
	Mn	0.22	-0.32	-0.04	-0.23	-0.34	**-0.62**	**0.56**	0.33	0.35	0.12	**-0.51**	-0.36	**-0.56**	**-0.52**
	Fe	-0.09	0.44	0.09	-0.44	-0.38	**-0.63**	0.01	0.44	0.40	0.46	-0.32	-0.29	-0.43	-0.24
	Co	0.26	-0.17	0.13	-0.27	-0.19	-0.29	0.28	0.28	0.32	0.39	-0.07	-0.15	-0.10	-0.03
	Ni	0.04	0.08	0.28	-0.44	-0.40	-0.32	-0.16	0.45	0.31	0.14	-0.27	-0.10	-0.36	-0.16
	Cu	0.01	-0.09	-0.06	0.32	-0.22	0.11	-0.30	-0.23	-0.25	-0.24	-0.23	-0.44	-0.18	-0.11
	Zn	0.01	-0.43	0.13	-0.19	-0.36	-0.25	0.30	0.27	0.22	-0.16	-0.33	-0.23	-0.39	-0.30
	Mo	0.02	-0.28	-0.23	**0.51**	0.13	0.23	0.06	-0.45	-0.37	-0.38	-0.09	-0.22	-0.01	-0.09
	I	-0.14	**0.59**	0.08	-0.37	-0.26	-0.45	-0.18	0.34	0.30	0.49	-0.13	-0.18	-0.22	-0.05

The correlation test revealed that some soil nutrients, particularly some ETM, are correlated with those in the plant. In terms of plant trace elements uptake and control, a highly significant correlation was discovered between Ca, V, Mn, Fe, Ni, and Cu (Table 10).

3.6 Soil Effects on Maize Growth and Chemical Content

Soils significantly increased maize height (P = 0.031). The highest maize height was 29.83 cm in soil sample M3, followed by 26.92 cm in control soil UM. The plants grown on RFM soil had the lowest height of 13.83 cm, which was significantly different from the other height mean values (Table 11).

Soil samples had no discernible effect on the Ni, V, Mn, Fe, Co, Cu, Zn, I, and Mo contents of maize. Furthermore, only the soil V and Mn contents were significantly and positively correlated with the V and Mn contents of maize plants. The Ni content of the soil was not related to the Ni content of the maize plant (Table 12).

3.7 Plant Species Effect on Trace Elements Accumulation in Plant Roots and Shoots on Different Soils

The results revealed that plant species accumulated trace elements for Mn and Cr in different ways. Ni accumulation varied significantly between shoot and root.

Soil had a significant influence on the plant's Cr, Mn, Co, and Ni content. The main factor, the plant, had a significant effect on Cr and Mn content. Only the soil/plant interaction had a significant effect on plant Cr content (Table 13).

The analysis revealed a significant difference in Co and Ni concentrations between the shoot and root. In general, the root contained more Ni than the shoot. However, among the three crops, maize had the highest concentration of Ni in the root, with a Ni_{root}/Ni_{shoot} ratio of 5.09, while soybean and common bean had 1.89 and 1.59, respectively. Furthermore, the interaction Plant*Part had no effect on plant trace element content (Table 14).

Table 13. Plant and soil, and plant and part (root and shoot) interaction effect on plant chemical content

	Cr	Mn	Co	Ni
Soil*plant				
ord. origine	28.45704	33.29534	4.099975	399.5033
Soil	**1.12676***	**0.45414***	**0.082817***	**36.1076***
Plant	**0.50235***	**0.56859***	0.017670	4.9242
Soil*Plant	**0.20770***	0.10582	0.018712	7.6175
Error	0.07828	0.10365	0.020902	5.3119
Plant*Parts (Shoot and root)				
ord. origine	28.45704	33.29534	4.099975	399.5033
Plant	**0.50235***	**0.56859***	0.017670	4.9242
Part	0.00160	0.40198	**0.282241***	**57.2728***
Plant*Part	0.15330	0.02979	0.042025	3.3480
Error	0.29442	0.15920	0.023263	10.0694

The bolded stared means squared showed significant effect. Parts meaning shoot and root

Table 14. Plant and soil, and plant and part (root and shoot) interaction effect on plant chemical content

Plant	Part	Ni wt%	Ni Ratio root/shoot
Common bean	Shoot	2.219	1.59
Common bean	Root	3.531	
Soybean	Shoot	2.392	1.89
Soybean	Root	4.497	
Maize	Shoot	0.767	5.09
Maize	Root	3.904	

4. DISCUSSION

The effect of soil on plant growth revealed the difference in nutrient requirements between crops. In fact, plant response to soil differed from crop to crop in relation to plant height. In the case of soybean, HM produced significantly more plants than the control soil UM. In terms of common bean, HM provided the highest yield, but no significant difference was observed when compared to the control.

Soil M3, soil from the mining site, had the highest maize height. The negative effects of high Ni concentrations in soils on plants include reduced shoot and root growth, as well as low biomass [17]. However, it has been demonstrated that plant nutrient uptake is dependent on the concentration and solubility of metals present in soil solutions, as well as the plant species grown on these soils [18].

The chemical content of the soil samples used in the current study was characterized, and it was discovered that Ni content varied, as did some micronutrients. The highest height value obtained from HM for soybean and common bean could be attributed to adequate Ni and Mo soil content. In fact, combined Ni+Mo fertilization had a significant effect on soybean growth and biological nitrogen fixation parameters [19]. Ni and Mo are two micronutrients that legumes use in their biological nitrogen fixation processes; Mo is a component of the plant nitrate reductase enzyme and nitrogenase of the symbionts, and Ni increases urease activity and extends enzyme activity time [19,20].

Furthermore, there was a positive and significant correlation between soil and plant Ni contents for soybean and common bean, but not for maize. This observation suggests two interpretations: first, that legumes absorb more Ni from soil than maize for their metabolisms, and secondly, that legumes' high absorption of Ni may be a source of human contamination. Thus, maize appeared to be more tolerant to high Ni content than the two grain legume species, as no lethal effect on the plant was observed. Furthermore, the concentration of Ni in the root of maize was about five times higher than that of the shoot (RootNi /ShootNi = 5.09) which is important in lowering Ni toxicity in human.

In terms of the two grain legumes, soybean was able to grow on all soil without being killed, whereas common bean recorded dead plants at the start of the experiment for the first two weeks. This could be due to high Ni concentrations in plant tissue, which inhibit photosynthesis and plant respiration [17].

The correlation analysis revealed that many soil trace elements were related to those found in grain legumes (only Mn for maize). This observation implied that the uptake of those chemicals could be influenced by the plant nutrient uptake process or could be chemically dependent. However, the direct result of the correlation is the possibility of phytotoxicity from soil containing high levels of these chemicals, particularly Ni [10].

Furthermore, Ca and V uptake may reduce or mitigate the negative effects of Ni on the soybean plant. As a result, growing grain legumes on Ni-enriched soils may result in human Ni toxicity. Nickel is highly mobile in phloem, which aids in its translocation and accumulation in fruits and seeds [21]. Furthermore, the interaction of micronutrients may influence the plant's uptake of one or more element(s).

5. CONCLUSION

Some trace elements are controlled by the root system because their concentration in the soil does not match their content in the plant. This study found that maize concentrated more nickel (Ni) in the root than the two legumes, soybean and common bean, suggesting that there was less nickel transferred to the edible corncob. According to this research, of the three crops, maize should be the one most suitable for cultivation in the vicinity of the Ni mining region of Foungouesso-Moyango.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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