



Status of micronutrients in soils of a basement complex area of Samaru, Zaria, Nigeria

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Abstract

A great deal of research has underscored the role of micronutrients in plant nutrition and crop production. The objective of this study is to examine the status of total and available copper, zinc, nickel, iron and manganese in soils of the study area in relation to crop production and soil genesis. The landscape of the study area was stratified into different five parts using with two soil profiles dug at random in each slope unit. Soil samples were obtained from genetic horizons. The 0.1 M HCl extraction method was used to determine available Cu, Fe, Mn, Ni and Zn in the soil samples while total Cu, Zn, Ni, Fe, and Mn were extracted after a mixed acid digestion involving perchloric, nitric and sulphuric acids. Total and available contents of copper were generally low in the soils and crops grown on these soils may suffer from copper deficiency. Total zinc and nickel were higher than acceptable limits in the soils and suggest that the soils may have been polluted or contaminated. Very high values of available iron were observed most especially at intermediate to bottom slope areas suggesting that crops grown on these soils may suffer from iron toxicity.

Key words: basement complex, copper, zinc, nickel, iron, manganese

Introduction

The study area is located at the Institute for Agricultural Research (I. A. R), Ahmadu Bello University Research Farm, Samaru ($11^{\circ} 11' \text{ N}$ and $7^{\circ} 38' \text{ E}$). Samaru experiences a Tropical Continental climate with distinct seasonal regimes, oscillating between cool to hot dry and humid to wet (Iloeje, 2004). The long-term mean annual rainfall is 1100 mm (monomodal) and the length of the season is about 130 to 190 days from late May to September/October (Yaro et. al., 1999). Soils over the Samaru area have also developed from fined grained loess material, deposited by winds from the Sahara and mixed over the years with the local soils, derived from Basement Complex rocks (Wall, 1978; Iloeje, 2004).

The landscape on which this study was carried out is made up of gentle slopes ranging from 1.36 to 1.74% in gradient. Previous studies on the soils indicated that the surface soils are loamy in texture and; have low pH and organic matter content with a range of 3.50 to 4.65 and 0.11 to 1.69 % respectively (Owonubi, 2008). Poor drainage conditions were also observed at the bottom part of the slope. Soils of the study area have been under intensive arable farming for over 30 years making it imperative to know:

1. If crop production over the years have resulted in micronutrient depletion,
2. What impact continuous use of fertilizers over the years has had on micronutrient status, and
3. What effect soil forming processes has had on the soil's micronutrient status over time?

A great deal of research has underscored the role of micronutrients in plant nutrition and crop production (Brady and Weil, 1999). The import of this study is so that adequate management decisions can be made for sustainable crop production. The objective of this study therefore is to examine the status of total and available copper, zinc, nickel, iron and manganese in soils of the study area in relation to crop production and soil genesis.

Materials and Methods

The landscape was stratified into different parts using FAO (2006) guidelines. Two profiles (sited 100m apart) were dug at each part of slope. The experimental design involved a stratified random sampling approach. Sampling points were located at random in each slope unit. Soil weighted average of data in surface and subsurface soils were calculated to remove horizon bias (Ovalles and Collins, 1986). Weighted average was calculated as:

$$WA = \sum wx / \sum w$$

Where: WA is weighted average, x is soil data, and w is thickness of corresponding horizon.

The Fishers test of significance was used to compare the variance of soil data between landscape positions. Surface soil in this study was regarded as either an Ap horizon (top most mineral horizon that has undergone plowing or other disturbance) or combined Ap and AB horizons (transitional horizon from the top most mineral horizon to underlying illuvial horizon but dominated by properties of the former) as the case may be. Soil samples from genetic horizons were air-dried in the laboratory, crushed with porcelain pestle and mortar and sieved to remove material greater than 2mm (gravel and other coarse fragments). The 0.1 M HCl extraction method described by IITA (1979) was used to determine available Cu, Fe, Mn, Ni and Zn in the soil samples while total Cu, Zn, Ni, Fe, and Mn were extracted after a mixed acid digestion involving perchloric, nitric and sulphuric acids. The elements were read from the extracts with an atomic absorption spectrophotometer. The location of the profiles determined with a global position system (GPS) device is as follows:

Profile	Location
1	I.A.R Farm (11 ⁰ 10.504' N and 007 ⁰ 36.584' E)
2	I.A.R Farm (11 ⁰ 10.495' N and 007 ⁰ 36.651' E)
3	I.A.R Farm (11 ⁰ 10.589' N and 007 ⁰ 36.638' E)
4	I.A.R Farm (11 ⁰ 10.563' N and 007 ⁰ 36.695' E)
5	I.A.R Farm (11 ⁰ 10.829' N and 007 ⁰ 36.771' E)
6	I.A.R Farm (11 ⁰ 10.807' N and 007 ⁰ 36.821' E)
7	I.A.R Farm (11 ⁰ 10.148' N and 007 ⁰ 36.991' E)
8	I.A.R Farm (11 ⁰ 10.114' N and 007 ⁰ 36.033' E)
9	I.A.R Farm (11 ⁰ 10.252' N and 007 ⁰ 36.175' E)
10	I.A.R Farm (11 ⁰ 10.237' N and 007 ⁰ 36.196' E)

Results and Discussion

Copper

Contents of total copper in soils of the landscape are shown in Table 1; minimum and maximum contents in the soils were 3.6 and 32.1 mg/kg with a mean and standard deviation of 9.41 and 6.92 mg/kg respectively. These values are lower than those reported by Kparmwang et al (1998) for basaltic soils (range: 15 to 65 mg/kg; mean: 41 mg/kg) of the northern guinea savanna area of Nigeria. The distribution of total copper with depth in profiles across the landscape was generally irregular (Figure 1). The distribution pattern for profiles 1 and 2 of the highest part of slope were similar and shows an increase in contents of total copper with depth.

Distribution pattern of total copper in profiles 7 and 8 of lower part of slope were also similar though variation in contents with depth was irregular. The irregular trends in the distribution of total copper in the soils could be attributed to *in situ* formation of copper in the varying horizons. Bolt and Bruggenwert (1978) noted that mobility and displacement of copper in soils is slow because it forms strong bonds with organic matter, clay minerals and is even adsorbed on quartz. The weighted average of values of total copper in surface and subsurface soils are also presented in Table 2. These values when compared to typical soil content of total copper (range: 2.0 to 100 mg/kg; mean: 20 mg/kg) documented by Bolt and Bruggenwert (1978) and Bohn et al (1985) indicated that surface soil values are generally low except for the intermediate part of slope which has moderate values. In the subsurface soils, highest to intermediate parts of slope have moderate values while lower and bottom parts of slope have low levels. Values of total copper in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$) though higher values were recorded for surface and subsurface soils of intermediate slope area (Figure 1).

Weighted average values of available copper ranged from trace to 0.7 mg/kg and from 0.1 to 0.6 mg/kg in surface and subsurface soils (Table 3). Weighted mean contents of available copper in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$). The values are slightly lower than those reported by Olowolafe (2003) for soils derived from granite (range: 0.3 to 1.32 mg/kg; mean: 0.7 mg/kg) in the northern guinea savanna area of Nigeria. Wild (1973) noted that copper deficiencies are associated with soil concentrations < 0.2 mg/kg and indicates that deficiencies were prevalent in some of the soils of the landscape. The low content of available copper in these soils is not unconnected with the low total copper content levels in the parent materials. Olowolafe and Dung (1999) and Olowolafe (2003) have reported copper deficiencies in soils derived from granite in the northern guinea savanna of Nigeria. They attributed the deficiencies to the low content of copper in the parent materials.

Zinc

Total contents of zinc in soils of the landscape are shown in Table 1; with respective minimum and maximum values of 34.30 and 274.50 mg/kg, and mean and standard deviation of 120.83 and 67.41 mg/kg. The distribution of total zinc with depth in profiles across the landscape is shown in Figure 2. The distribution pattern for profiles of the highest part of slope shows an increase in contents of total zinc with depth while those of profiles 9 and 10 of the bottom part of slope showed a decrease in contents of total zinc with depth. The distributions of total zinc at other slope parts were

generally irregular. This could be attributed to variable distribution of zinc bearing minerals within the soils. Similarly, Bolt and Bruggenwert (1978) noted that prediction of the distribution of zinc in soils is complicated by its occurrence in a great number of complexes which have cationic and anionic characters. Weighted average of total zinc in surface and subsurface soils are also presented in Table 2. The values are higher than the range (20 -25 mg/kg) stated by Bolt, and Bruggenwert (1978) for zinc deficiencies to occur in soils. However total zinc values at the lower and bottom parts of slope are higher than soil management regulatory limits of 120 to 150 mg/kg (Mosquera-Losada et al 2009; Rennert et al 2009; Mishima et al 2005; Ogiyama et al 2005). Though zinc has been noted to be more available under low pH conditions (Brady and Weil, 1999) as is the case with these soils, it is not unlikely that the high content of zinc in the soils could be related to soil pollution. The soils of this landscape have been replenished with intensive fertilizer application in the past. Mishima et al (2005), in a study of zinc balance in soils associated with the use of chemical fertilizers, noted that continuous use of zinc containing fertilizers could over the years raise the zinc contents of soils to unfavorable levels.

Weighted average values of available zinc ranged from 1.4 to 21.3 mg/kg and from 3.0 to 17.2 mg/kg in surface and subsurface soils across the landscape (Table 3). Weighted mean contents of available zinc in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$). The values are higher than those reported by Olowolafe (2003) for soils derived from granite (range: 0.65 to 6.5 mg/kg; mean: 2.61 mg/kg) in the northern guinea savanna area of Nigeria. The higher values in these soils may not be unconnected to the low pH of the soils. Brady and Weil (1999) noted that zinc is more available under low soil pH conditions.

Nickel

Table 1 shows minimum and maximum values of 34.30 and 274.50 mg/kg respectively of total nickel in soil profiles across the landscape (mean: 67.41 mg/kg, standard deviation 120.83 mg/kg). These values are higher than those reported by Chukwuma (1994) for some south eastern Nigerian soils (range: 7 to 97 mg/kg; mean: 31.4 mg/kg). The distributions of total nickel with depth were generally irregular at all parts of slope (Figure 3). Weighted average of total nickel in surface and subsurface soils (Table 2) were not statistically different among slope positions ($P > 0.05$) however soil contents were much higher than the precautionary limits of 50 mg/kg given by German law for loamy soils (Rennert et al, 2009). This indicates that crops grown on these soils may produce lower yields due to nickel toxicity.

Weighted average values of available nickel in surface and subsurface soils ranged from 16.3 to 69.5 mg/kg and from 28.7 to 67.2

mg/kg across slope positions respectively (Table 3). Weighted average contents of available nickel in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$). The values were also higher than those reported by Ramos-Bello et al (2001) for some soils (range: 0.93 to 3.14 mg/kg). The higher values of available nickel in these soils could be attributed to the low pH of the soils coupled with reducing conditions most especially in the bottom slope area which has highest contents in the surface soils. Brady and Weil (1999) noted low pH and reducing conditions as factors responsible for high contents of available nickel in soils.

Iron

Values of total iron ranged from 2523.6 to 5484.3 mg/kg in surface soils and from 3545.4 to 4415.3 mg/kg in subsurface soils (Table 2). Weighted average of total iron in surface and subsurface soils are also presented in Table 2. The values though fairly high are lower than those reported by Tazisong et al. (2004) for some Ultisols (range: 10,670 to 70,840 mg/kg; mean: 30,900 mg/kg). Values in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$); however, subsurface soils had higher contents of total iron (Figure 4). This could be attributed to higher contents of silicate clays in the subsurface soils. Tazisong et al. (2004) in study of Ultisols noted that silicate clay was the dominant soil property influencing the distribution of residual iron. The distribution of total iron with depth in profiles across the landscape is shown in Figure 4. Total iron increased with depth at higher parts of slope. Distributions of total iron at other slope positions were generally irregular.

Values of available iron in surface and subsurface soils across slope positions ranged from 11.9 to 139.1 mg/kg and from 11.3 to 65.2 mg/kg respectively (Table 3). Weighted average contents of available iron in surface soils were higher than for subsurface soils in most cases probably due to higher content of iron oxides in the surface soils. The values are lower than those reported by Yaro (2005) for plinthic soils (range: 80,000 to 304,000 mg/kg; mean: 150,400 mg/kg). Values in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$). Becker and Asch (2005) noted that most Fe toxicities in soils occur at concentrations of greater than 20 mg/kg Fe^{2+} . Consequently values of available Fe at intermediate to bottom parts of slope were in excess of this. The low pH of the soils could have been responsible for this, though higher values of available Fe at the bottom part of slope is most likely accentuated by poor drainage conditions in the area. Brady and Weil (1999) observed that Fe is more soluble and available under low pH and poor drainage conditions

Manganese

Values of total manganese ranged from 28.8 to 96.2 mg/kg in surface soils and from 27.3 to 51.1 mg/kg in subsurface soils (Table 2). Weighted average of total manganese in surface and subsurface soils is lower than those reported by Tazisong et al. (2004) for some Ultisols (range: 30 to 33,300 mg/kg; mean: 3,080 mg/kg). Values in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$). Surface soil values were generally higher than those for subsurface soils (Figure 5) probably due to effect of organic matter in retaining and recycling manganese. The distribution of total manganese with depth in profiles across the landscape is shown in Figure 5. The trends in the distribution of manganese with depth varied with each slope position.

Values of available manganese ranged from 1.9 to 33.6 mg/kg and from 2.6 to 14 mg/kg in surface and subsurface soils respectively across slope positions (Table 3). Weighted average contents of available manganese in surface and subsurface soils were similar to those reported by Yaro (2005) for some plinthic soils (range: 1.0 to 27.2 mg/kg; mean: 8.63 mg/kg). Values in surface and subsurface soils were not statistically different among slope positions ($P > 0.05$). Wild (1973) reported a critical level of 25 mg Mn kg⁻¹ (extracted with 0.1 % hydroquinone in neutral molar ammonium acetate) which could serve as a rough guide for identifying soil manganese deficiencies. Using this critical level, it is observed that some of the surface and subsurface soils across the landscape could be deficient in manganese despite the low pH condition which should have favored satisfactory soil content (Brady and Weil, 1999). This indicates that the low available manganese content of the soils could likely result from the general low total manganese content of the soils as shown in Table 1 and 2.

Conclusion

This study was embarked upon to examine the status of total and available copper, zinc, nickel, iron and manganese in soils of the study area. Total and available contents of copper were generally low in the soils and crops grown on these soils may suffer from copper deficiency. Total zinc and nickel were higher than acceptable limits in the soils and suggest that the soils may have been polluted or contaminated. Very high values of available iron were observed most especially at intermediate to bottom slope areas suggesting that crops grown on these soils may suffer from iron toxicity.

Statistical analysis indicated no significant differences in the micronutrient contents among slope units. These suggest that slope position had little or no effect on the distribution of micronutrients across the landscape or either that anthropic activities have overshadowed its influence.

Acknowledgement

I appreciate Late Prof. T. Kparmwang and Prof B. A. Raji of Soil Science Department, A. B. U., Zaria for supervising this work. I also appreciate the constructive criticisms of Prof E. A. Olowolafe of Geography and Planning Department, University of Jos.

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Table 1: total and available micro nutrients (mg/kg) in profiles

Profile	Horizon	Depth (cm)	Copper		Zinc		Nickel		Iron		Manganese	
			Total	Available	Total	Available	Total	Available	Total	Available	Total	Available
Highest												
1	Ap	0-17	3.6	0.4	107.8	3.9	97.8	16.3	2616.5	11.9	41.9	7.8
	BA	17-34	7.1	0.4	73.5	2.0	65.2	16.3	3789.5	14.7	39.5	4.9
	Bt	34-65	10.7	0.4	73.5	5.9	130.4	65.2	3969.9	10.1	22.2	1.3
	Btc	65-95	10.7	0.0	73.5	25.0	130.4	16.3	4240.6	14.7	39.5	3.2
	Btv	95-150	17.9	0.4	83.3	9.8	81.5	48.9	4962.4	11.9	54.3	2.3
2	Ap	0-6	3.6	0.0	73.5	2.9	97.8	32.6	3157.9	13.7	56.7	4.2
	BA	6-35	7.1	0.0	63.7	2.5	146.7	48.9	3699.3	15.6	24.7	2.9
	Bt1	35-73	3.6	0.4	83.3	2.5	114.1	48.9	3969.9	9.2	29.6	2.3
	Bt2	73-115	10.7	0.0	102.9	3.9	97.8	48.9	4060.2	20.2	27.1	5.2
	Higher											
3	Ap	0-14	7.1	0.0	58.8	2.0	179.4	32.6	3609.0	11.9	96.2	1.9
	BA	14-24	3.6	0.0	83.3	8.8	81.5	32.6	3428.6	40.3	49.3	25.2
	Bt1	24-55	3.6	0.4	88.2	1.5	130.4	48.9	3609.0	30.2	37.0	1.3
	Bt2	55-87	3.6	0.0	83.3	2.9	195.7	65.2	3699.3	9.2	37.0	4.9
	Bt3	87-125	7.1	0.4	98.0	4.4	130.4	65.2	3879.7	11.0	54.3	6.1
	Bt4	125-165	3.6	0.0	107.8	4.9	130.4	48.9	4330.9	13.7	66.6	6.8
4	Ap	0-6	3.6	0.4	58.8	1.4	97.8	32.6	3067.7	26.6	64.1	16.2
	BA	6-23	3.6	0.0	73.5	3.9	48.9	16.3	3428.6	19.2	29.6	11.0
	Bt1	23-52	25.0	1.1	68.6	5.9	130.4	81.5	3759.5	22.9	39.5	14.6
	Bt2	52-95	17.9	0.4	93.1	3.4	97.8	16.3	4060.2	16.5	49.3	23.9
	Bt3	95-119	14.3	0.0	102.9	7.8	130.4	32.6	4240.6	12.8	32.1	6.14
	Bt4	119-165	25.0	1.1	93.1	3.4	179.4	16.3	4511.3	10.1	32.1	1.94

Table 1 (continued): total and available micro nutrients (mg/kg) in profiles

Profile	Horizon	Depth (cm)	Copper		Zinc		Nickel		Iron		Manganese	
			Total	Available	Total	Available	Total	Available	Total	Available	Total	Available
Intermediate												
5	Ap	0-22	32.1	0.7	93.1	3.9	130.4	48.9	3338.4	13.7	86.4	2.3
	BA	22-49	17.9	0.4	107.8	9.3	146.7	32.6	3067.7	34.8	64.1	26.5
	Bt1	49-110	14.3	0.0	93.1	3.9	130.4	65.2	4150.4	22.0	44.4	10.7
	Bt2	110-140	21.4	1.1	107.8	7.4	146.7	81.5	4060.2	17.4	24.7	1.3
	Btv3	140-170	10.7	0.7	49.0	4.9	114.1	97.8	3248.1	19.2	17.3	2.3
6	Ap	0-17	10.7	0.7	83.3	4.4	130.4	32.6	2255.6	82.4	44.4	33.6
	BA	17-43	14.3	0.4	73.5	5.4	195.7	16.3	3338.4	11.9	37.0	3.9
	Bt	43-97	14.3	0.7	73.5	4.9	130.4	48.9	3518.8	12.8	27.1	1.9
	Btv	97-130	21.4	1.1	63.7	5.9	130.4	48.9	3699.3	17.4	27.1	2.3
	Btc	130-150	17.9	0.0	73.5	6.9	130.4	65.2	3969.9	11.0	39.5	4.5
Lower												
7	Ap1	0-22	7.1	0.4	230.4	12.3	81.5	16.3	2526.3	29.3	49.3	25.9
	Ap2	22-44	3.6	0.0	254.9	5.4	81.5	48.9	3518.8	2.6	74.0	34.3
	Bt1	44-84	7.1	0.4	34.3	13.7	130.4	32.6	3789.5	15.6	41.9	4.9
	Bt2	84-112	7.1	0.4	235.3	47.6	97.8	48.9	4150.4	16.5	54.3	5.2
	Btv3	112-170	3.6	0.0	259.8	4.9	130.4	16.3	4060.2	17.4	39.5	2.3
8	Ap	0-11	7.1	0.4	240.2	33.3	146.7	32.6	3518.8	42.1	113.5	26.3
	AB	11-37	3.6	0.0	215.7	16.2	81.5	32.6	6315.8	20.2	46.9	9.1
	Bt1	37-59	3.6	0.7	220.6	18.6	114.1	32.6	3969.9	14.7	24.7	6.8
	Bt2	59-92	7.1	0.7	220.6	30.9	130.4	32.6	4150.4	11.9	37.0	2.6
	Btv3	92-165	3.6	0.0	245.1	9.8	81.5	48.9	4330.8	10.1	44.4	1.6

Table 1 (continued): total and available micro nutrients (mg/kg) in profiles

Profile	Horizon	Depth (cm)	Copper		Zinc		Nickel		Iron		Manganese	
			Total	Available	Total	Available	Total	Available	Total	Available	Total	Available
Bottom 9	Ap	0-8	3.6	0.0	274.5	15.7	65.2	32.6	3067.7	146.56	54.86	24.6
	AB	8-32.5	3.6	0.4	220.6	4.4	114.1	81.5	2345.9	100.76	18.42	5.5
	Bt1	32-65	3.6	0.0	225.5	4.4	81.5	48.9	3248.1	155.73	30.93	14.9
	Bt2	65-85	3.6	0.0	107.8	4.9	212.0	48.9	3067.7	78.28	41.80	24.9
	Bcg	85-152	10.7	1.1	117.7	3.9	146.7	32.6	3699.2	17.4	50.35	10.4
10	Ap	0-18	10.7	1.1	147.1	7.8	212.0	65.2	2887.2	183.2	29.93	14.2
	AB	18-32	10.7	1.1	117.7	4.4	146.7	65.2	2977.4	82.4	20.93	11.6
	Bg1	32-58	10.7	0.7	83.3	2.9	130.4	97.8	2526.3	40.3	19.42	4.5
	Bg2	58-82	3.6	0.0	107.8	2.0	114.1	32.6	3699.3	18.3	28.96	3.2
	Btg1	82-126	3.6	0.0	83.3	6.9	114.1	32.6	3969.9	14.7	20.95	4.2
	Btg2	126-165	3.6	0.0	78.4	8.3	81.5	16.3	3879.7	10.1	30.38	2.3

Table 2: Total micronutrients (mg/kg) in surface and subsurface soils

	Highest			Higher			Intermediate			Lower			Bottom			
	P1	P2	WA	P3	P4	WA	P5	P6	WA	P7	P8	WA	P9	P10	WA	
Copper	Surface															
	Subsurface	3.6	3.6	3.6	7.1	3.6	6.1	32.1	10.7	22.8	5.4	4.6	5.0	3.6	10.7	7.1
Zinc	Surface	13.2	7.3	10.5	4.5	19.2	12.0	15.7	16.6	16.1	5.5	4.5	5.0	7.6	5.0	6.2
	Subsurface	107.8	73.5	98.9	58.8	58.8	58.8	93.1	83.3	88.9	242.7	223.0	233.7	233.9	134.2	184.4
Nickel	Surface	77.6	85.7	81.2	94.7	88.1	91.3	89.9	71.1	81.0	182.7	234.6	208.9	145.3	86.3	114.3
	Subsurface	97.8	97.8	97.8	179.4	97.8	154.9	130.4	130.4	130.4	81.5	100.9	90.4	102.1	183.4	142.4
Iron	Surface	101.9	116.5	108.5	140.9	127.0	133.8	133.4	143.2	138.0	123.2	99.7	111.4	139.9	107.8	123.0
	Subsurface	2616.5	3157.9	2757.8	3609.0	3067.7	3446.6	3338.4	2255.6	2866.4	3022.6	5484.3	4147.0	2523.6	2926.7	2723.6
Manganese	Surface	4418.3	3932.7	4199.6	3881.5	4101.1	3993.4	3751.7	3596.1	3678.1	3994.3	4222.3	4109.2	3470.8	3612.4	3545.4
	Subsurface	41.9	56.7	45.8	96.2	64.1	86.5	86.4	44.4	68.1	61.7	66.7	64.0	30.7	28.8	29.8
		41.5	27.3	35.2	50.2	37.8	43.9	38.5	30.9	34.9	43.6	39.1	41.3	51.1	29.7	39.8

P = soil profile; WA = Weighted average

Table 3: Available micronutrients (mg/kg) in surface and subsurface soils

		Highest			Higher			Intermediate			Lower			Bottom		
		P1	P2	WA	P3	P4	WA	P5	P6	WA	P7	P8	WA	P9	P10	WA
Copper																
	Surface	0.4	0.0	0.3	0.0	0.4	0.1	0.7	0.7	0.7	0.2	0.1	0.2	0.3	1.1	0.7
	Subsurface	0.3	0.1	0.3	0.2	0.6	0.4	0.4	0.6	0.5	0.2	0.3	0.3	0.6	0.1	0.4
Zinc																
	Surface	3.9	2.9	3.7	2.0	1.4	1.8	3.9	4.4	4.1	8.8	21.3	14.5	7.2	6.3	6.8
	Subsurface	11.3	3.0	7.6	3.9	4.6	4.3	5.8	5.5	5.7	17.2	16.8	17.0	4.2	5.6	5.0
Nickel																
	Surface	16.3	32.6	20.6	32.6	32.6	32.6	48.9	32.6	41.8	32.6	32.6	32.6	69.5	65.2	67.4
	Subsurface	41.2	48.9	44.7	55.3	30.7	42.8	67.2	45.0	56.7	28.7	41.9	35.4	39.8	40.6	40.2
Iron																
	Surface	11.9	13.7	12.4	11.9	26.6	16.3	13.7	82.4	43.7	16.0	26.7	20.9	112.0	139.1	125.5
	Subsurface	12.5	15.1	13.7	17.2	15.5	16.3	22.8	13.5	18.4	16.6	11.3	14.0	65.2	19.0	40.9
Manganese																
	Surface	7.8	4.2	6.8	1.9	16.2	6.2	2.3	33.6	16.0	30.1	14.3	22.9	10.2	13.1	11.6
	Subsurface	2.6	3.6	3.0	6.3	11.8	9.1	10.0	2.8	6.6	3.7	2.8	3.2	14.0	3.5	8.5

P = soil profile; WA = Weighted average

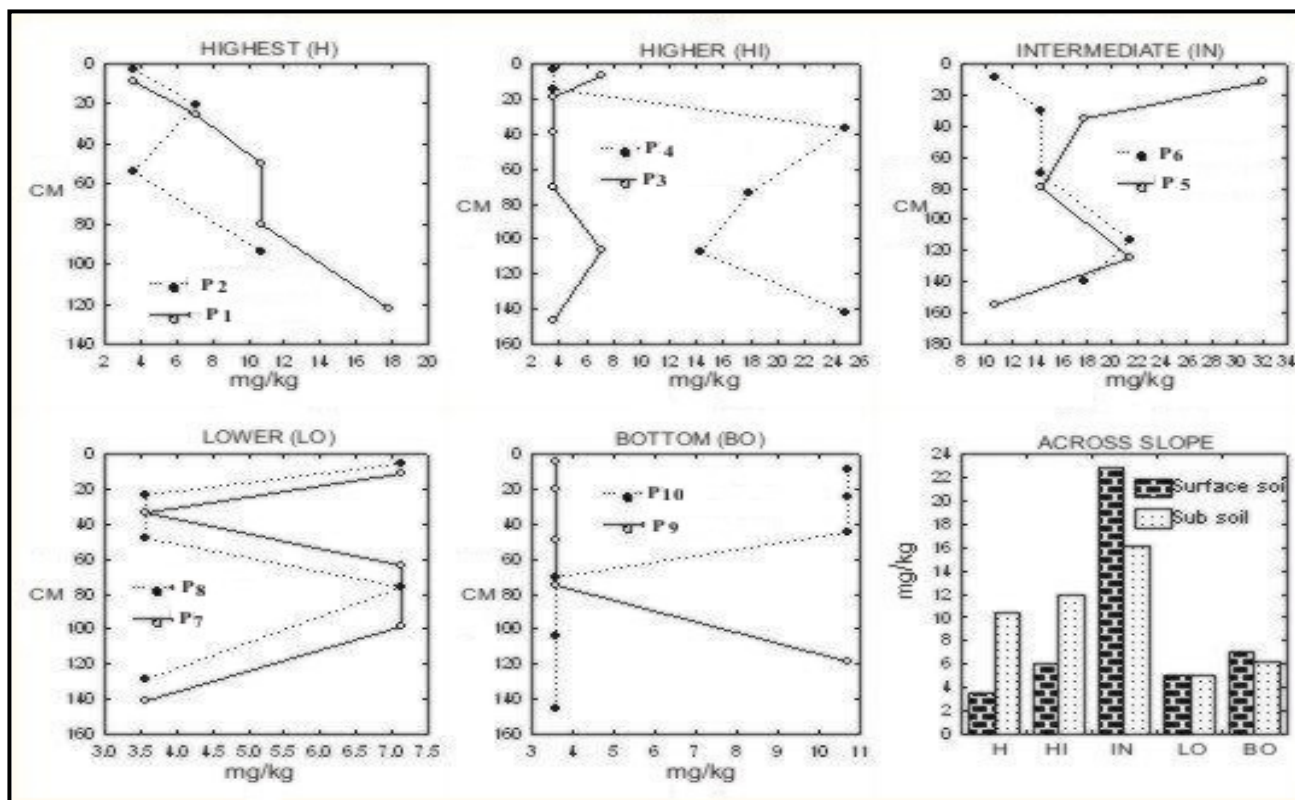


Figure 1: Distribution of total copper in profiles (p) across slope positions

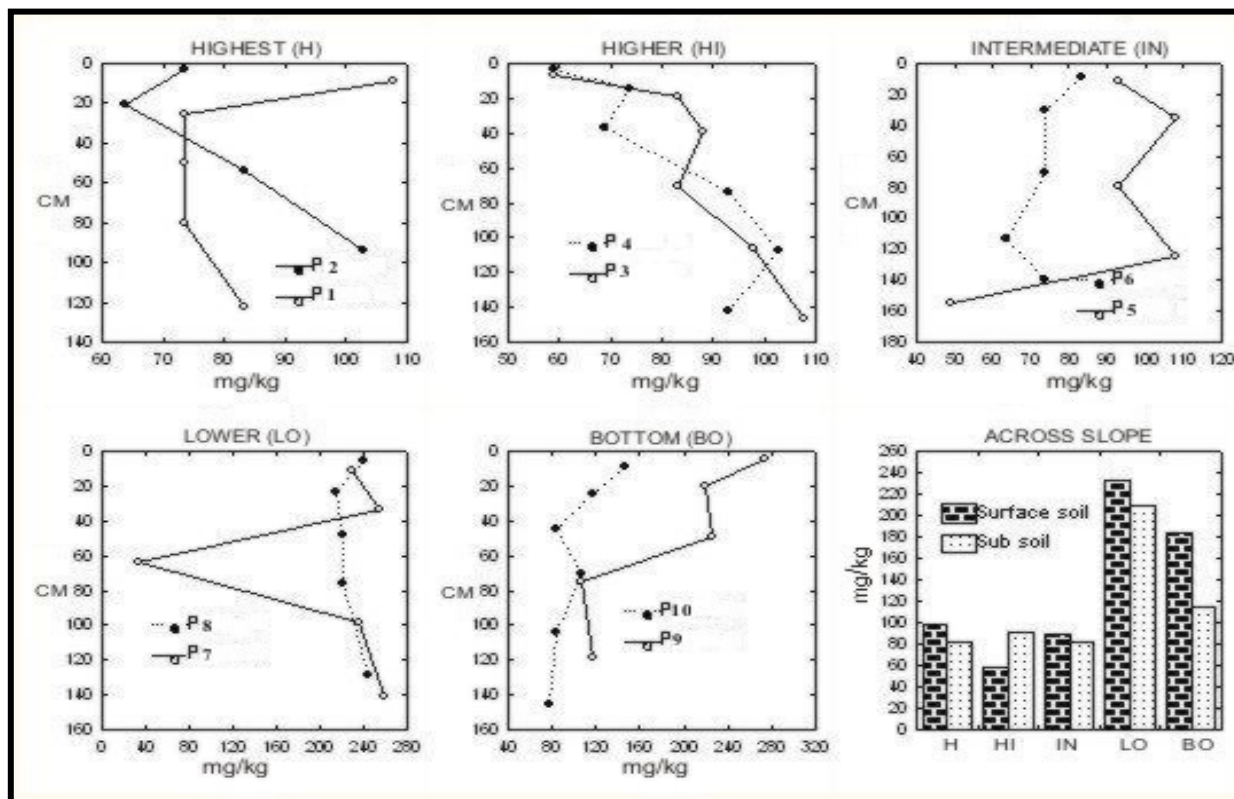


Figure 2: Distribution of total zinc in profiles (p) across slope positions

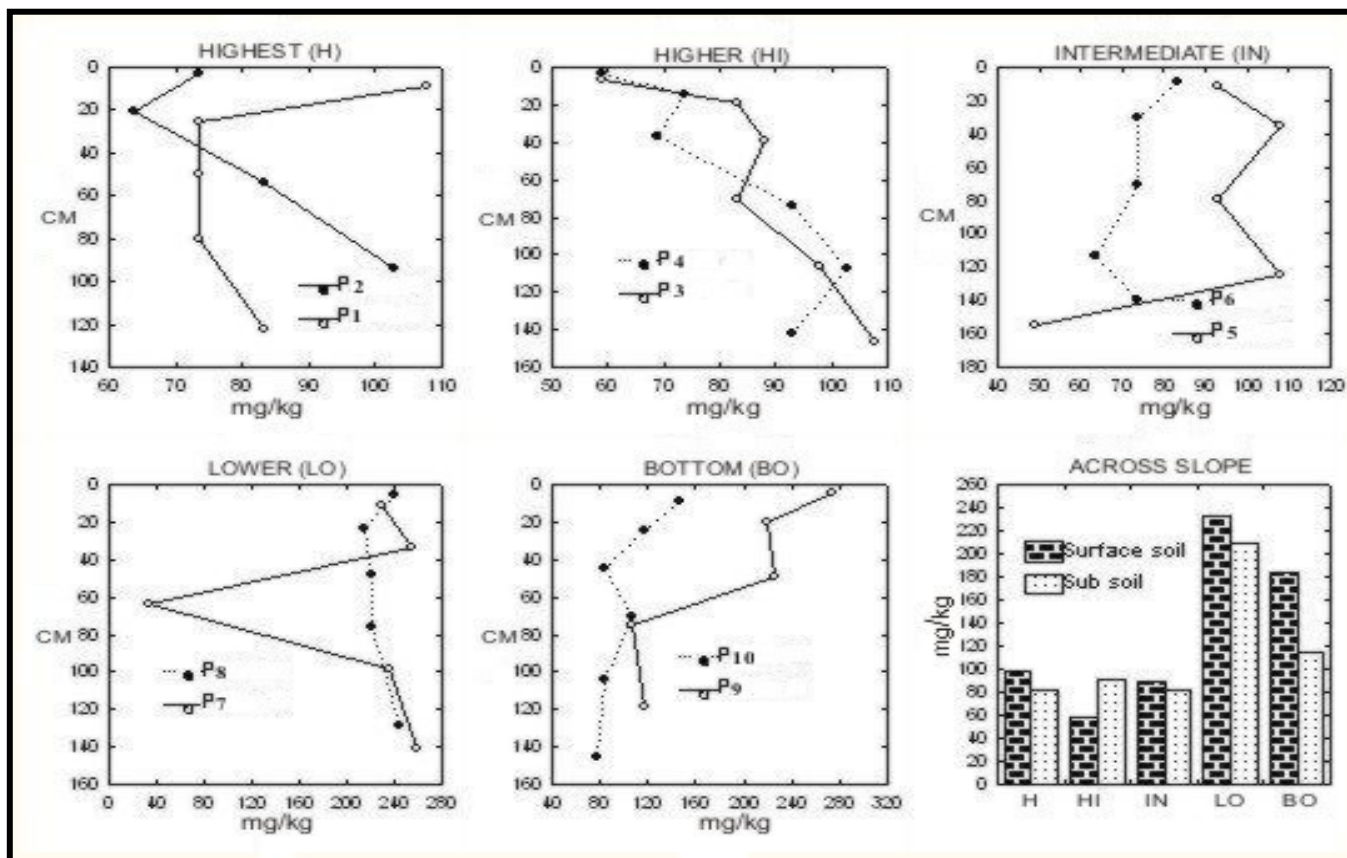


Figure 3: Distribution of total nickel in profiles (p) across slope positions

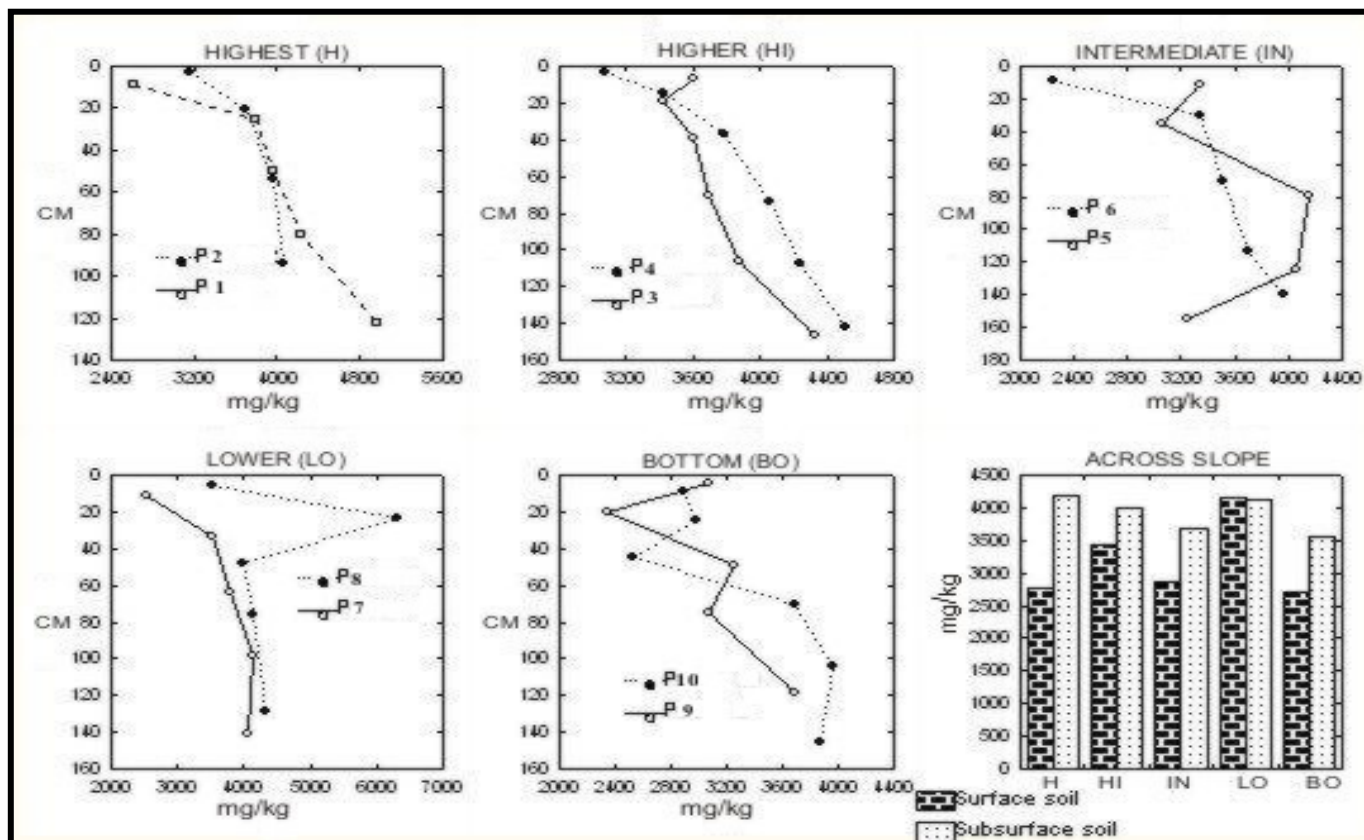


Figure 4: Distribution of total iron in profiles (p) across slope positions

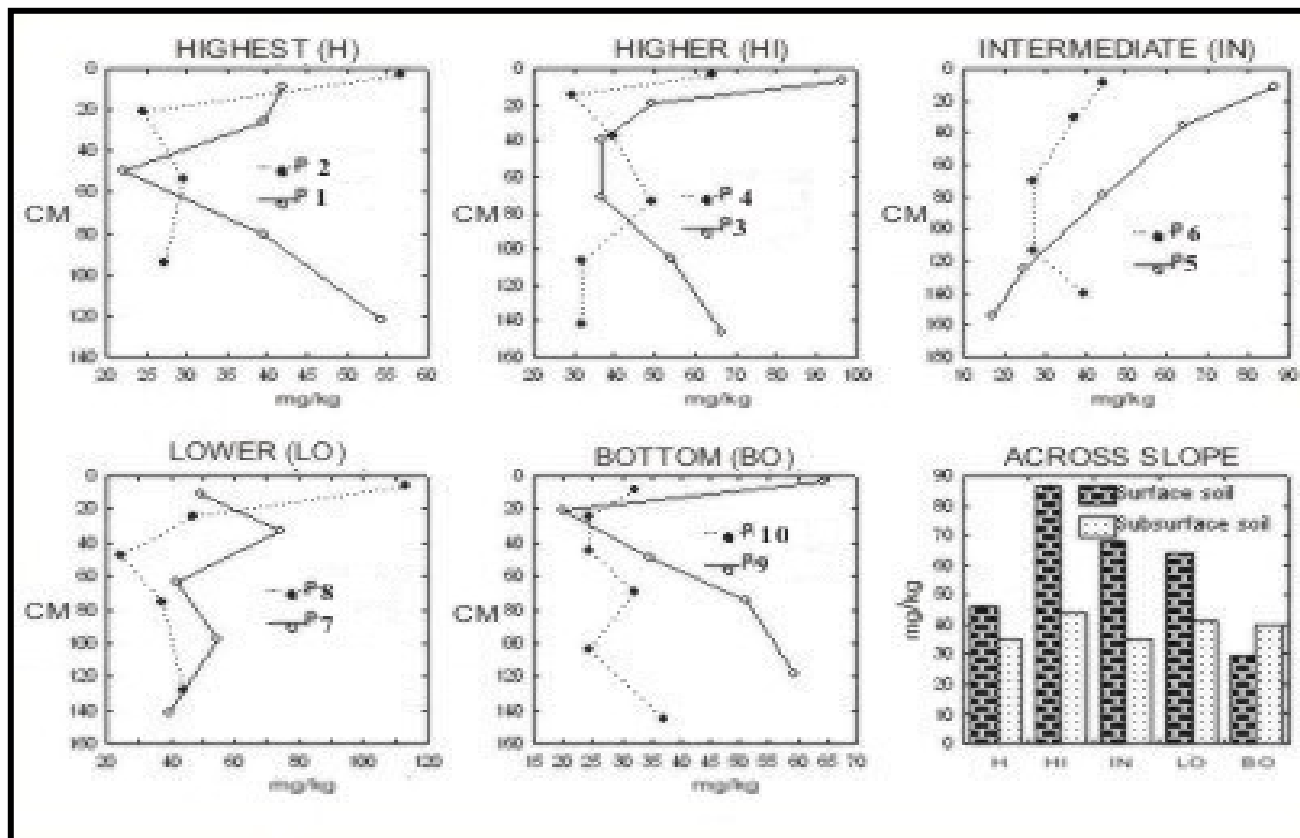


Figure 5: Distribution of total manganese in profiles (p) across slope positions