

Distribution of Zn Fractions with Relation to Soil Properties in Coconut Lands

D. M. D. I. Wijebandara^a, and A. A. Zanofer^b

^a - Coconut Research Institute, Lunuwila 61150, Sri Lanka

^b - Wayamba University of Sri Lanka, Makandura, Gonawila, Sri Lanka

* - Corresponding author: iraniew@gmail.com

ABSTRACT

Distribution of various fractions of Zn and their relationship with soil properties were studied in coconut growing soils collected from different agroclimatic zones in coconut triangle of Sri Lanka. Though the content of different fractions varied among the soils, the order of preponderance of different Zn fractions remained same, *viz.* water soluble plus exchangeable Zn < organically bound Zn < manganese oxide bound Zn < amorphous sesquioxide bound Zn < crystalline bound Zn < residual Zn. The water soluble plus exchangeable Zn fraction was the least dominant fraction of Zn and the residual Zn was the most dominant fraction of Zn in soil. Correlation and regression analysis indicated that the availability of different fractions of Zn mainly depend on soil properties such as pH, free CaCO₃, organic carbon, clay and free Fe₂O₃ content in soil.

The different fractions of Zn in these soils showed significant and positive correlation amongst one and other, which indicated the existence of a dynamic equilibrium among the different pools of Zn in soils. This indicated the depletion of Zn concentration of readily available pool is replenished by other pools of Zn.

Key words: Coconut growing soils, sequential extraction, soil properties, Zn fractions

INTRODUCTION

Zinc is one of the essential micronutrients which plays a significant role in nutrition of coconut for growth, development and optimum yield. It involves in major physiological functions in the coconut palms. The survey carried out to study the micronutrient availability in coconut

plantations revealed that lower levels of Zn in both soil and coconut leaf than their sufficiency levels (Wijebandara and Somasiri, 2004). The coconut rapid decline palms also showed that leaf Zn levels were below the sufficiency range (Wijebandara and Ranasinghe, 2004). The long term field experiment results revealed that there was no increase of leaf Zn levels

after continuous application of Zn through soil or root feeding (Somasiri and Hewage, 2001; Wijebandara and Ranasinghe, 2004). These observations lead to study the chemistry of Zn in soil.

Zinc exists in soil in a number of discrete chemical forms differing in their solubility and thus availability to plants (Sarkar and Deb, 1982). Zinc in exchange positions and soluble complexes was the major importance in maintaining of Zn level sufficient for plants. According to Viets (1962), Zn in soils divided in to different chemical pools, viz., water soluble, easily exchangeable, adsorbed, chelated, or complexed, occluded by or co-precipitated with metal oxides, carbonates or phosphates and other secondary minerals and held in primary minerals.

These pools differ in strength (or reversibility) and therefore in their susceptibility to plant uptake, leaching, and extractability. The equilibrium among the different pools is influenced by pH, Eh, and concentration of Zn and other cations, particularly iron and manganese. The readily available Zn forms viz., water soluble, exchangeable and chelated Zn forms were in reversible equilibrium with each other (Viets, 1962). Water soluble plus exchangeable and organically complexed forms are considered to be available, amorphous sesquioxide bound form is potentially available and crystalline sesquioxide bound and residual Zn forms are unavailable to plants (Mandal *et al.*, 1992).

Widespread occurrence of Zn deficiency in soils suggests that both native and applied Zn react with the inorganic and organic phases

in the soil and thereby affect the availability of Zn. The availability of Zn in soils is a function of its partition among different forms (Viets, 1962). A proper understanding the fractions which control the distribution of Zn between active soil constituents and soil solution is fundamental to an understanding of the chemistry of Zn in soil (Viets, 1962). The availability of Zn to plants has been observed to vary with different Zn fractions. About 5% or less of total Zn present in soil is available to plants at any given time. The form in which Zn is present in soil plays a crucial role in determining its availability to plants. Distribution of forms of Zn in soils depends on the chemical and physical properties. The availability of soil Zn to plants is governed by different fractions of soil Zn. Knowledge on distribution of Zn fractions in soils and important soil properties influencing its availability might prove to be the best approach for obtaining reliable information about the availability of Zn. Therefore, the objective was to study the distribution of different fractions of Zn and their relationship with soil properties in coconut lands of Sri Lanka.

MATERIALS AND METHODS

Sixty soil samples were collected from surface layer (0-20 cm) of the manure circles of coconut palms representing Wet, Intermediate and Dry zones falling into coconut triangle in Sri Lanka. Agro climatic zones, land form, great soil group, soil series and sampling locations are given in Table 1. The processed soil (< 2 mm) was analysed for pH (Michael, 1965), Organic carbon (Nelson and Sommers, 1982), clay (Gee and Bauder, 1986), free Calcium

Table 1 - Agroclimatic zones, land form, great soil group, soil series and sampling location of soils used for the study

Agro climatic Zone	Land form	Great soil group*	Soil series**	Location
Wet Zone	Coastal Plain	Sandy Regosols		
		Latosols and Regosols on old red and yellow sands	Katunayake, Weliketiya	Katunayake, Kadirana
	Mantled plain	Red Yellow Podzolic (RYP)	Boralu	Walpita, Barduragoda, Gampaha
		Non Calcic Brown (NCB) Colluvial member of Red Yellow Podzolics with soft or hard laterites	Pallama	Walpita, Lunuwila, Marapola
Alluvial plain	Alluvial soils	Metikotuwa	Metikotuwa	
Intermediate zone	Coastal Plain	Sandy Regosols	Weliketiya	Marawila
		Latosols and Regosols on old red and yellow sands	Madampe, Rathupasa, Sudu, Madagama,	Kudawewa, Pumbala, Kakapalliya, Kajulanda, Medagama
	Mantled plain	Red Yellow Podzolic (RYP)	Andigama, Kurunegala, Kuliypitiya, Kiriwana,	Welipannagahamula, Polpathtala, Kurunegala, Ganangamuwa
		Non Calcic Brown (NCB)	Tambarawa, Wariyapola,	Welipannagahamula, Madawakkulama, Kobeigana
		Colluvial member of Red Yellow Podzolics with soft or Hard laterites	Wilattawa	Henegedara
	Alluvial plain	Alluvial soils	Welipelessa, Palugaswewa, Ambakele, Kakkapalliya, Rajakadaluwa, Bangadenya	Weerapokuna, Thittakadae, Marawila, Karukkuwa, Mahawilathtawa, Kottagae
Dry zone	Coastal Plain	Sandy Regosols	Mumpuri, Madurankuliya, Weliketiya, Kalpitiya	Talawila, Palakuda, Daluwa, Thoduwawa, Kadayamatte
		Yellow Latosols	Gambura, Wilpattu, Mavillu, Borupan	Palavi, Attawilluwa, Wanathavilluwa
	Alluvial plain	Alluvial soils	Aruvi - Katupotha - Labugama - Siyambalan kotuwewa complex	Bodirajapura

*(De Alwis and Panabokke, 1972)

** (Somasiri *et al.*, 1994)

carbonate (Piper, 1966), free Fe_2O_3 (Mehra and Jackson, 1960), total Zn (Page et al, 1982) and available Zn (Lindsay and Norvell, 1978). The different forms of Zn were extracted by sequential fractionation procedure outlined by Murthy, (1982) and modified by Mandal and Mandal, (1986). A sequential fractionation procedure was used to partition the total contents of Zn into different forms of Zn *viz.*, water soluble plus exchangeable Zn (WSEX - Zn) organically complexed Zn (OC - Zn) amorphous sesquioxide bound Zn (AMOX - Zn), crystalline sesquioxide bound Zn (CRYOX - Zn). The soils were sequentially extracted with 1M $(\text{NH}_4)\text{OAc}$ (pH 7.0), 0.05 M $\text{Cu}(\text{OAc})_2$, 0.2 M $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$ + 0.2 M $\text{H}_2\text{C}_2\text{O}_4$ (pH 3.0) and 0.3 M Sodium citrate + 1.0 M NaHCO_3 + 1 g $\text{Na}_2\text{S}_2\text{O}_4$ [Citrate Bicarbonate - Dithionite] and 0.1 M $\text{NH}_2\text{OH} \cdot \text{HCl}$ (pH 2.0) (Chao, 1972) to extract WSEX - Zn, OC - Zn, AMOX - Zn, CRYOX - Zn and MnOX - Zn respectively. The concentrations of Zn in the extracts were determined using Atomic Absorption Spectrophotometer. Residual fraction of Zn (RES-Zn) was obtained by deducting all the fractions of Zn from the total Zn. Minitab software 15 was used to analyse the data.

RESULTS AND DISCUSSION

The physical and chemical properties for the soils used for the study are given in Table 2. The soils were acidic to alkaline in nature in reaction with a mean value of 5.92. The Organic carbon (OC) content in soils were varied from 0.065 to 3.2% with mean value of 0.84 and clay values ranged from 5 to 38 % with a mean value of 15.3%. Low amounts of free CaCO_3 were observed in soils and it varied from 0.6 to 4.2% with a mean value of 1.87% and free Fe_2O_3 content in soils were ranged from 0.06 to 2.85% with mean value of 0.617%.

Different fractions of Zn, total Zn and available Zn in soils are given in Table 3. The results showed that the total content of Zn in soils varied within a narrow range of 12 to 40 mg kg^{-1} with a mean value of 26.7 mg kg^{-1} . The water soluble plus exchangeable form of Zn, which represents the most readily available source of Zn and lowest among all the fraction studied and was comparatively low ranging from 0.002 to 0.425 mg kg^{-1} with a mean value of 0.104 mg kg^{-1} constituting only 0.45% of the total amount. The concentration

Table 2 - Mean physico-chemical characteristics of soils

	pH	OC%	Clay %	CaCO_3 %	Fe_2O_3 %
Mean	5.92	0.84	15.3	1.87	0.617
SD	0.93	0.652	9.81	0.855	0.745
Range	4.3 - 8.06	0.065 - 3.2	5.0 - 38.0	0.6 - 4.2	0.06 - 2.85

Table 3 - Different fractions of Zn, total Zn and available Zn in soils

	WSEX-Zn (mg kg ⁻¹)	OC-Zn (mg kg ⁻¹)	CRYOX- Zn (mg kg ⁻¹)	AMOX- Zn (mg kg ⁻¹)	MnOX- Zn (mg kg ⁻¹)	RES-Zn (mg kg ⁻¹)	Total -Zn (mg kg ⁻¹)	Avail.-Zn (mg kg ⁻¹)
Mean	0.104	0.525	2.23	1.36	0.68	21.7	26.7	0.68
% from total	0.45	1.97	8.37	5.10	2.55	81.29	-	-
SD ±	0.14	0.41	2.39	1.49	0.73	8.88	7.94	0.48
Range	0.002-0.425	0.002-2.2	0.25-9.11	0.12-7.12	0.06-3.52	7.09-37.9	12-40	0.002-2.61

WSEX - Water soluble plus exchangeable
MnOX - Manganese oxide bound
CRYOX - Crystalline sesquioxide bound
TOTAL - Total

OC - Organically complexed
AMOX - Amorphous sesquioxide bound
RES - Residual
Avail - DTPA extractable.

of OC-Zn was next only to WSEX-Zn. This may be due to the fact that the most of the soil samples studied were low to medium in organic carbon. The OC - Zn was found to vary from 0.002 to 2.2 mg kg⁻¹ with a mean value of 0.525 mg kg⁻¹ constituting 1.97 % of the total content. The MnOX-Zn content was higher than both WSEX-Zn and OC-Zn and very from 0.06 to 3.52 mg kg⁻¹ with a mean

value of 0.68 mg kg⁻¹ constituting only 2.55% of the total amount. The higher content of CRYOX-Zn than AMOX-Zn was observed in these soils. The crystalline sesquioxide bound Zn formed the major fraction amongst the five active forms of soil Zn. It ranged from 0.25 to 9.11 mg kg⁻¹ with a mean value of 2.23 mg kg⁻¹ and constituted 8.37% of the total amount.

Table 4 - Correlation between soil properties and Zn fractions of soils

Parameter	WSEX- Zn	OC-Zn	CRYOX- Zn	AMOX- Zn	MnOX- Zn	RES-Zn	Total-Zn	Avail.- Zn
pH	-0.442**	-0.451**	-0.116	-0.140	-0.155	0.033	-0.058	-0.528**
OC	0.174	0.599**	-0.066	-0.119	-0.110	-0.354	-0.425**	0.564**
CaCO ₃	-0.392	-0.542**	-0.081	-0.082	-0.101	0.160	0.108	-0.583**
Fe ₂ O ₃	-0.156	-0.143	0.843**	0.793**	0.784**	-0.292	0.153	-0.155
Clay	-0.026	0.331	0.311	0.368	0.356	-0.169	0.020	0.282

** Significant at 5 % probability level

The AMOX - Zn was comparatively low, ranging from 0.12 to 7.12 mg kg⁻¹ with a mean value of 1.36 mg kg⁻¹, and constituted 5.1 % of the total amount. The AMOX - Zn have a greater ability to adsorb Zn because of their high specific area (Davis and Leckie, 1978). The results therefore, show that about 81 % of the total Zn in these soils was in highly unavailable forms, apparently not contributing to the provisions of the immediate Zn requirement of the plants. The correlation between soil properties and Zn fractions of soils are given in Table 4. The water soluble plus exchangeable Zn showed a significant negative correlation with pH (r = -0.442**).

This is due to the increased solubility of Zn at low pH and its subsequent adsorption by soil exchange complex (Bar-Yosef, 1979; Seed and Fox, 1977). It appears that soils having comparatively low pH values confirmed a higher amount of Zn in this form. Seed and

Fox (1977) reported that the solubility and exchangeability of Zn in soil increased with a decreased in soil pH. The OC - Zn showed a highly significant positive correlation (r = 0.599**) with the organic carbon content of the soil and negative correlation with pH (r = 0.451**) and CaCO₃ (r = -0.542**) content of the soils. This appeared to vary directly with the organic carbon content of the soils. Both the amorphous and crystalline sesquioxide bound forms of Zn showed significant positive correlations (r = 0.793** and r = 0.843** respectively) with Fe₂O₃ content of the soil. The amounts of these two fractions appeared to be related directly with free Fe₂O₃ content of the soils. The MnOX - Zn bound Zn showed positive correlation (r = 0.784**) with Fe₂O₃ content of the soils.

The results therefore suggest that soil rich in oxides of iron and aluminium contain much of their Zn in the amorphous and crystalline

Table 5 - Correlation coefficients (r) among different fractions of Zn

Parameter	WSEX-Zn	OC-Zn	CRYOX-Zn	AMOX-Zn	MnOX-Zn	RES-Zn	Total-Zn
WSEX-Zn	-	-	-	-	-	-	-
OC-Zn	0.376**	-	-	-	-	-	-
CRYOX-Zn	-0.157	-0.164	-	-	-	-	-
AMOX-Zn	-0.131	-0.142	0.951**	-	-	-	-
MnOX-Zn	-0.111	-0.130	0.943**	0.997**	-	-	-
RES-Zn	-0.106	0.012	-0.455**	-0.403	-0.404	-	-
Total-Zn	-0.177	-0.056	-0.068	0.126	0.124	0.852**	-
Avail.-Zn	0.608**	0.962**	-0.17	-0.7146	-0.131	-0.021	-0.093

** Significant at 5 % probability level

WSEX - Water soluble plus exchangeable

MnOX - Manganese oxide bound

CRYOX - Crystalline sesquioxide bound

TOTAL - Total

OC - Organically complexed

AMOX - Amorphous sesquioxide bound

RES - Residual

Avail - DTPA extractable.

Table 6 - Multiple regression models for different fractions of Zn (mg kg⁻¹) in soils as influenced by soil properties

Multiple Regression Models	R ²	%
WSEX - Zn = 0.520 - 0.052 pH - 0.002 Clay + 0.012 OC - 0.027 CaCO ₃ - 0.017 Fe ₂ O ₃	0.280	28.0
OC - Zn = 0.779 - 0.043 pH + 0.006 Clay + 0.282 OC - 0.154 CaCO ₃ - 0.079 Fe ₂ O ₃	0.567**	56.7
CRYOX- Zn = 0.60 + 0.146 pH - 0.002 Clay - 0.02 OC - 0.472 CaCO ₃ + 2.77 Fe ₂ O ₃	0.730**	73.0
AMOX- Zn = 0.62 + 0.031 pH + 0.014 Clay - 0.207 OC - 0.232 CaCO ₃ + 1.53 Fe ₂ O ₃	0.658**	65.8
MnOX-Zn = 0.420 + 0.005 pH + 0.005 Clay - 0.094 OC - 0.126 CaCO ₃ + 0.745 Fe ₂ O ₃	0.645**	64.5
RES - Zn = 37.2 - 2.19 pH + 0.018 Clay - 5.38 OC + 2.43 CaCO ₃ - 4.42 Fe ₂ O ₃	0.275	27.5
Total - Zn = 39.8 - 2.05 pH + 0.037 Clay - 5.47 OC + 1.47 CaCO ₃ + Fe ₂ O ₃	0.232	23.2
Avail.- Zn = 1.43 - 0.111 pH + 0.004 Clay + 0.30 OC - 0.185 CaCO ₃ - 0.093 Fe ₂ O ₃	0.518**	51.8

**Significant at 5 % probability level

WSEX - Water soluble plus exchangeable

MnOX - Manganese oxide bound

CRYOX - Crystalline sesquioxide bound

TOTAL - Total

OC - Organically complexed

AMOX - Amorphous sesquioxide bound

RES - Residual

Avail - DTPA extractable.

sesquioxide bound forms. The total Zn showed significant negative correlation ($r = -0.425^{**}$) with organic carbon content of soil. The available Zn showed significant negative correlation with pH and CaCO₃ ($r = -0.528^{**}$ and $r = -0.583^{**}$ respectively) and significant positive correlation ($r = 0.564^{**}$) with organic carbon.

Znic fractionation of the soils (Table 3) showed that major amounts of the soil Zn were associated with clay mineral fractions of the soils, which has been designated the residual fraction and computed as the difference between the total Zn of the soil and the sum of the other determined extractions.

As shown in the Table 5 the different fractions of Zn in these soils showed significant and positive correlation amongst one and other,

which indicates the existence of a dynamic equilibrium among the different pools of Zn in soils. This indicated the depletion of Zn concentration of readily available pool is replenished by other pools of Zn.

Multiple regression models (Table 6) showed that different fractions of soil Zn were significantly influenced by combined effect of pH, OC, clay, free CaCO₃, and free Fe₂O₃. The 28%, 56.7%, 73%, 65.8%, 64.5%, 27.5%, 23.2% and 51.8% variability in WSEX-Zn, OC-Zn, CRYOX-Zn, AMOX-Zn, MnOX-Zn, RES-Zn, Total-Zn and Avail. - Zn respectively, were mainly due to combined affect of tested soil properties.

Table 7 - Multiple regression models for available Zn as influenced by different fractions of Zn

Multiple Regression Models	R ²	%
$\text{Avail. Zn} = -0.005 + 1.10 \text{ WSEX-Zn} + 1.01 \text{ OC-Zn} - 0.023 \text{ CRYOX-Zn} + 0.057 \text{ AMOX-Zn} - 0.132 \text{ MnOX-Zn} - 0.015 \text{ RES Zn} + 0.015 \text{ total Zn}$	0.996**	99.6

** Significant at 5 % probability level

WSEX - Water soluble plus exchangeable

MnOX - Manganese oxide bound

CRYOX - Crystalline sesquioxide bound

TOTAL - Total

OC - Organically complexed

AMOX - Amorphous sesquioxide bound

RES - Residual

Avail - DTPA extractable.

Multiple regression equation (Table 7) showed that highly significant 99.6% variability in available Zn was mainly due to combined affect of WSEX-Zn, OC-Zn, CRYOX-Zn, AMOX-Zn, MnOX-Zn, RES-Zn and Total Zn. According to these findings, it is important to increase the readily available Zn pools in soils of coconut lands to increase the growth and crop production. Organic manure application and Zn fertilizer application would be better approach to increase the available Zn pols in soils. Further research have to be done to find out proper dose of Zn fertilizer and the method of application.

CONCLUSIONS

The results revealed that concentration of different Zn fractions remained same viz; WSEX-Zn < OC-Zn < MnOX-Zn < AMOX-Zn < CRYOX-Zn < RES-Zn. The WSEX-Zn fraction was the least fraction of Zn and the RES-Zn was the dominant fraction of Zn in soil. Availability of different fractions of Zn mainly depend on soil properties such as pH and organic carbon content. The different fractions of Zn in these soils

showed significant and positive correlation amongst one and other, which indicates the existence of a dynamic equilibrium among the different pools of Zn in soils. This indicated the depletion of Zn concentration of readily available pool is replenished by other pools of Zn.

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