STATUS AND DISTRIBUTION OF ZINC IN THE ULTISOLS OF SOUTH INDIA UNDER RUBBER CULTIVATION

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Status and distribution of total and different fractions of zinc (Zn) in the nine major series of the rubber growing soils of South India was assessed. Total Zn status of the soil was comparatively low and the values for the Ap horizon ranged from 47.9 to 81.7 $\mu g\ g^{-1}$. Major share of the total Zn was in the residual fraction which ranged from 25.9 to 70.8 $\mu g\ g^{-1}$ in the Ap horizon among the series. The water soluble plus exchangeable fraction of Zn for the Ap horizon ranged from 0.19 to 1.83 $\mu g\ g^{-1}$ among the series and the values reduced down the horizons. Among the nine series, the plant available fraction of Zn was found to be extremely low in Kanjirappally, Thiruvanchoor and Lahai series. Low status of total Zn indicates chances of depletion of Zn reserve with repeated cycles of cultivation. Replenishment of Zn through fertilizer to these soils especially to Kanjirappally, Thiruvanchoor and Lahai series may be beneficial for improving the plant growth and maintaining/sustaining the Zn status of the soil.

Key words: Acid soils, Laterite soil, Plant available zinc, Rubber growing soils, Ultisols, Zinc fractions

INTRODUCTION

In India, the traditional belt of natural rubber (*Hevea brasiliensis*) cultivation is confined to a narrow tract in the western side of the Western Ghats, mainly in the state of Kerala and Kanyakumari district of Tamil Nadu state. In this traditional belt, cultivation of rubber is now in the third or fourth cycle, each cycle being 25 to 30 years long. The soils of this tract are laterite and lateritic types, red soils, forest soils and alluvial soils. These soils are acidic in reaction with pH ranging from 4.5 to 6.0 (NBSS and LUP, 1999; Karthikakuttyamma *et al.*, 2000; Joseph, 2016).

Natural rubber (NR) growing soils of Kerala and Tamil Nadu have been characterized as per modern soil taxonomy in to 62 soil series. Among the 62 series, 51 were under Ultisols, nine were under Inceptisols and two were under Entisols (NBSS and LUP, 1999). Low Zn content of the rubber growing soils in the traditional belt of NR cultivation was reported by Joseph *et al.* (1995). Further, through an extensive study covering 9682 surface soil samples from the NR growing tract of Kerala and Tamil Nadu it was reported that 41.0 per cent of the soils were deficient in available Zn (NBSS and LUP, 1999). Recently, Philip *et al.* (2020) reported that 50 per cent of the

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NR growing soils of Kerala and major share of the NR growing soils of Karanataka are deficient in available Zn.

Zinc is known to occur in soil in a number of discrete chemical forms *viz.* water soluble, easily exchangeable, adsorbed, chelated or complexed, associated with secondary minerals and held in primary minerals differing in their solubility and thus, availability to plants (Viets, 1962). Water soluble plus exchangeable and organically bound forms are considered to be available, amorphous sesquioxide bound form is potentially available and crystalline sesquioxide bound and residual Zn forms are unavailable to plant (Mandal *et al.*, 1992; Sureshkumar *et al.*, 2004). Expression of Zn deficiency symptoms in young rubber plants in the initial years in the replanting fields especially in slope lands is a common feature in these days and recently recommendation on Zn application is included in the fertilizer recommendation schedule of rubber. In this context, the information presented in this paper is very useful to have an in depth understanding on the Zn status of the NR growing soils in the traditional belt of NR cultivation.

MATERIALS AND METHODS

Nine major soil series *viz.* Kanjirappally, Vijayapuram, Thiruvanchoor, Vazhoor, Lahai, Thrikkannamangal, Kunnathur, Panachikkad and Kaipuzha as per the soil survey report (NBSS & LUP,1999) were selected for the study. Among the nine series, Kanjirapally, Vijayapuram, Thiruvanchoor, Lahai and Vazhoor belong to the Charnokite land form, Kunnathur and Thrikkannamangal to the Kondalite land form and Panachikkad and Kaipuzha to the Laterite land form (NBSS & LUP, 1999). Series were located at the type location and pits were taken up to the parent rock. Horizons were identified and samples were collected horizon-wise from each profile. Soil samples were processed, dried and sieved through 2 mm sieve. Physico-chemical properties of the soil, *viz.* pH, organic carbon (OC), cation exchange capacity (CEC) and clay content were measured as per the procedure outlined by Jackson (1958). Total Zn status of the soil was determined by the procedure of Lim and Jackson (1982). Sequential extraction method for the determination of forms of Zn in soils adapted from Shuman (1985) was followed for estimating the fractions of Zn. Residual fraction of Zn was estimated from the remaining portion of soil obtained after Zn fractionation, following the procedure for total Zn estimation. The available Zn status was estimated by DTPA extraction (Lindsay and Norwell, 1978). Correlations between soil properties were calculated as per Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

pH, organic carbon, CEC and clay content of the horizon-wise soil samples are presented in Table 1. The soil was strongly to extremely acidic with pH below 5.0, except in the lower layers of Thiruvanchoor and Vazhoor series. Organic carbon content of the surface layer was high and decreased with depth of the soil. As expected, the CEC was low in these soils dominated with oxides and hydrous oxides of iron and aluminium and kaolinite clay. The values decreased with depth of the soil. Clay content was found to be increasing with depth and higher values were recorded in the lower layers especially in the Bt horizons.

Horizon wise status and distribution of total and different forms of Zn in the individual soil series belonging to Charnokite land form are

Table 1. **Physicochemical properties of different soil series**

Horizon	Depth (cm)	OC (%)	pH	CEC (cmoles (+) kg^{-1})	Clay (%)
Kanjirappally series					
Ap	0-13	1.34	4.4	6.6	27
Bt1	13-32	0.91	4.4	4.8	9
Bt2	32-56	0.49	4.5	3.1	33
Bt3	56-83	0.49	4.5	2.7	31
Bt4	83-112	0.33	4.4	2.4	36
Bt5	112-150	0.33	4.4	2.9	36
Vijayapuram series					
Ap	0-15	1.01	4.6	5.3	40
Bt1	15-40	0.70	4.5	4.5	40
Bt2	40-70	0.46	4.8	4.4	47
Bt3	70-103	0.42	4.9	3.4	40
Bt4	103-151	0.23	5.0	2.5	44
Thiruvanchoor series					
Ap	0-13	1.17	4.7	6.8	47
Bt1	13-37	0.88	4.9	5.0	54
Bt2	37-69	0.52	4.9	4.9	62
Bt3	69-104	0.52	5.0	4.7	58
Bt4	104-132	0.29	5.1	3.2	55
Vazhoor series					
Ap	0-12	1.47	4.5	7.1	31
AB	12-31	0.82	4.8	5.2	34
Bt	31-53	0.49	5.3	4.3	46
R	53-83	0.26	5.3	3.8	40
Lahai series					
Ap	0-15	1.60	4.9	8.7	45
Bt1	15-38	1.56	4.7	7.9	43
Bt2	38-74	1.43	4.8	5.9	47
Bt3	74-104	0.53	5.0	5.0	49
Thrikkannamangal series					
Ap	0-14	0.68	4.7	4.2	35
Bt1	14-35	0.42	4.7	4.0	44
Bt2	35-67	0.52	4.6	4.2	43
Bt3	67-103	0.55	4.8	4.5	44
Bt4	103-152	0.52	5.1	3.7	45

Horizon	Depth (cm)	OC (%)	pH	CEC (cmoles (+) kg^{-1})	Clay (%)
Kunnathur series					
Ap	0-16	0.68	4.9	6.0	42
AB	16-38	0.68	4.6	5.4	43
Bt1	38-72	0.42	4.7	4.8	50
Bt2	72-103	0.33	4.9	5.5	48
Bt3	103-130	0.17	4.6	5.1	50
Panachikkad series					
Ap	0-15	2.00	4.5	8.2	18
Bt1	15-46	0.75	4.8	6.7	33
Bt2	46-74	0.72	4.9	11.3	44
Bt3	74-99	0.45	4.9	5.5	46
BC	99-136	0.16	4.9	6.3	56
Kaipuzha series					
Ap	0-12	1.40	4.7	4.1	25
Bt1	12-31	0.92	4.7	3.4	42
Bt2	31-52	0.73	4.7	4.9	31
Bt3	52-71	0.61	4.8	7.2	34

presented in Table 2. Total Zn content in the Kanjirappally series ranged from 40.9 μg g^{-1} in the lowermost layer to 66.9 μg g^{-1} in the surface horizon. Major portion of the total Zn is in the residual pool which ranged from 19.2 μg g^{-1} in the Bt3 horizon to 52.6 μg g^{-1} in the Bt4 horizon. The water soluble and exchangeable Zn values ranged from 0.42 μg g^{-1} in the Ap horizon to 0.04 μg g^{-1} in the Bt4 horizon. In the Vijayapuram series the total Zn content ranged from 60.0 μg g^{-1} in the Ap horizon to 93.0 μg g^{-1} in the Bt 2 horizon. The water soluble and exchangeable Zn ranged from 0.10 μg g^{-1} in the Bt 4 horizon to 1.37 μg g^{-1} in the Ap horizon. The residual Zn values ranged from 40.4 μg g^{-1} in the Ap horizon to 78.7 μg g^{-1} in the Bt 2 horizon which accounts for the major share of the total Zn. Similarly, in the Thiruvanchoor series, the total Zn values ranged from 53.4 μg g^{-1} in the Bt 2 horizon to 71.4 μg g^{-1} in the Bt 3 horizon. Water soluble + exchangeable Zn ranged from 0.12 μg g^{-1} in the Bt 2 horizon to 0.53 μg g^{-1} in the Ap horizon showing a gradual decline in values down the depth. Total Zn values in the Lahai series ranged from 55.2 μg g^{-1} in the Bt 3 horizon to 63.8 μg g^{-1} in Ap horizon. Similarly, the water soluble + exchangeable Zn fraction ranged from 0.03 in the Bt 2 horizon to 0.19 μg g^{-1} in the Ap horizon. Lahai series was found to be low in total Zn content and the water soluble + exchangeable form was found to be extremely low and deficient. Total Zn content for the Vazhoor series ranged from 36.6 μg g^{-1} in the AB horizon to 86.0 μg g^{-1} in the Bt horizon. The water soluble + exchangeable Zn values ranged from 0.16 μg g^{-1} in the lowermost horizon (of rock fragments) to 1.04 μg g^{-1} in the Ap

Table 2. **Total and different forms of zinc in the soil series belonging to charnokite land form ($\mu g\ g^{-1}$)**

Horizon	Depth (cm)	Water soluble + exchangeable Zn	Organically bound Zn	Mn Oxide bound Zn	Amorphous Fe oxide bound Zn	Crystalline Fe oxide bound Zn	Residual Zn	Total Zn	DTPA-Zn
Kanjirappally series (Clayey-Skeletal, kaolinitic, isohyperthermic, Ustic Kandihumults)-Lat-9° 35′ 05″N, Long. 76° 47′ 00″E									
Ap	0-13	0.42 (0.60)	0.42 (0.60)	6.54 (9.8)	5.30 (7.9)	6.65 (9.9)	47.6 (71.2)	66.9	0.36 (0.5)
Bt1	13-32	0.25 (0.50)	0.40 (0.80)	4.06 (7.7)	7.23 (12.2)	6.43 (12.2)	34.5 (65.1)	52.0	0.16 (0.3)
Bt2	32-56	0.18 (0.34)	0.24 (0.46)	5.02 (9.6)	7.40 (14.1)	6.93 (13.25)	32.5 (62.1)	52.3	0.10 (0.2)
Bt3	56-83	0.11 (0.27)	0.36 (0.88)	3.56 (8.7)	9.75 (23.8)	7.95 (19.4)	19.2 (46.9)	40.9	0.14 (0.3)
Bt4	83-112	0.04 (0.06)	0.42 (0.67)	1.12 (1.8)	2.58 (4.1)	6.23 (9.9)	52.6 (83.5)	63.0	0.11 (0.2)
Bt5	112-150	0.07 (0.17)	0.39 (0.92)	1.06 (2.5)	2.35 (5.5)	7.28 (17.2)	31.3 (73.8)	42.4	0.08 (0.2)
Vijayapuram series (Clayey, kaolinitic, isohyperthermic, Ustic Kandihumults) - Lat. 9° 36′ 45″N, Long. 76° 34′ 15″E									
Ap	0-15	1.37 (2.28)	0.39 (0.65)	4.02 (6.7)	8.89 (14.8)	4.94 (8.2)	40.4 (67.3)	60.0	1.10 (1.8)
Bt1	15-40	1.17 (1.63)	0.31 (0.56)	4.00 (5.6)	7.90 (11.0)	4.50 (6.3)	53.7 (75.1)	71.6	1.1 (1.5)
Bt2	40-70	0.48 (0.52)	0.30 (0.32)	2.58 (2.8)	7.25 (7.8)	3.68 (3.9)	78.7 (84.6)	93.0	0.4 (0.4)
Bt3	70-103	0.11 (0.16)	0.24 (0.34)	1.52 (2.2)	3.15 (4.5)	4.98 (7.1)	59.5 (85.3)	69.8	0.1 (0.1)
Bt4	103-151	0.10 (0.14)	0.25 (0.36)	2.22 (3.2)	3.85 (5.6)	3.70 (5.4)	59.0 (85.4)	69.1	0.1 (0.1)
Thiruvanchoor series (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaplohumults)-Lat.9° 32′40″N, Long. 76° 33′ 25″E									
Ap	0-13	0.53 (0.9)	0.46 (0.8	2.28 (3.8)	3.4 (5.8)	2.20 (3.7)	51 (85)	60.0	0.35 (0.6)
Bt1	13-37	0.30 (0.5)	0.36 (0.6)	1.60 (2.7)	3.25 (5.4)	3.13 (5.2)	54 (90)	62.8	0.20 (0.3)
Bt2	37-69	0.12 (0.2)	0.32 (0.6)	2.00 (3.7)	2.75 (5.1)	6.03 (11.3)	39 (73)	53.4	0.12 (0.2)
Bt3	69-104	0.13 (0.2)	0.21 (0.3)	1.32 (1.9)	2.58 (3.6)	4.25 (6.0)	63 (88)	71.4	0.08 (0.1)
Vazhoor series (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaplohumults)-Lat. 9° 44′ 35″ N, Long. 76° 37′15″E									
Ap	0-12	1.04 (2.2)	0.53 (1.1)	2.94 (6.2)	3.73 (7.9)	4.40 (9.3)	33 (70)	47.1	1.33 (2.8)
Ab	12-31	0.37 (0.8)	0.39 (0.8)	1.92 (4.1)	2.55 (5.4)	3.25 (6.9)	28 (60)	36.6	0.45 (1.2)
Bt	31-53	0.21 (0.2)	0.60 (0.7)	1.56 (1.8)	3.38 (3.9)	2.83 (3.3)	77 (90)	86.0	0.14 (0.2)
R	53-83	0.16 (0.3)	0.28 (0.5)	1.20 (2.1)	2.60 (4.6)	2.48 (4.4)	50 (88)	57.0	0.06 (0.1)
Lahai series (Clayey, kaolinitic, isohyperthermic, Ustic Kanhaplohumults)-Lat. 9° 22′ 00″N, Long. 76° 54′ 00″E									
Ap	0-15	0.19 (0.30)	0.58 (0.90)	1.08 (1.7)	4.93 (7.8)	7.43 (11.5)	49.6 (77.8)	63.8	0.17 (0.27)
Bt1	15-38	0.18 (0.32)	0.55 (0.95	1.00 (1.7)	3.15 (5.4)	7.30 (12.6)	45.8 (79.0)	58.0	0.09 (0.16)
Bt2	38-74	0.03 (0.05)	0.46 (0.73)	0.88 (1.4)	3.65 (5.8)	7.70 (12.2)	50.4 (79.9)	63.1	0.07 (0.11)
Bt3	74-104	0.08 (0.14)	0.67 (1.21)	1.14 (2.1	3.63 (6.6)	4.85 (8.8)	44.8 (81.1)	55.2	0.06 (0.11)
Bt4	104-138	0.08 (0.12)	0.53 (0.82)	1.26 (1.9)	2.4 (3.7)	5.10 (7.9)	55.5 (85.5)	64.9	0.10 (0.15)

Figures in parenthesis are the per cent of the total Zn horizon. The manganese oxide bound fraction ranged from 6.54 μg g^{-1} in the Ap horizon of Kanjirappally series to 0.88 μg g^{-1} in the Bt 2 horizon of Lahai series. In general, the Zn content decreasing with soil depth. The amorphous iron oxide bound fraction ranged from 9.75 μg g^{-1} in the Bt3 horizon of Kanjirappally series to 2.35 μg g^{-1} in the Bt5 horizon of the same series. Similarly, the crystalline iron oxide bound Zn ranged from 7.95 μg g^{-1} in the Bt3 horizon of Kanjirapally series to 2.20 μg g^{-1} in the Ap horizon of Thiruvanchoor series. In general, high Zn content were recorded in the Bt2 and Bt3 horizon.

Kunnathur series had comparatively higher values for total Zn and the values ranged from 81.7 μg g^{-1} in the Ap horizon to 103.8 μg g^{-1} in the Bt3 horizon (Table 3). Though the total Zn status was found to be high, the water soluble + exchangeable Zn values were low and ranged from 0.16 to 0.55 μg g^{-1}. The major share of the total Zn was found to be in the residual fraction and the values ranged from 70.8 μg g^{-1} in the Ap horizon to 74.6 μg g^{-1} in the Bt3 horizon. Total Zn status of the Thrikkannamangal series ranged from 48.9 to 65.3 μg g^{-1} indicating comparatively low Zn status in this series (Table 4). The water soluble + exchangeable Zn ranged from 0.16 μg g^{-1} in the lowermost horizon to 0.95 μg g^{-1} in the surface horizon. The residual Zn values ranged from 40.8 μg g^{-1} in the Bt 1 horizon to 56.4 μg g^{-1} in the Bt4 horizon indicating that the major pool of the total Zn is in the residual fraction which is not plant available. The manganese oxide bound Zn was comparatively lower in the Thrikkannamangal and Kunnathur series compared to the five series described in the Charnokite land form. The values ranged from 3.36 μg g^{-1} in the Bt 2 horizon of Thrikkannamangal series to 1.26 μg g^{-1} in the Bt1 horizon of the same series. The amorphous iron oxide bound Zn among the two series ranged from 3.70 μg g^{-1} in the Ap horizon of Kunnathur series to 2.57 μg g^{-1} in the Bt 1 horizon of the same series. Similarly, the values of crystalline iron oxide bound Zn ranged from 4.53 μg g^{-1} in the Ap horizon of Thrikannamangal series to 2.68 μg g^{-1} in the Bt 2 horizon of Kunnathur series.

The total Zn values for the Panachikkad series ranged from 68.6 μg g^{-1} in the Ap horizon to 92.1 μg g^{-1} in the lowermost layer and the plant available fraction (water soluble + exchangeable Zn) ranged from 0.15 μg g^{-1} in the BC horizon to 1.83 μg g^{-1} in the Ap horizon (Table 4). In the Kaipuzha series the total Zn values ranged from 47.9 μg g^{-1} in the Ap horizon to 92.6 μg g^{-1} in the Bt 3 horizon Water soluble + exchangeable Zn values ranged from 0.34 μg g^{-1} in the lowermost layer to 1.53 μg g^{-1} in the Ap horizon. The Ap horizon alone recorded high water soluble + exchangeable Zn fraction and the lower layers recorded low values (Table 4). The water soluble + exchangeable Zn fraction was high in the topmost two layers and showed declining trend with depth which might be due to the high OC status in the top layers as reported earlier (Umesh *et al.*, 2013). Among the two series belonging to the laterite land form, the manganese oxide bound Zn ranged from 6.58 μg g^{-1} in the Ap horizon of Panachikkad series to 1.02 μg g^{-1} in the Bt 3 horizon of the same series. The amorphous iron oxide bound Zn ranged from 5.50 μg g^{-1} in the Ap horizon of Kaipuzha series to 2.48 μg g^{-1} in the BC horizon of Panachikkad series. Crystalline iron oxide bound Zn ranged from 9.65 μg g^{-1} in the Ap horizon of Kaipuzha series to 2.35 μg g^{-1} in the Bt2 horizon of Panachikkad series. The organically bound fraction ranged from 0.12 μg g^{-1} in the Bt2

Table 3. **Total and different forms of zinc in the soil series belonging to Khondalite land form ($\mu g\ g^{-1}$)**

Horizon	Depth (cm)	Water soluble + exchangeable Zn	Organically bound Zn	Mn Oxide bound Zn	Amorphous Fe oxide bound Zn	Crystalline Fe oxide bound Zn	Residual Zn	Total Zn	DTPA-Zn
Thrikkannamangal series (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kandihumults)-Lat.8° 58′ 20″, Long. 76° 46′ 25″E									
Ap	0-14	0.95 (1.8)	0.36 (0.7)	2.18 (4.3)	3.45 (6.6)	4.53 (8.6)	41.7 (78.0)	53.2	0.76 (1.4)
Bt1	14-35	0.30 (0.6)	0.41 (0.8)	1.26 (2.6)	2.57 (5.3)	3.53 (11.2)	40.8 (78.0)	48.9	0.23 (0.5)
Bt2	35-67	0.26 (0.40)	0.36 (0.6)	3.36 (5.2)	2.96 (4.6)	3.93 (6.1)	53.9 (83.2)	64.8	0.16 (0.3)
Bt3	67-103	0.22 (0.36)	0.22 (0.4)	2.86 (4.7)	2.98 (4.9)	4.09 (6.7)	50.9 (83.7)	60.8	0.14 (0.2)
Bt4	103-152	0.16 (0.24)	0.42 (0.6)	2.22 (3.4)	2.96 (4.5)	3.13 (4.8)	56.4 (86.3)	65.3	0.09 (0.1)
Kunathur series (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaplohumults)-Lat.9° 00′ 50″N, Long.76° 44′ 25″ E									
Ap	0-16	0.55 (0.7)	0.31 (0.4)	3.32 (4.1)	3.70 (4.3)	3.30 (4.0)	70.8 (86.4)	81.7	0.72 (0.9)
AB	16-38	0.16 (0.2)	0.23 (0.3)	2.82 (3.4)	3.51 (4.2)	3.48 (4.2)	72.9 (87.7)	83.1	0.25 (0.3)
Bt1	38-72	0.17 (0.20)	0.28 (0.3)	2.50 (2.9)	2.89 (3.4)	2.95 (3.4)	71.4 (82.8)	86.2	0.15 (0.2)
Bt2	72-103	0.16 (0.19)	0.22 (0.3)	2.26 (2.7)	2.94 (3.6)	2.68 (3.2)	74.5 (90.1)	82.8	0.12 (0.1)
Bt3	103-130	0.25 (0.24)	0.21 (0.2)	2.60 (2.5)	2.83 (2.7)	2.83 (2.7)	94.6 (90.8	103.8	0.10 (1.0)

Figures in parenthesis are the per cent of the total Zn

Table 4. **Total and different forms of zinc in the soil series belonging to Laterite land form ($\mu g\ g^{-1}$)**

Horizon	Depth (cm)	Water soluble + exchangeable Zn	Organically bound Zn	Mn Oxide bound Zn	Amorphous Fe oxide bound Zn	Crystalline Fe oxide bound Zn	Residual Zn	Total Zn	DTPA-Zn
Panachikkad series (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaplohumults)-Lat. 9° 31′ 15″N Long. 76° 33′ 05″E									
Ap	0-15	1.83 (2.7)	2.22 (3.2)	6.58 (9.6)	5.03 (7.3)	5.60 (8.2)	47.3 (69.0)	68.6	6.72 (9.8)
Bt1	15-46	0.57 (0.6)	0.63 (0.7)	2.58 (2.8)	3.08 (3.4)	6.53 (7.1)	78.4 (85.4)	91.8	1.45 (1.6)
Bt2	46-74	0.21 (0.28)	0.52 (0.7)	1.26 (1.7)	2.50 (3.4)	2.35(3.2)	67.7 (90.7)	74.5	0.25 (0.3)
Bt3	74-99	0.23 (0.29)	0.67 (0.9)	1.02 (1.3)	2.83 (3.6)	6.93 (8.8)	67.3 (85.5)	79.0	0.20 (0.3)
BC	99-136	0.15 (0.16)	0.40 (0.4)	1.26 (1.4)	2.48 (2.7)	5.60 (6.5)	82.2 (88.8)	92.1	0.13 (0.1)
Kaipuzha series (Clayey-skeletal, kaolinitic, isohyperthermic, Ustic Kanhaoplohumults)-Lat.9° 34′ 50″ N, Long. 76° 47′ 00″ E									
Ap	0-12	1.53 (3.3)	0.47 (1.0)	4.66 (9.8)	5.50 (11.5)	9.65 (20.2)	25.9 (54.2)	47.9	2.22 (4.6)
Bt1	12-31	0.84 (1.2)	0.37 (0.5)	2.58 (3.8)	3.60 (5.3)	7.62 (11.2)	53.2 (78.0)	68.2	0.83 (1.2)
Bt2	31-52	0.35 (0.48)	0.18 (0.3)	2.06 (2.8)	2.50 (3.45)	4.15 (5.73)	63.1 (87.1)	72.3	0.31 (0.4)
Bt3	52-71	0.34 (0.37)	0.32 (0.4)	2.54 (2.7)	2.82(3.05)	4.72 (5.10)	81.8 (88.3)	92.6	0.23 (0.3)

Figures in parenthesis are the per cent of the total Zn horizon of Kaipuzha to 1.83 μg g^{-1} in the Ap horizon of Panachikkad series (Table 4).

Major portion of the total Zn remains in residual form and the quantity in the plant available forms like water soluble + exchangeable Zn, complexed Zn and organic bound Zn were very low. The order of dominance of different fractions in soil was residual Zn > crystalline iron oxide Zn > manganese oxide bound Zn > amorphous iron oxide bounded Zn > organically bound Zn > water soluble + exchangeable Zn as reported by Sureshkumar *et al.* (2004). Mutual transformations of water soluble + exchangeable Zn, organically bound Zn, crystalline iron oxide bound Zn and residual Zn was reported to be dominant for maintaining Zn equilibria in soil (Wijebandara *et al.*, 2011; Umesh *et al.*, 2013).

Total Zn content for the Ap horizon ranged from 47.9 μg g^{-1} in Kaipuzha series to 81.7 μg g^{-1} in Kunnathur series. The water soluble + exchangeable fraction of Zn for the Ap horizon among the series ranged from 0.19 μg g^{-1} (0.3 % of total Zn) in Lahai series to 1.83 μg g^{-1} (2.7 % of the total Zn) in Panachikkad series and the organically bound fraction ranged from 0.31 μg g^{-1} (0.4% of total Zn) in Kunnathur series to 2.22 μg g^{-1} (2.7 % of total Zn) Panachikkad series (Fig. 1). The water soluble + exchangeable fraction and the organically bound fraction together is the plant available form which was only a very small fraction of the total Zn and the per cent of this fraction to total Zn for the Ap horizon ranged from 0.7 to 5.9. The residual fraction of Zn for the Ap horizon among the series ranged from 25.9 μg g^{-1} (54.2 % of total Zn) in Kaipuzha series to 70.8 μg g^{-1} (86.4 % of total Zn) in Kunnathur series. From the data it is evident that most of the total Zn is present in residual

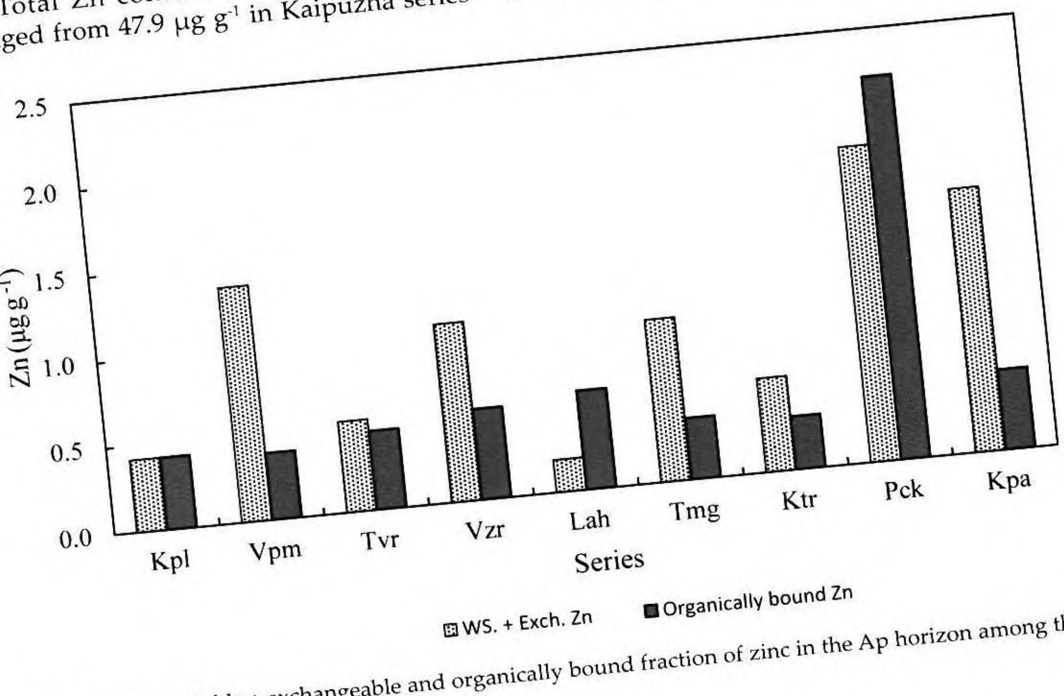

Fig. 1. Water soluble + exchangeable and organically bound fraction of zinc in the Ap horizon among the series

Table 5. **Correlations**

Parameters	Water soluble + exchangeable Zn ($\mu g\ g^{-1}$)	Organically bound Zn ($\mu g\ g^{-1}$)	DTPA-Zn ($\mu g\ g^{-1}$)	Clay (%)	OC (%)	CEC (C moles (+)kg^{-1})
Total Zinc ($\mu g\ g^{-1}$)	-0.10	-0.05	-0.03	0.30 *	-0.32 *	0.25
Water soluble & exchangeable Zn ($\mu g\ g^{-1}$)	1.00	0.51 **	0.81 **	0.30 *	-0.32 *	0.25
Organicallybound Zn ($\mu g\ g^{-1}$)	0.51 **	1.00	0.86 **	-0.38 *	0.56 **	0.40 **
DTPA-Zn	0.81 **	0.86 **	1.00	-0.55	0.58 **	0.28

*Significant at 5 percent level; ** Significant at 1 percent level

form and small fraction is present in easily available form as reported earlier by Sedberry and Reddy (1976) and Katyal and Rattan (1993).

The available Zn (DTPA extracted Zn) status of the soil for the Ap horizon ranged from 0.17$\mu g\ g^{-1}$ for Lahai series to 6.72 $\mu g\ g^{-1}$ for Panachikkad series. The values ranged from extreme deficiency to sufficiency. Normally, under acidic conditions, Zn is available for plant growth. However, the soils under NR cultivation are highly weathered and are prone to severe leaching losses due to the intense rainfall and the undulating physiographic conditions promoting intense leaching. This is in conformity with the studies reported by Joseph *et al.* (1995), NBSS and LUP (1999) and Philip *et al.* (2020). The values were decreasing with depth and extremely low values were recorded in the lower horizons. 0.6 $\mu g\ g^{-1}$ being the critical value for DTPA-Zn, Kanjirapally, Lahai and Thiruvanchoor series were found to be extremely deficient in Zn availability.

Correlations between relevant parameters are presented in Table 5. Correlations between DTPA extracted Zn and different fractions of Zn showed positive significant relation with water soluble + exchangeable Zn (0.80**) and organically bound Zn (0.86**) indicating that the DTPA extractant is extracting the plant available fraction of Zn from these acid red ferruginous soil with predominance of Fe and Al oxides and hydrous oxides as reported earlier by Sureshkumar *et al.* (2004). Positive direct effect of water soluble + exchangeable Zn on available Zn in soil was reported by Wijebandara *et al.* (2011).

A state of dynamic equilibrium exists among different fractions and were influenced by pH, CEC, OC, clay and free Fe_2O_3 (Hazra *et al.*, 1993; Chowdhary *et al.*, 1997; Umesh *et al.*, 2013). Total Zn, water soluble + exchangeable Zn and organically bound Zn were related with OC, CEC and clay content. Water soluble + exchangeable Zn showed positive and significant relation with OC (0.54**) and negative relation with clay content (-0.44**). Similarly, organically bound Zn showed highly significant positive correlation with OC (0.59**) and negative correlation with clay content (-0.34*) (Table 5). Positive correlation with OC indicates that the organic matter provides exchange sites for the adsorption of Zn (Prasad and Sakal 1988; Pal *et al.*, 1997; Wijebandara *et al.*, 2011). Contradicting the observations of Wijebandara *et al.* (2011), in our studies, water soluble + exchangeable and organically bound fraction of Zn was negatively correlated with clay content. The dominance of low active kaoinite clay and oxides and hydrous oxides of Ie and Al in soil is not promoting Zn adsorption which might be the reason for the negative correlation between water soluble + exchangeable Zn and organically bound Zn with clay content. Total Zn recorded positive and significant correlation with CEC (0.34*) and clay (0.39*).

CONCLUSION

Assessment of the status and distribution of Zn in the nine major soil series of the traditional belt of NR cultivation indicated that the total Zn status of the soil was comparatively low. Major share of the Zn was in the residual fraction and is not available for plant growth. Similarly, the water soluble + exchangeable fraction of the Zn was very low and the content reduced down the horizons. Even though the water soluble + exchangeable fraction was high in the Ap horizon in some series, drastic reduction in the values were recorded in the subsurface horizons indicating that Zn availability is restricted to the Ap horizon *ie.* only to the 0 to 15 cm layer of the soil and down the layers the availability is low. Kanjirappally, Thiruvanchoor and Lahai series were found to be extremely low in available fraction of the Zn. Added to that the total Zn status of these soils was found to be low indicating chances of depletion of Zn reserve in the long run. In view of the repeated cycles of NR cultivation in these soils, application of Zn fertilizer especially to Kanjirappally, Thiruvanchoor and Lahai soils may be beneficial for the Zn nutrition of rubber plants and maintaining the Zn status of the soil.

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