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Profile Distribution of Micronutrient Cations in Soils under *Jhum* Land in Chandel District of Manipur (India)

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A B S T R A C T

Profile distribution of DTPA-extractable micronutrient cations (Fe, Cu, Mn and Zn) and their relationship with various soil physico-chemical properties were studied in twenty *jhum* land of Chandel district of Manipur. Soils of the upper horizon had higher content of DTPA-extractable micronutrient cations (Fe, Cu, Mn and Zn) than the lower horizons. In the profiles, the value of Fe, Cu, Mn and Zn varied from 10.27 to 159 mg kg^{-1}, 0.04 to 3.21 mg kg^{-1}, 0.44 to 38.67 mg kg^{-1} and 0.10 to 1.67 mg kg^{-1} soil, respectively. The contents of DTPA- extractable Fe and Mn were sufficient in all the profiles, while Cu was adequate the surface layer (0 – 20 cm) in majority of the soil samples with the exception of a few samples. However, 51.25 per cent soils were deficient in DTPA-Zn content in the surface layer. Multiple regression analysis showed that the DTPA-extractable micronutrient cations (Fe, Cu, Mn and Zn) content in the soils were influenced by pH, OC, Mg, K, EC, CEC and clay to the degree of 54.5, 28.8, 42.4 and 46.2 per cent in the surface layer, however, their influenced were significant only by soil OC, Mg and pH in all the profiles.

Introduction

Micronutrients are the elements required by plants in very small but it is essential for proper growth and development of the plants. Zn, Cu, Mn, Fe and B are essential micronutrients for plant growth. Through their involvement in various enzymes and other physiologically active molecules, these micronutrients are important for gene expression, biosynthesis of proteins, nucleic acids, growth substances, chlorophyll and secondary metabolites, metabolism of carbohydrates and lipids, stress tolerance, etc. (Singh, 2004; Rengel, 2007; Gao *et al.*, 2008).

Soil plays a major role in determining the sustainable productivity of an agro-ecosystem. The sustainable productivity of a soil mainly depends upon its ability to supply essential nutrients to the growing plants. The deficiency of micronutrients has become major constraint to productivity, stability and sustainability of soils (Bell and Dell, 2008).

Deficiency of micronutrients may either be primary, due to their low total content or secondary, caused by soil factors reducing their availability to plants. Due to continuous cultivation, soils under particular land use system may affect physico-chemical properties which may modify DTPA-extractable micronutrient contents and their availability to plants.

Jhum is one of the main forms of agriculture in North Eastern Region (NER) of India. It is also known as shifting cultivation or slash and burn cultivation. Out of the total geographical area of north-eastern region (25.5 million hectares), 2.7 million hectares is under *jhum* of which 17% is under use at any given time. Manipur has a geographical area of 22,327 sq. kms which constitutes 0.7 % of the total land surface of India. Ninety per cent of the total geographical area of the state i.e. 20,097 sq. kms is covered by hills. In Manipur, *jhum* is mainly confined in the hill districts. The practice of *jhum* is not merely done for their sustenance but also it is a traditional method of earning livelihood. Without the adequate availability of micronutrients, it is impossible to get maximum benefit from crop production. The availability of micronutrients to plants is also influenced by the distribution within the soil profile (Singh and Dhankar, 1989). The knowledge of pedogenic distribution of micronutrients is important as plant roots penetrate to the lower layers of the soil and draw a part of the nutrient requirement from the subsurface horizon of the soils. However, there is little or no information regarding status and distribution of micronutrients in soils under *jhum* in Chandel district of Manipur. Therefore, the present work has been undertaken to assess the distribution of micronutrient cations of the soils under *jhum* and to find out the relationship between the soil properties and micronutrients.

Materials and Methods

The district has a geographical area of 496 sq. km with 2.22 % of the total geographical area of the state. The district (24°40' N latitude and 93°50' E longitude), is located in the south-eastern part of Manipur and it experiences hot summer and cold winter. The mean annual temperature exceeds 22˚C and experiences summer temperature to the range of 35 to 46˚C. The mean annual precipitation varies from 2000 to 2400 mm. The area belongs to warm, humid agro-ecological zone with thermic ecosystem and length of growing period of 300-330 days. The vegetation is predominated by pine including woody and herbaceous species. The soil types of Chandel district are mostly coarser, varying from fine loamy, loamy to sandy in texture and deep in soil depth. Twenty typical soil profiles from different *jhum* lands of Chandel District, Manipur were exposed and soil samples were collected depth-wise i.e. 0 - 20, 20 - 40, 40 - 60 and 60 - 80 cm in clean polythene bags. Altogether, eighty soil samples were collected. The soil samples were air-dried in the shade, ground and passed through 2 mm sieve for chemical analysis. The collected samples were processed and analyzed following standard procedures: for mechanical analysis using Bouyoucos hydrometer method (Bouyoucos, 1951); soil pH and electrical conductivity (EC) using 1:2.5 soil: water suspension (Jackson, 1973), CEC by leaching with 1N NH_4OAc (Borah *et al.*, 1987) and organic carbon by Walkley and Black's rapid titration method (Walkley and Black, 1934). The soil samples were determined for available nitrogen (Subbiah and Asija, 1956), available P (Bray and Kurtz, 1945), K, Ca and Mg of the soil were extracted with neutral normal ammonium acetate as described by Gupta (2006) and DTPA-extractable Zn, Cu, Mn and Fe following standard procedures as outlined by (Lindsay and Norvell, 1978). The relationship between various soil properties and micro-nutrients distribution were established by using simple correlation coefficient. Multiple regression equations were computed between DTPA-extractable micronutrients and soil properties by adopting statistical procedures (Panse and Sukhatme, 1961).

Results and Discussion

The physico-chemical properties as well as DTPA- extractable Fe, Cu, Mn and Zn are presented in Table 1 and 2. There was no definite pattern in the distribution of sand, silt and clay soil profiles. Sand, silt and clay fractions in the soils ranged from 19.5 to 82.5, 2.5 to 48.8 and 10.5 to 62.3 per cent, respectively. The samples were very strongly acidic (pH 4.67) to slightly acidic (pH 6.29) in reaction. The EC values of the soils ranged from 0.01 to 0.35 dSm^{-1}. OC content of the studied soil samples ranged from 0.9 to 23.1 g kg^{-1}. CEC varied from 4.6 to 16.8 [cmol(p^+) kg^{-1}] soil.

The N, P_2O_5 and K_2O content in the soil samples varied from 60.63 to 551.94 kg ha^{-1}, 7.75 to 34.05 kg ha^{-1} and 40.32 to 365.10 kg ha^{-1}, respectively. Exchangeable Ca^{++} content varied from 0.1 to 5.6 [cmol(p+) kg^{-1}] and Mg^{++} from 0.1 to 5.6 [cmol(p+) kg^{-1}]. Low content of these bases in the soils might be due to the leaching losses as the area is high in rainfall. The content of these nutrients decreased with increase in depth in most of the studied profiles. Similar results were also reported by Athokpam *et al.,* (2016) and Athokpam *et al.,* (2018) in the soils of Ukhrul and Tamenglong districts of Manipur, respectively.

Iron (Fe)

DTPA-extractable Fe in the soil profiles varied from 10.27 to 159.00 mg kg^{-1} soil in the *jhum* soils of Chandel district of Manipur. The high amount of Fe content in the soil profiles might be the leaching loss of exchangeable bases from the surface soils, thus increasing the acidity, which in turn increasing the Fe content in the soils. Considering 4.5 mg kg^{-1} as critical limit as suggested by Lindsay and Norvell (1978), all the soils had sufficient amount of Fe. It showed significant regression coefficient with OC (8.968*) and Cu (28.598*) in the 2nd layer and Mg (11.638*) and Cu (48.849*) in the 3rd layer. Multiple correlation and regression analyses indicated that 54.5, 55.5, 55.9 and 32.2 per cent variability in the DTPA-extractable Fe in the profiles was due to the simultaneous effect of pH, OC, Cu, Mn, Mg and Zn in the soils. The surface layer soil contained more available Fe than those in lower depth and showed a decreasing pattern along with depth except for few samples. These findings are in agreement with earlier works of Sen *et al.,* (1997), Gupta *et al.,* (2003), Sharma *et al.,* (2003), Pati and Mukhopadhyay (2011), Athokpam *et al.,* (2013), Athokpam *et al.,* (2016) and Athokpam *et al.,* (2018).

Copper (Cu)

DTPA-extractable Cu content in the profiles ranged from 0.04 to 3.21 mg kg^{-1} soils. Considering 0.20 mg Cu kg^{-1} soil as critical level (Lindsay and Norvell, 1978), all the samples except a few in the sub-surface horizons, were well supplied with available Cu. Similar findings were also made by Sen *et al.,* (1997). DTPA-extractable Cu content was higher in the surface soils and decreased gradually in most of the profiles. This might be due to higher biological activity and organic carbon content in the surface layer (Murthy *et al.,* 1997). Similar results were also reported by various researchers (Gupta *et al.,* 2003, Verma *et al.,* 2007a, Verma *et al.,* 2007b, Athokpam *et al.,* (2013), Athokpam *et al.,* (2016) and Athokpam *et al.,* (2018)). However, irregular distribution of DTPA-extractable Cu with depth was observed in a few samples. Similar findings were made by Sangwan *et al.,* (1993), Kumar *et al.,* (1996) and Satyavathi and Reddy (2004). It showed significant multiple regression coefficient with Fe (0.008*) in the second layer, Fe (0.005*) and Zn (0.663*) in the third layer and Zn (0.986*) in the fourth layer.

Table.1 Physico-chemical properties of the soil profiles

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	Ph	EC (dSm^{-1})	CEC [cmol (p^+) kg^{-1}]	OC (g kg^{-1})	Ca [cmol (p^+) kg^{-1}]	Mg [cmol (p^+) kg^{-1}]	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
1.Panchai													
0-20	27.5	17.5	55	SCL	5.3	0.18	6.4	7.8	0.5	0.4	100.35	20.04	218.21
20-40	45.7	12.5	41.8	C	5.40	0.05	6	5.1	1.0	0.4	314.66	15.31	153.48
40-60	43	15	42	C	5.51	0.05	5.8	4.2	0.2	0.3	225.79	10.99	112.63
60-80	36.4	25	38.6	CL	5.49	0.03	5.6	4.5	0.1	0.1	100.35	9.55	91.12
2.Charangching Khunkha													
0-20	47.3	5.0	47.7	SC	5.34	0.14	10.4	9.3	0.5	3.4	200.70	15.11	365.1
20-40	58.2	17.5	24.3	C	5.45	0.03	11.4	3.0	1.5	0.7	188.16	10.63	266.38
40-60	60.9	12.5	26.6	C	5.50	0.04	9.4	3.7	0.7	0.5	188.16	13.51	192.86
60-80	56.6	12.5	30.9	C	5.69	0.03	9.2	2.3	2.8	0.4	175.61	9.91	155.37
3.Charangching Khullen													
0-20	36.2	15	48.8	SC	5.63	0.15	11.4	23.1	2.9	2.7	413.95	20.72	305.62
20-40	37.7	17.5	44.8	CL	5.61	0.06	11.2	10.8	5.6	0.5	238.34	16.75	166.25
40-60	37	10	53	SC	5.99	0.05	10.8	8.7	4.5	3.5	175.63	13.87	136.68
60-80	34.6	17.5	47.9	SCL	6.15	0.03	10.8	3.0	4.5	2.3	163.07	7.75	104.29
4.Hnatham													
0-20	33.2	22.5	44.3	CL	5.43	0.05	9.4	15.4	3.8	3.1	263.42	17.11	163.97
20-40	36.6	25	38.4	CL	5.52	0.03	9.2	10.2	2.5	3.0	250.88	14.23	148.51
40-60	30.7	32.5	36.8	CL	5.91	0.02	5.2	6.5	2.7	2.5	213.24	13.15	139.91
60-80	42.5	15	42.5	C	5.97	0.03	5	6.0	2.2	2.1	163.07	10.27	161.28
5.Hnahringkhu													
0-20	11.6	10	78.4	SL	5.5	0.08	9.4	6.9	4.5	5.6	551.94	16.39	198.51
20-40	25	10	65	SCL	5.67	0.16	8.4	8.1	4.0	3.9	263.42	13.15	202.68
40-60	27.5	2.5	70	SCL	5.88	0.25	7.4	6.9	4.1	3.7	137.98	11.71	125.40
60-80	25.9	15	59.1	SCL	6.14	0.07	7	4.5	3.9	3.2	112.90	9.55	109.80
6.Lambung													
0-20	27.5	17.5	55	SCL	5.73	0.05	12.4	5.7	5.5	3.0	314.66	15.31	181.04
20-40	25	5	70	SCL	6.08	0.26	13.2	6.3	5.5	3.8	163.07	13.87	196.63
40-60	10.5	7	82.5	LS	6.1	0.02	12.8	2.1	5.4	4.9	150.53	11.35	160.74
60-80	16.6	15	68.4	SL	6.29	0.02	13	1.5	5.1	3.0	75.26	10.27	128.62
7.Mantripantha													
0-20	30	20	50	SCL	5.68	0.1	7.8	18.3	2.5	1.5	275.97	23.96	355.07
20-40	42.7	15	42.3	C	5.72	0.06	7.2	9.6	2.7	1.0	275.97	18.92	240.10
40-60	41.7	15	43.3	C	5.70	0.04	7.6	4.8	2.4	1.9	263.42	10.63	210
60-80	43	15	42	C	5.79	0.04	6.8	3.9	2.0	2.1	213.25	9.91	190.57
Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	pH	EC (dSm^{-1})	CEC [cmol (p^+) kg^{-1}]	OC (g kg^{-1})	Ca [cmol (p^+) kg^{-1}]	Mg [cmol (p^+) kg^{-1}]	N (kg ha^{-1})	P_2O_5 ($kgha^{-1}$)	K_2O ($kgha^{-1}$)
8.Modi													
0-20	37	15.5	47.5	SC	5.69	0.06	10.6	15.2	3.9	1.2	238.34	23.60	273.26
20-40	40	9.75	50.25	SC	5.82	0.03	9.8	8.7	4.2	0.9	225.79	20.72	143.40
40-60	44.1	10	45.9	SC	6.01	0.02	9.8	1.8	4.5	0.8	150.53	18.92	110.53
60-80	29.8	12.5	57.7	SCL	6.19	0.02	8.2	0.9	4.2	0.7	137.98	17.11	108.08
9.Angthi													
0-20	37	20	43	CL	5.43	0.06	8.8	8.7	2.4	2.0	175.62	29	310.46
20-40	41.5	35	23.5	C	5.35	0.03	7.2	8.4	2.1	1.9	200.70	21.08	194.47
40-60	38.2	20	41.8	CL	5.6	0.01	9	6.3	2.0	1.9	163.07	16.39	177.40
60-80	45.7	12.5	41.8	C	5.9	0.02	8	3.1	1.9	0.9	150.53	17.47	138.83
10.Lamphou Charu													
0-20	34.1	12.5	53.4	SCL	5.61	0.06	6.4	13.8	5.3	4.4	275.97	25.04	270.61

20-40	29.1	40	30.9	CL	5.67	0.12	4.6	9.5	4.8	3.9	225.79	18.92	250.52
40-60	24.1	25	50.9	SCL	5.79	0.05	5.2	4.5	4.2	3.3	137.98	16.75	152.28
60-80	36.6	25	38.4	CL	6.12	0.04	5.2	3.5	4.0	3.1	87.81	15.67	150.93
11.Lamphou Pasna													
0-20	28	32.5	39.5	CL	5.22	0.04	6.2	7.2	0.5	0.2	200.70	18.92	225.92
20-40	30.5	40	29.5	CL	5.44	0.03	6.0	6.9	0.8	0.7	188.16	14.59	276.86
40-60	21.4	32.5	46.1	L	5.49	0.03	5.6	4.8	0.4	1.1	175.62	10.63	98.92
60-80	26.4	35	38.6	L	5.63	0.03	5.4	1.7	0.7	1.7	175.62	9.91	137.49
12.Liwa Sarei													
0-20	33	35	32	CL	4.67	0.16	7.0	9.9	0.9	0.1	175.62	34.05	120.28
20-40	50.5	25	24.5	C	4.97	0.12	6.4	5.7	0.2	1.9	163.07	24.68	235.06
40-60	53	25	22	C	5.42	0.03	6	2.4	1.0	0.7	137.98	17.47	216.79
60-80	53	27.5	19.5	C	5.41	0.02	5.8	1.8	0.6	0.8	100.35	12.79	197.30
13.Thotchanram													
0-20	28.2	17.5	54.3	SCL	5.21	0.05	6.4	5.9	2.2	2.9	150.53	28.28	152.54
20-40	45.7	12.5	41.8	C	5.43	0.05	6.0	4.8	1.3	1.1	137.98	18.92	154.28
40-60	23.2	30	46.8	L	5.3	0.04	5.8	3.9	1.1	1.7	100.35	11.35	127.40
60-80	41.7	15	43.3	C	5.51	0.03	5.6	1.1	1.0	3.5	87.81	10.99	111.39
14.Cheengkhu													
0-20	29.3	17.5	53.2	SCL	5.07	0.06	8.6	7.2	0.4	2.1	539.39	21.08	278.75
20-40	36	17.5	46.5	SC	5.19	0.04	8.2	6.3	0.5	1.7	238.34	14.59	167.81
40-60	29.8	17.5	52.7	SCL	5.24	0.04	7.8	3.8	0.2	1.3	175.62	10.27	147.83
60-80	27.3	17.5	55.2	SCL	5.53	0.03	7.6	2.2	0.1	1.2	100.35	9.19	132.24
15.Angkhel Chayang													
0-20	43	24.1	32.9	C	4.88	0.05	7.2	9.0	1.2	1.7	514.30	26.48	263.64
20-40	42	33.8	24.2	C	5.1	0.03	9.4	8.1	1.2	0.3	363.78	22.88	221.22
40-60	48	24.1	27.9	C	5.3	0.04	7.4	4.8	0.8	0.2	301.06	16.03	194.07
60-80	33.5	48.8	17.7	SiCL	5.34	0.03	6.8	1.2	0.5	0.2	275.96	12.79	146.23
16.Japhou													
0-20	46.6	15	38.4	C	5.23	0.08	9.6	12	0.7	0.2	464.13	27.20	40.32
20-40	41.6	15	43.4	C	5.26	0.05	9.4	8.4	0.8	0.3	288.51	20.36	43.95
40-60	44.1	15	40.9	C	5.49	0.04	7.4	6.9	0.6	0.3	288.51	16.39	71.90
60-80	44.1	12.5	43.4	C	5.81	0.02	7.2	3.5	0.4	0.5	313.60	17.47	53.63
17.Monsang Pantha													
0-20	59.8	5	35.2	C	5.16	0.06	11.6	12.7	0.7	1.3	326.14	29.72	225.24
20-40	44.8	17.5	37.7	C	5.18	0.06	11.4	9.6	0.6	1.4	275.96	20.36	273.5
40-60	62.3	5	32.7	C	5.23	0.04	11	6.2	0.6	0.4	275.96	16.75	228.21
60-80	47.3	12.5	40.2	C	5.55	0.03	10.8	3.3	2.5	2.3	60.63	10.63	180.23
18.Thangkin													
0-20	42.8	17.5	39.7	C	4.96	0.19	13.6	13.5	0.8	0.4	376.32	32.25	276.85
20-40	42.8	17.5	39.7	C	5.24	0.09	13.2	7.4	1.1	0.2	351.23	27.20	233.72
40-60	46.9	22.5	30.6	C	5.25	0.06	12.8	3.4	0.3	0.1	288.51	13.87	219.88
60-80	49.4	22.5	28.1	C	5.34	0.03	11.4	3.6	0.2	0.1	188.16	10.27	156.04
19.Chumthar													
0-20	42.5	20	37.5	C	4.67	0.06	12.6	7.9	1.3	1.5	200.70	26.84	315.30
20-40	39.1	20	40.9	CL	5	0.05	11.8	8.4	1.2	1.0	188.16	21.44	235.33
40-60	41	22.5	36.5	C	5.11	0.04	11.4	3.7	1.1	0.8	175.62	18.92	208.05
60-80	36.6	20.9	42.5	CL	5.29	0.03	10.0	3	1.0	0.6	175.62	15.67	149.05
20.Khongjon													
0-20	40.7	20	39.3	C	5.1	0.35	16.8	21.3	2.4	0.4	162.72	27.56	304.13
20-40	48.2	12.5	39.3	C	5.08	0.15	16.2	8.1	2	2.8	213.25	22.52	159.94
40-60	48.2	10	41.8	C	5.14	0.03	15.8	6.6	0.4	1.2	188.16	16.39	126.74
60-80	53.2	2.5	44.3	C	5.21	0.03	16.4	3.9	0.4	1.5	137.98	13.87	111.96

Table.2 Distribution of available DTPA – Extractable micronutrients of soils

Depth (cm)	Fe	Cu	Mn	Zn	Depth (cm)	Fe	Cu	Mn	Zn
1.Panchai					2.Charangching Khunkha				
0-20	51.8	0.77	11.48	0.65	0-20	36.19	0.85	14.91	0.92
20-40	19.73	0.43	4.97	0.29	20-40	13.21	0.78	13.64	0.56
40-60	14.96	0.22	2.73	0.14	40-60	10.27	0.32	7.21	0.53
60-80	17.01	0.19	6.22	0.10	60-80	11.50	0.14	5.54	0.3
3.Charangching Khullen					4.Hnatham				
0-20	122.08	0.35	16.54	1.12	0-20	130.21	1.48	30.53	0.91
20-40	90.74	0.25	19.39	0.49	20-40	105.24	0.84	29.50	0.76
40-60	65.84	0.18	19.84	0.38	40-60	68.78	0.65	23.35	0.54
60-80	41.13	0.04	10.40	0.17	60-80	49.07	0.20	19.93	0.48
5.Hnahringkhu					6.Lambung				
0-20	85.69	1.05	15.63	0.65	0-20	112.92	1.21	26.25	0.96
20-40	82.26	0.75	19.71	0.56	20-40	88.69	0.47	16.80	0.75
40-60	80.69	0.52	18.87	0.58	40-60	89.96	0.22	15.28	0.43
60-80	69.77	0.51	15.37	0.46	60-80	50.92	0.45	13.06	0.39
7.Mantripantha					8.Modi				
0-20	159	3.21	14.52	1.05	0-20	110.16	1.58	37.31	0.86
20-40	156.98	2.54	14.10	0.97	20-40	59.66	0.57	14.23	0.79
40-60	154.48	1.87	9.33	0.99	40-60	34.26	0.50	11.91	0.68
60-80	105.54	1.70	11.5	0.75	60-80	33.36	0.44	9.74	0.49
9.Angthi					10.Lamphou Charu				
0-20	52.92	0.19	27.24	0.51	0-20	65.24	1.84	31.36	0.78
20-40	50.59	0.54	25.32	1.22	20-40	46.96	0.65	24.91	1.59
40-60	50.20	0.47	24.81	0.57	40-60	30.01	0.97	20.41	1.06
60-80	48.74	0.46	13.05	0.40	60-80	17.83	1.03	20.06	0.64
11.Lamphou Pasna					12.Liwa Sarei				
0-20	77.01	2.06	6.21	0.47	0-20	53.19	0.85	10.53	1.12
20-40	25.84	1.15	15.89	0.30	20-40	52.62	0.33	2.78	0.83
40-60	19.28	0.76	10.30	0.30	40-60	51.19	0.65	1.52	0.97
60-80	19.10	0.23	9.19	0.13	60-80	49.62	0.35	0.86	0.65
13. Thotchanram					14. Cheengkhu				
0-20	36.70	1.63	3.70	0.87	0-20	87.18	1.19	27.25	1.43
20-40	46.55	0.32	2.37	0.49	20-40	44.61	0.98	7.56	0.45
40-60	43.57	0.55	4.39	0.53	40-60	43.38	0.58	14.14	0.39
60-80	34.32	0.19	3.14	0.48	60-80	36.55	0.51	25.90	0.11
15. Angkhel Chayang					16. Japhou				
0-20	49.71	0.33	11.53	1.06	0-20	63.16	1.23	13.57	0.61
20-40	26.85	0.76	11.43	0.96	20-40	57.68	0.36	12.51	0.47
40-60	21.89	0.60	11.39	0.73	40-60	56.76	0.32	38.67	0.45
60-80	23.42	0.78	8.48	0.53	60-80	53.24	0.28	25.12	0.49
17. Monsang Pantha					18. Thangkin				
0-20	113.01	0.61	21.99	1.67	0-20	44.13	0.80	9.31	1.48
20-40	83.87	1.04	26.12	1.38	20-40	37.15	0.72	5.67	0.83
40-60	52.92	0.77	21.52	1.23	40-60	36.98	0.60	5.66	0.51
60-80	33.88	0.54	23.71	0.51	60-80	34.13	0.10	4.20	0.33
19. Chumthar					20. Khongjon				
0-20	60.91	0.37	1.37	0.97	0-20	80.21	0.85	15.63	1.66
20-40	48.47	0.06	0.44	0.56	20-40	51.84	0.65	1.98	0.89
40-60	42.52	0.29	1.24	0.32	40-60	40.34	0.40	1.87	0.68
60-80	45.64	0.34	0.57	0.27	60-80	40.21	0.32	1.63	0.48

Table.3 Effect of soil characteristics on predictability of micronutrient cations

Depth	Available Fe	R^2 X 100
0-20 cm	-93.814 + 21.667 pH + 2.583 OC + 14.587 Cu + 0.744 Mn	54.5*
20-40 cm	-29.601 + 8.968* OC + 28.598* Cu	55.5*
40-60 cm	4.375 + 11.638* Mg + 48.849 * Cu	55.9*
60-80 cm	20.040 + 21.483 Cu + 27.590 Zn	32.2*
	Available Cu	
20-40 cm	0.226 + 0.008* Fe	28.8*
40-60 cm	-0.068 + 0.005* Fe + 0.663* Zn	54.5*
60-80 cm	-0.186 + 0.005 Fe + 0.986* Zn	46.3*
	Available Mn	
0-20 cm	-43.436 + 10.239 pH + 1.595 Ca + 0.042 Fe	42.4*
20-40 cm	-127.146 + 22.757* pH + 2.040* OC – 2.096 Ca + 8.512 Zn	46.7*
40-60 cm	-0.853 + 2.932* OC	30.0*
60-80 cm	-51.010 + 10.913* Ph	20.9*
	Available Zn	
0-20 cm	0.086 + 1.145 EC + 0.044 CEC + 0.010 Clay	46.2*
40-60 cm	0.057 + 0.002 K + 0.384* Cu	48.4*
60-80 cm	0.225 + 0.002 Fe + 0.250* Cu	42.1*

The multiple correlation and regression analyses indicated that 28.8, 54.5 and 46.3 per cent variability in the respective 2nd, 3rd and 4th layers may be the combined effect of Fe and Zn content in the profiles.

Manganese (Mn)

DTPA-extractable Mn in the soil profiles varied from 0.44 to 38.67 mg kg^{-1} soil. Taking into consideration the critical value of 1.0 mg Mn kg^{-1} soil (Lindsay and Norvell, 1978), the studied soil profiles were above the critical limit. The high amount of Mn in the soils might be due to the solubility of this cation is higher at low pH.

The abundance of DTPA – Mn in soils of Manipur was also reported by Sen *et al.*, (1997), Sarkar *et al.*, (2002), Athokpam *et al.*, (2013), Athokpam *et al.*, (2016) and Athokpam *et al.*, (2018). The surface soils contained higher Mn and decreased with increase in depth. Only 3.75 per cent of the studied samples were below critical limits. It observed significant multiple regression coefficient with pH (22.757*) and OC (2.040*) in the second layer, OC (2.932*) in the third layer and pH (10.913*) in the fourth layer. Multiple correlation and regression analyses indicated that 42.4, 46.7, 30.0 and 20.9 per cent variability of the available Mn content could be attributed to the simultaneous effect of pH, Ca, Fe, OC and Zn in the soil profiles.

Zinc (Zn)

DTPA-extractable Zn in the soil profiles varied from 0.10 to 1.67 mg kg^{-1} soil. Sen *et al.*, (1997) reported the available Zn content varies from 0.2 to 1.4 mg kg^{-1} and decreased down the profile (Khanday *et al.*, 2017). Similar report was also reported by Athokpam *et al.*, (2016) in the citrus orchard of Ukhrul district, Manipur. Considering 0.6 mg kg^{-1} as the critical limit of available Zn as suggested by (Lindsay and Norvell, 1978), 48.75 per cent were sufficient and 51.25 per cent soils were deficient in Zn status. The low content of this cation might be the lost from the surface soils as the soils are very acidic in most of the profiles. DTPA-extractable Zn showed significant regression with Cu (0.384*) in the third layer and also Cu (0.250*) in the fourth layer. The multiple regression equations presented in the Table 3 indicate a predictability value of 46.2, 48.4 and 42.1 per cent by all factors taken together in the 1st, 3rd and 4th layers, respectively.

There exists variation in soil properties with respect to depth in soil profiles. Surface layers tend to have more content of nutrients which gradually decreases downward in most of the profiles especially from 40 cm to 80 cm depth. The surface layer soils were high in organic carbon.

The macronutrients content varies from low to medium. For micronutrients, Fe, Cu, and Mn were sufficient in most samples. However, some soils were deficient in Zn. This may be one of the important reasons for decreasing production potential of *jhum* practice in Chandel district of Manipur. Therefore, it is advisable to supply both macro as well as Zn to the crop to sustain the fertility of the soils as well as productivity of crop.

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