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Distribution and plant availability of soil copper fractions to oat (*Avena sativa*) nutrition in Haryana soils

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ABSTRACT

The distribution of copper (Cu) among various chemical forms and its availability to oat nutrition may vary significantly in response to changing soil properties. Therefore, a pot and laboratory study were conducted to investigate the distribution of native and added Cu fractions and their plant availability to oat (*Avena sativa* L.) nutrition in eighteen (18) different soils of Haryana that varied in physical and chemical properties. Seven-step sequential fractionation showed that most of the total Cu (51.12%) was associated in the residual fraction (RES). The percentage of soil Cu in the exchangeable fraction (EX-), carbonate bound (CARB-), organically associated (OM-), Mn oxide bound (MnOX-), amorphous Fe oxide bound (AFeOX-) and crystalline Fe oxide bound (CFeOX-) fractions averaged 2.71, 0.74, 2.74, 0.21, 13.35, and 29.11%, respectively. Amount of Cu in MnOX, AFeOX, CFeOX, RES-fractions and total Cu were interdependent and varied directly with DTPA-extractable Cu and clay content. On the basis of stepwise regression analysis, the residual fraction contribute very little whereas exchangeable and carbonate bound fraction contribute maximum to the availability of Cu to oat plant. The concentration of Cu and its uptake in oat were positively correlated with DTPA-extractable Cu, MnOX-Cu, AFeOX-Cu and total Cu, which in turn were correlated with clay content. Plant Cu concentration and uptake can be predicted by an equation which includes DTPA-extractable Cu and clay content. These results showed that DTPA-extractable Cu is a good predictor of Cu availability in Haryana soils.

Key words: Cu fractions, Clay content, DTPA-extractable Cu, Haryana soils, Oat

Understanding the mechanism of distribution of Cu in different fractions helps to know its retention in soils and release to plants. Like other micronutrients, copper also occurs in various forms associated with inorganic and organic components of soils differing in their solubility and thus availability to plants. Among different factors, variation in soil properties plays a major role in influencing the distribution of Cu among various chemical pools through adsorption, chemisorptions and chelation. The amount and rate of transformation of various forms of Cu in solution determine the size of labile Cu pool. However, there are only a few studies which quantitatify the contribution of these pools of Cu occurring in soils to available amount extracted by different extractants.

The proportions of different Cu forms vary considerably, depending on the soil and fractionation technique used. McLaren and Crawford (1973) used a sequential fractionation procedure to categorise soil Cu into soluble plus exchangeable, specifically adsorbed, organically bound, oxide occluded and residual forms. They found that, although there was considerable variation in the proportion of total Cu present in various fractions, but on an average over 50% remained in the residual fractions and about 30% was found associated with organic matter. The authors concluded that the amount of Cu available to plants was controlled by equilibrium involving specifically adsorbed forms and the organically bound fraction. Viets (1962) suggested that Cu present in water-soluble, exchangeable and adsorbed forms is readily available to plants. McKenzie (1978) pointed out that incorporation of Mn oxide into the soil did not affect Cu availability and suggested that Mn oxide is not an important soil property affecting Cu availability.

Tessier *et al.* (1979) have developed a sequential chemical extractions analytic procedure for partitioning of particulate trace metals into five fractions. These results showed that DTPA-extractable Cu is a good predictor of Cu availability. Hence, the present study was planned to investigate the fractional distribution of native and added Cu in soils with diverse properties and their plant availability in Haryana.

MATERIALS AND METHODS

In order to assess the distribution and plant availability

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of soil copper fractions to oat nutrition, a pot experiment was conducted in the screen house of Department of Soil Science, College of Agriculture, CCS HAU, Hisar. For pot experiment, four kg thoroughly mixed soil collected from eighteen (18) different locations in the state was filled in plastic pots. The soil samples were air dried, ground and passed through 2 mm sieve and stored in cloth bags for laboratory studies. The pH and electrical conductivity of soils (Table 1) were determined in (1:2) soil: water suspension with the help of glass electrode pH meter and conductivity meter, respectively as per the methods described by Richards (1954). Organic Carbon (OC) was estimated by wet digestion method (Walkley and Black 1934). Calcium Carbonate ($CaCO_3$) was estimated by rapid titration method (Puri's 1930). Mechanical analysis was done using international pipette method (Piper 1966). DTPA-extractable Cu was determined according to the method developed by Lindsay and Norvell (1978). Total Cu was determined using Aqua regia-HF-HNO_3 and HCl, according as outlined by Shuman (1979).

A basal application of recommended doses of N, P and K was done using 50 mg N/kg soil as urea, 50 mg P/kg soil as potassium dihydrogen phosphate (KH_2PO_4) and 15 mg K/kg soil as potassium sulphate (K_2SO_4) in each pot. Five levels of Cu, viz. 0, 5, 10, 15 and 20 mg/kg soil through $CuSO_4$. $5H_2O$ were applied at the time of sowing of oat (*Avena sativa* L.) crop. In all the pots soil was moistened with distilled water, dried and thoroughly mixed for equilibration. The pots were arranged in completely randomized design (CRD) in the screen house according to Steel and Torrie (1980). Ten viable seeds of oat were sown in each pot. Thinning was done after fifteen days and four uniform plants per pot were allowed to grow up to forty five days. Pots were irrigated with distilled water as and when required. Copper fractionation was carried out on soil samples collected before nutrient addition, prior to the seeding and at harvesting to assess the forms and distribution of native and applied Cu. Copper in the plant digest and soil extractants were determined by atomic absorption spectrophotometry (AAS). For the contribution of different Cu fractions in soil, a seven step sequential fractionation procedure of Tessier *et al* (1979) was followed to partition Cu into exchangeable fraction (EX-), carbonate bound

Table 1 Physical and chemical properties of experimental soils

Locations of soil sampling	pH (1:2)	EC (dS/m)	OC (%)	$CaCO_3$ (%)	Clay (%)	DTPA-Cu (mg/kg)	Total Cu (mg/kg)
Sadalpur	8.40	0.30	0.27	1.50	4.00	0.20	12.5
Shahnal	8.20	0.75	0.66	2.05	4.00	1.02	13.5
Sagwan	8.30	0.36	0.20	2.60	2.00	0.18	7.5
Narwana	7.60	0.47	0.67	0.00	8.00	1.22	20.0
Dhani lamba	8.30	0.44	0.43	3.05	4.00	0.26	5.0
Kalawali	8.60	0.62	0.40	2.55	6.00	0.22	7.5
Lakhan Mazra	7.00	1.18	0.69	0.00	14.00	1.80	5.0
Dharsul Bhuna	8.10	0.42	0.36	0.00	16.00	0.43	11.5
Siser Khurd	8.40	0.47	0.37	0.00	6.00	0.38	15.5
Kourk	8.35	0.36	0.51	0.00	12.00	0.46	15.0
Kalayat	8.05	1.71	0.48	1.00	12.00	0.30	27.5
Butana	8.30	0.60	0.31	1.05	14.00	0.88	16.0
Nidani	8.00	0.82	0.43	3.12	16.00	0.66	17.5
Madanheri	8.30	0.83	0.69	0.00	16.00	0.25	22.5
Kurkawali	8.25	0.93	0.27	3.50	16.00	0.74	37.5
Kharakheri	8.40	0.40	0.25	0.00	8.00	0.28	2.5
Kaul	8.10	0.41	0.66	0.00	14.00	0.45	90.0
Damla	7.70	1.70	0.33	0.00	12.00	0.40	35.0
Range	7.00-8.60	0.30-1.71	0.20-0.69	0.00-3.50	2-16	0.18-1.8	2.5-90
Mean	8.13	0.70	0.44	2.26	10.22	0.56	20.08
CV	4.55	61.42	36.36	40.70	48.33	76.84	99.60

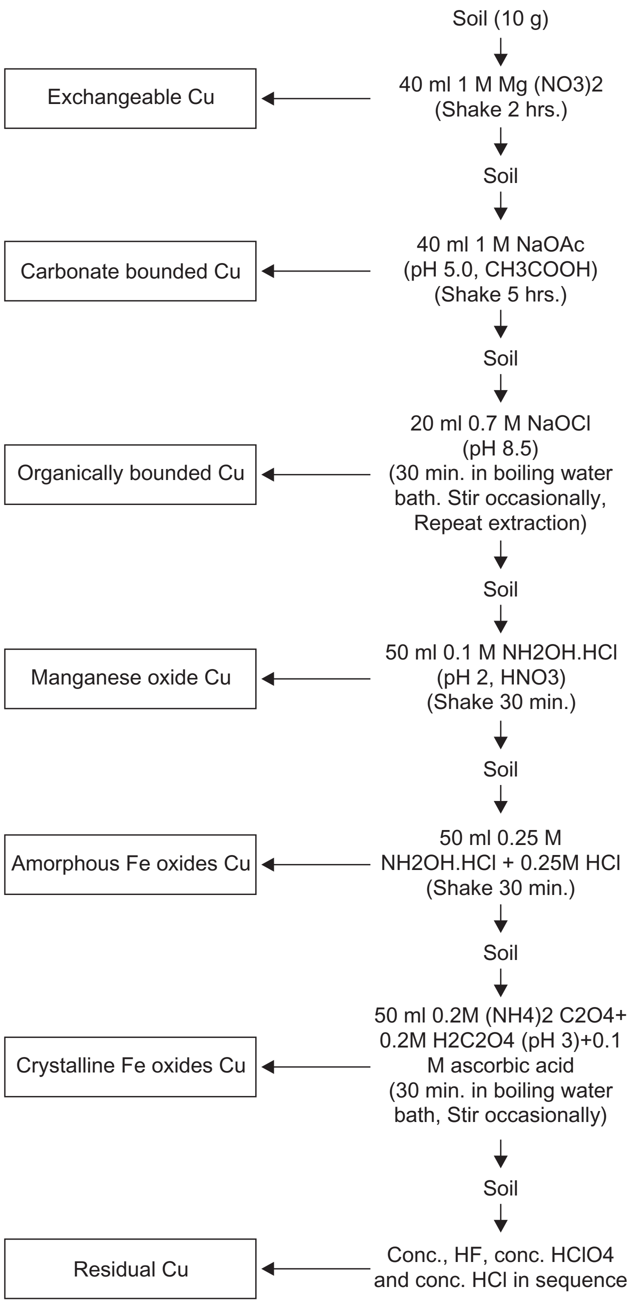

Fig 1 Sequential procedure used for Cu fractionation in soils

(CARB-), organically associated (OM-), Mn oxide bound (MnO-), amorphous Fe oxide (AFeOX-), crystalline Fe oxide (CFeOX-), and residual fraction (RES-) as given in Fig 1.

RESULTS AND DISCUSSION

Physico-chemical characteristics of experimental soils

The physico-chemical characteristics of soils collected from different locations have been presented in Table 1. The results showed that majority of the soils were alkaline in nature with soil pH ranging from 7.00 to 8.60 and a mean of 8.13. The electrical conductivity of soils varied from 0.30 to 1.71 dS/m with a mean of 0.70 dS/m. Organic carbon content varied from 0.20 to 0.69% with a mean of 0.44%. The experimental soils were almost low in organic carbon content. DTPA-Cu content of soils varied from 0.18 to 1.8 mg/kg with an average of 0.56 mg/kg soils used for the experiment and total Cu content varied from 2.5 to 90.0 mg/kg with an average of 20.08 mg/kg.

Contribution of different chemical pools of copper to oat nutrition

The distribution of trace metals among various chemical forms varied significantly in response to changing soil properties. The data on copper fractionation (Table 2) revealed that copper associated with EXCH fraction varied from 0.52 to 0.65 mg/kg and constituted 2.71% of the total soil Cu. CARB-Cu ranged from 0.05 to 0.39 mg/kg and OM fraction from 0.51 to 0.65 mg/kg and accounted for 0.74% and 2.74% of total soil Cu, respectively (Table 2). Copper in MnOX was quite low (0.00 to 0.07 mg/kg) and accounted for 0.21% of total soil Cu. Whereas, AFeOX-Cu and CFeOX-Cu ranged from 1.37 to 5.67 mg/kg and 4.03 to 8.60 mg/kg which accounted for 13.35% and 29.11% of total soil Cu, respectively. Maximum copper was found associated in residual fraction which ranged from 5.47 to 15.67 mg/kg and constituted 51.12% of total soil Cu. Copper associated with different fraction in this study was found in the order of: RES>CFeOX>AFeOX> OM>EX>CARB>MnOX. Similar results were reported by Raghupathi and Vasuki (1991) who carried out sequential fractionation of copper in 26 soil samples collected from six profiles derived from different parent materials. Both water soluble plus exchangeable as well as inorganically bound copper were very low while the latter was nearly ten times higher than former. The organically bound copper was the major fraction next to residual copper constituting about 2.6 to 35.3 percent of total copper. Substantial proportion of total copper content was also occluded by oxides. Tessier *et al*. (1979) found that appreciable concentration (16 to 18 per cent) of total sediments Cu bound to the carbonates fraction, compared to the soils of this study. This difference is probably due to much higher

Table 2 Total Cu and Cu fractions expressed as amount extracted and percentage of total Cu for different soils in Haryana

Soil	Total-Cu	EX-Cu		CARB-Cu		OM-Cu		MnOX-Cu		AFeOX-Cu		CFeOX-Cu		RES-Cu	
	(mg/kg)	(mg/kg)	(%)^y	(mg/kg)	(%)^y	(mg/kg)	(%)^y	(mg/kg)	(%)^y	(mg/kg)	(%)^y	(mg/kg)	(%)^y	(mg/kg)	(%)^y
1	21.80	0.65	2.98	0.12	0.55	0.63	2.88	0.07	0.32	1.70	7.79	8.17	37.47	10.47	48.02
2	15.02	0.56	3.72	0.20	1.33	0.63	4.19	0.07	0.46	3.00	19.97	5.10	33.95	5.47	36.41
3	20.45	0.59	2.88	0.08	0.39	0.55	2.68	0.07	0.34	1.70	8.31	5.20	25.42	12.27	60.00
4	24.35	0.53	2.17	0.09	0.36	0.52	2.13	0.07	0.28	3.77	15.48	8.37	34.37	11.00	45.17
5	23.72	0.53	2.23	0.08	0.33	0.57	2.40	0.07	0.29	1.90	8.01	7.97	33.60	12.60	53.11
6	20.15	0.52	2.58	0.08	0.39	0.59	2.92	0.07	0.34	1.60	7.94	6.70	33.25	10.60	52.60
7	25.99	0.60	2.30	0.20	0.76	0.59	2.27	0.07	0.26	4.77	18.35	6.83	26.27	12.93	49.74
8	18.80	0.55	2.92	0.05	0.26	0.57	3.03	0.00	0.00	1.37	7.28	7.07	37.60	9.20	48.93
9	23.19	0.56	2.41	0.05	0.21	0.57	2.45	0.00	0.00	2.53	10.90	8.60	37.08	10.87	46.87
10	20.47	0.59	2.88	0.24	1.17	0.50	2.44	0.07	0.34	2.87	14.02	5.20	25.40	11.00	53.73
11	21.81	0.63	2.88	0.24	1.10	0.61	2.79	0.00	0.00	5.67	25.99	4.60	21.09	10.07	46.17
12	22.81	0.63	2.76	0.13	0.56	0.59	2.58	0.07	0.30	4.23	18.54	4.70	20.60	12.47	54.66
13	26.01	0.60	2.30	0.20	0.76	0.61	2.34	0.00	0.00	2.90	11.14	6.03	23.18	15.67	60.24
14	23.15	0.60	2.59	0.12	0.51	0.63	2.72	0.07	0.30	2.67	11.53	5.93	25.61	13.13	56.71
15	22.15	0.63	2.84	0.16	0.72	0.60	2.70	0.07	0.31	2.07	9.34	7.23	32.64	11.40	51.46
16	21.28	0.56	2.63	0.13	0.61	0.59	2.77	0.07	0.32	2.50	11.74	7.17	33.69	10.27	48.26
17	17.05	0.56	3.28	0.31	1.81	0.65	3.81	0.00	0.00	3.37	19.76	4.03	23.63	8.13	47.68
18	25.74	0.65	2.52	0.39	1.51	0.58	2.25	0.00	0.00	3.67	14.25	4.93	19.15	15.53	60.33
Range	15.02-26.01	0.52-0.65	2.17-3.72	0.05-0.39	0.21-1.81	0.51-0.65	2.13-4.19	0.00-0.07	0.00-0.46	1.37-5.67	7.28-25.99	4.03-8.60	19.15-37.60	5.47-15.67	36.41-60.33
Mean	21.75	0.58	2.71	0.17	0.74	0.59	2.74	0.04	0.21	2.96	13.35	6.32	29.11	11.21	51.12
CD (P = 0.05)		NS		0.03		NS		NS		0.08		2.39		3.84	

^{Y} Expressed as percentage of total

carbonates content of the sediments used in the former study. The percentage of Cu in the exchangeable fraction was also within the 1 to 7 per cent as reported by Shuman (1979).

Effect of copper application on dry matter yield of oat

The data on dry matter yield of oat (Table 3) revealed a significant increase in yield from 2.88 g/pot in control to 3.28, 3.76, 3.52 and 3.47 g/pot with application of 5, 10, 15 and 20 mg Cu/kg soil. A maximum yield of 3.76 g/pot was obtained with application of 10 mg Cu/kg soil, but it was at par with that of 15 mg Cu/kg soil applied. Though the dry matter yield of oats responded significantly to graded levels of Cu application upto 15 mg Cu/kg soil but yield declined significantly at 20 mg Cu/kg soil. Similar results were obtained by Singh *et al.* (1994) in a pot culture experiment, where they showed that graded addition of Cu (0, 2.5, 5.0 and 10 µg Cu/g soil) significantly increased the dry matter yield of cowpea. Dry matter yields of cowpea plants increased appreciably with an increase in level of Cu application. Similarly, Kopittke and Menzies (2006) reported that at 20 µg Cu/g soil of applied Cu, root and shoot growth of cowpea was reduced.

Effect of copper application on copper content in oat

The data on Cu concentration in oat as influenced by Cu fertilization is presented in Table 4. Mean concentration of Cu increased significantly from 6.69 mg/kg in control to 8.13, 9.70, 11.02 and 12.53 mg/kg with application of 5, 10, 15 and 20 mg Cu/kg soil, respectively. In oat plant, increasing levels of Cu application were found to increase Cu content and maximum Cu content of 12.53 mg/kg was recorded with the application of 20 mg Cu/kg soil. Similar results were also obtained by Kumar *et al*. (1990) and Malhi *et al*. (2004) which they observed that Cu content of shoots as well as grain of wheat increased significantly with Cu application. Gupta *et al*. (1993) also found that with increasing Cu level from 0 to 5 µg Cu/g soil, its concentration in maize shoots increased significantly from 3.2 to 4.7 µg Cu/g dry matter. Lower content of Cu, Zn and Mn in all feed ingredients like wheat, bajra, cottonseed cake and wheat straw was also reported by Lall *et al.* (2000) in the Hisar district of Haryana.

Table 3 Effect of copper application on dry matter yield of oat (g/pot)

Soil	Copper level (mg/kg)					Mean	Relative yield (%)
	0	5	10	15	20		
Sadalpur	2.23	2.69	4.20	3.25	3.36	3.15	53.0
Shahnal	3.12	3.36	4.02	3.82	3.86	3.63	77.6
Sagwan	2.78	2.83	3.55	3.48	3.47	3.22	78.1
Narwana	3.09	3.20	3.28	3.70	3.27	3.30	83.6
Dhani lamba	2.12	2.15	3.28	2.96	3.23	2.75	64.5
Kalawali	3.48	3.76	5.79	4.63	4.18	4.37	60.0
Lakhan Mazra	3.22	3.42	3.82	3.75	3.75	3.59	84.2
Dharsul Bhuna	2.97	4.33	3.42	3.48	3.67	3.57	68.6
Siser khurd	3.16	3.21	3.55	3.52	3.75	3.44	84.1
Kourk	2.74	4.29	3.70	3.01	3.53	3.45	63.6
Kalayat	2.28	2.50	3.37	3.14	2.80	2.82	67.5
Butana	2.62	2.86	2.70	2.72	2.74	2.73	91.4
Nidani	2.41	2.58	2.82	2.66	2.70	2.63	85.5
Madanheri	2.10	2.68	2.96	3.58	3.02	2.87	58.6
Kurkawali	3.88	4.14	4.51	4.44	4.22	4.24	86.1
Kharakheri	2.34	2.48	3.45	2.82	2.98	2.82	67.8
Kaul	3.57	4.56	4.13	3.64	3.82	3.94	78.3
Damla	3.73	3.92	5.10	4.82	4.08	4.33	73.2
Mean	2.88	3.28	3.76	3.52	3.47		

CD (P=0.05) Soil= 0.37, Cu-level = 0.19 Soil × Cu-level = 0.84

Table 4 Effect of copper application on copper content in oat (mg/kg)

Soil	Copper level (mg/kg)					Mean
	0	5	10	15	20	
Sadalpur	6.83	7.50	8.33	9.50	10.50	8.53
Shahnal	4.83	5.50	6.67	7.50	9.17	6.73
Sagwan	5.67	9.17	10.33	10.67	11.67	9.50
Narwana	5.33	6.83	10.67	11.17	12.17	9.23
Dhani lamba	6.00	8.50	9.00	9.67	10.17	8.67
Kalawali	6.50	8.17	9.17	10.50	11.17	9.10
Lakhan Mazra	6.83	7.50	10.67	12.33	16.50	10.77
Dharsul Bhuna	7.83	10.67	13.17	16.17	17.00	12.97
Siser khurd	5.50	7.00	10.67	15.17	17.83	11.23
Kourk	7.17	7.50	8.00	10.17	11.67	8.90
Kalayat	7.50	8.50	9.83	10.17	10.83	9.37
Butana	7.17	8.00	8.83	10.17	10.67	8.97
Nidani	7.33	11.00	12.67	14.83	15.67	12.30
Madanheri	6.33	7.83	8.83	9.17	9.67	8.37
Kurkawali	9.50	10.83	13.33	14.17	17.50	13.07
Kharakheri	8.83	9.50	10.83	12.50	15.33	11.40
Kaul	5.67	6.00	6.17	6.33	8.33	6.50
Damla	5.67	6.33	7.50	8.17	9.67	7.47
Mean	6.69	8.13	9.70	11.02	12.53	

CD (P=0.05) Soil = 1.51, Cu-level = 0.79 Soil × Cu-level = NS

Effect of copper application on copper uptake by oat

The data presented in Table 5 revealed that the Cu uptake increased significantly over control at all the levels of Cu application. The highest uptake of 43.85 µg Cu/pot was observed at highest level of Cu (20 mg Cu/kg); however, it was statistically at par to that of 15 mg Cu/kg soil application. An increase in the uptake of Cu with its application was also reported by Singh *et al*. (1994) in cowpea. They observed that uptake of Cu by cowpea increased significantly to 33.9, 43.8 and 50.1 µg Cu/pot over control (27.0 µg Cu/pot) with its application@2.5, 5.0 and 10 µg Cu/pot soil, respectively. Similar results were obtained by Gupta *et al*. (1993) that Cu uptake in maize increased significantly with Cu fertilization@1.25, 2.5 and 5 µg Cu/g soil to 149.3, 177.6 and 186.6 µg Cu/pot, respectively in a Cu deficient sandy soil.

Table 5 Effect of copper application on copper uptake by oat (μg/pot)

Soil	Copper level (mg/kg)					Mean
	0	5	10	15	20	
Sadalpur	15.18	20.39	34.66	29.98	35.51	27.14
Shahnal	15.02	18.38	26.59	30.15	35.36	25.10
Sagwan	15.74	26.34	36.57	37.13	40.55	31.26
Narwana	16.48	21.63	35.22	41.48	39.24	30.81
Dhani lamba	12.42	18.38	28.82	28.60	32.60	24.16
Kalawali	22.29	30.667	53.15	48.56	46.47	40.23
Lakhan Mazra	22.16	25.69	40.76	46.03	61.97	39.32
Dharsul Bhuna	23.26	47.13	45.14	55.90	62.88	46.86
Siser khurd	17.39	22.23	37.22	53.32	70.08	40.05
Kourk	19.70	31.03	29.38	30.65	41.74	30.50
Kalayat	16.66	21.52	33.05	31.94	29.97	26.63
Butana	18.77	22.83	23.32	27.37	29.33	24.32
Nidani	17.70	28.41	35.74	39.49	42.73	32.85
Madanheri	13.17	21.12	26.34	32.78	29.92	24.67
Kurkawali	36.25	44.96	60.18	62.79	74.10	55.69
Kharakheri	20.79	22.89	38.50	35.36	45.21	32.55
Kaul	20.07	27.49	25.20	22.97	31.87	25.52
Damla	21.18	23.75	38.27	40.06	39.73	32.59
Mean	19.12	26.38	36.01	38.59	43.85	
CD (P=0.05) Soil = 6.43, Cu-level = 3.39 Soil × Cu level = NS						

Plant availability of copper fractions

The simple correlations between Cu concentration, Cu uptake of oats and selected soil properties are shown in Table 6. The Cu concentration and uptake of oats varied directly with the amounts of Cu in Mn oxides, organic matter, AFe oxides, CFe oxides, total Cu, DTPA-extractable Cu and clay content. Therefore, the total content of Cu in soils, its fractions associated with oxides and organic matter are more important to Cu availability than Cu in other fractions. Clay content is the key soil property affecting soil Cu availability. Similar results were obtained by Sims (1986) and Martens (1968) who found that Cu uptake significantly correlated with organic Cu, oxide-bound Cu, as well as with exchangeable Cu. The role of oxide-bound Cu has generally been omitted in assessing Cu availability (Viets 1962, McLaren and Crawford 1973), but data in this study indicate that organic Cu as well as oxide-bound Cu is the important sources of available Cu. These fractions increase as clay content increases.

Table 6 Correlation coefficients between indices of Cu plant availability and selected soil properties for the experimental soils

Soil properties	DTPA-Cu	Clay %	Plant Cu concentration	Plant Cu uptake
MnOX-Cu	0.91**	0.88*	0.86*	0.88*
OM-Cu	0.81*	0.90*	0.66*	0.71*
AFeOX-Cu	0.94**	0.91**	0.84*	0.92**
CFeOX-Cu	0.92**	0.90**	0.82*	0.90**
Total-Cu	0.89*	0.96**	0.70*	0.81*
DTPA-Cu	1.00	0.90*	0.90**	0.94**
Clay %	0.91*	1.00	0.72*	0.84**

**Significant at 1% level, *Significant at 5% level

Stepwise regression analysis showed that about 44 per cent of the variation in copper uptake by oat was due to the contribution of exchangeable copper only (Table 7). When carbonate bound Cu was included along with exchangeable Cu in the regression equation the R^2 value raised from 0.445 to 0.628 which suggested that 18.0 per cent of the variations in Cu uptake were due to the influence of organic matter bounded Cu. The inclusion of organic matter bound Cu along with exchangeable and carbonate bound Cu further raised R^2 from 0.628 to 0.663. This means that it was not only exchangeable Cu but organic matter and carbonate bound Cu also simultaneously enhanced the Cu-uptake. The further inclusion of manganese oxide Cu fractions raised R^2 values from 0.663 to 0.683 only. This shows that these forms of Cu fractions account 4 to 5 per cent variations in Cu uptake. Also, Cu in amorphous crystalline Cu oxide and residual fraction contributed negligible amount to oat nutrition in the present study. Thus, the residual fraction contribute very little whereas exchangeable and carbonate bound fraction contribute maximum to the availability of Cu to oat plant. Similar findings were also reported by Sims (1986) while studying the influence of soil pH and micronutrient sources on the distribution and plant availability of Cu in four soils varied widely in OM content and CEC. Inconsistent correlations and low R^2 values for all models involving Cu, illustrated the difficulty in predicting crop responses to native or added copper. Singh *et al.* (2008) showed that the major portion of the Cu

Table 7 Stepwise regression analysis relating the different forms of copper to Cu uptake

Plant parameter	Intercept	EXCH	CARB	OM	MnOX	AFeOX	CFeOX	RES	R^2
Cu uptake	36.675	0.478*							0.445**
(μg/pot)	20.498	0.266	0.237						0.628**
	–19.415	–0.107	–0.370	–0.200					0.663**
	–4.105	0.347	0.541*	0.081	–0.215				0.683**
	–1.169	–0.334	–0.669**	–0.252	0.227	–0.433			0.452**
	0.916	0.392	0.134	–0.208	–0.089	0.100	0.054		0.529**
	–0.375	0.183	0.143	–0.022	–0.035	–0.095	0.045	0.008	0.612**

**Significant at 1% level, *Significant at 5% level resided in the residual fraction and also found the coefficient of correlation for Cu fraction amongst the fractions and soil properties, viz. silt, clay and organic carbon.

Hence, the result of this study showed that DTPA-extractable Cu is a good predictor of Cu availability. The concentration of Cu and its uptake in oat were positively correlated with DTPA-extractable Cu, MnOX-Cu, AFeOX-Cu and total Cu, which in turn were correlated with clay content. Organic and oxide-bound Cu are the important sources of available Cu for plant. These fractions are closely correlated with total Cu and clay content. Therefore total Cu and clay contents are important in assessing soil Cu availability.

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