Annals of Arid Zone 48(2): 103-112, 2009

Micronutrient Status of Different Land Use Systems in Relation to Soil Quality and Sustainability under Different Watersheds in Submontaneous Tract of Punjab

S.S. Dhaliwal, B.D. Sharma and Bijay-Singh
Department of Soils, Punjab Agricultural University, Ludhiana 141 003, India

Abstract: Four watersheds were selected in 'Kandi' region adjoining the Zonal Research Station for dry land (PAU) in Shaheed Bhagat Singh Nagar district of Punjab to investigate the available and total Zn, Cu, Fe and Mn for surface soils and profile and to evaluate the sustainability of four land use systems each existing under four watersheds. Our results reported that in surface soils, CS and FS in the BSW (clay 18.60-23.80% and organic carbon 0.16-0.41%), SDKW (clay 8.80-14.70% and organic carbon 0.24-0.38%) and TW (clay 15.9-20.6% and organic carbon 0.20-0.52%) had significantly higher levels of available and total micronutrients and were of better soil quality compared with PS and US. The higher levels of micronutrients in CS were due to addition of fertilizers and farm yard manure whereas, higher levels of available and total micronutrients in FS were due to the regular addition of organic matter in the form of leaf litter. The magnitude of micronutrients increased with depth in profile, which was mainly associated with higher clay content and organic matter. In all the watersheds except in KW both PS and US exhibited low magnitude of available Zn, Cu, Fe and Mn with poor soil quality and thus were not sustainable (Sustainability index <1). Based on soil samples drawn from profiles, the CS and FS in the BSW, SDKW and TW had higher levels of available and total micronutrients compared with US and PS. The higher levels of available and total Zn, Cu, Fe and Mn in profile were associated with higher content of clay and organic.

Key words: Soil quality, soil quality indices, sustainability, watersheds, cultivated, undisturbed, pasture and forest land use systems, Kandi area.

The submontaneous tract of Punjab and the adjoining undulating piedmont plains in the South of Siwalik hills popularly known as the 'Kandi' zone, covers parts of Roop Nagar, Nawanshahar, Hoshiarpur, Gurdaspur and Patiala districts of the Punjab state. The total area of this belt is 0.5 million hectares constituting about 10% of the geographical area of the state. Although this belt has a distinct advantage of having higher rainfall than other parts of the state, because of topographical and lithological constraints, the irrigation facilities in this zone are very limited and most of the area is rainfed. As a consequence, this belt is characterized by existence of very distinct land use systems. Cultivated (CS), forest (FS), pasture (PS) and undisturbed (US) land constitute four major land use systems in the region. This zone is also subjected to severe water erosion during rainy season, which causes nutrient losses. As there does not exist much possibility of increasing agricultural production in the 'Kandi' zone, pressure on other land use systems is increasing. Apart from N, P and K the soils are becoming deficient in available Zn, Cu, Fe and Mn. As a result, soil quality and sustainability are rapidly deteriorating.

Different land use systems influence availability of micronutrients by altering their distribution and including a changes in their chemical forms by influencing soil pH organic matter, clay content and submergence (Doran and Gregorich, 2002). Hargrove *et al.* (1982) reported greater accumulation of Mn and Zn in the surface layers with undisturbed system (no tillage) compared to conventional cultivated system. Rattan *et al.* (1999) in a long-term experiment on organic soil system and conventional system under intensive rice-wheat cropping system reported higher levels of available Zn (6.00 mg kg^{-1}), Cu (2.33 mg kg^{-1}), Fe (30.70 mg kg^{-1}) and Mn (29.10 mg kg^{-1}) in organic system as compared with amount of Zn (3.90 mg kg^{-1}), Cu (1.42 mg kg^{-1}), Fe (2.30 mg kg^{-1}) and Mn (25.0 mg kg^{-1}) in conventional system and these observations were supported by Bhardwaj and Omanwar (1994) and Bellakki and Badanur (1997). Singh and Tilak (1998) in different organic systems observed higher amounts of available Zn, Mn and Cu (237, 231 and 112.4 mg kg^{-1} respectively) from the system prepared with the addition of organic slurry. Katyal and Sharma (1991) reported available and total Zn, Cu, Fe and Mn in 57 benchmark soils of India classified under different soil orders and it was observed that available Zn declined with rise in pH, lime content and fall in organic matter and lime content whereas, the available Cu increased with increase in OM and clay content. It has been further reported that total content of Zn, Cu, Fe and Mn increased with increase in lime and clay content. Sharma *et al.* (1992) investigated profile distribution of available and total Zn, Cu, Fe and Mn on three physiographic zones of Punjab and reported that the available and total content of micronutrients were the highest in soils of alluvial terraces followed by soils of interdunal areas and sand dunes. Irrespective of physiographic zone, the soil did not show any pattern of depth distribution of available Zn, Cu, Fe and Mn whereas, the total Zn and Mn showed accumulation in B-horizon.

A lot of work is done on macronutrient status of soils, but very little attention is so far paid to micronutrients in relation to soil quality and sustainability with particular reference to different land use systems under different watersheds. A detailed investigation of the processes leading to delineation of available and total Zn, Cu, Fe and Mn can help in finding ways and means to achieve sustainable high production levels in the region. Little attention has so far been paid to monitor the quality of soil under different land use systems existing in this region. Thus it becomes difficult to interpret effects of management practices on available and total Zn, Cu, Fe and Mn status of surface and profile soils. Keeping in view that several distinct land use systems exist in the region, the present investigation was carried out with the objective to study the effect of different land use systems on the distribution of available and total Zn, Cu, Fe and Mn in surface as well as profile of rainfed soils and to investigate soil quality and sustainability of different land use systems lying in the 'Kandi' area of Punjab.

Materials and Methods

Micronutrient status in different types of land use systems was studied in Nawanshahar district of Punjab, India. The study area was located near Punjab Agricultural University, Zonal Research Station for Kandi area (Zone-1), Ballowal-Saunkhari. The selected watersheds were located at 76°23′42′′E and 31°6′24′′N with height of 360 meter above mean sea level. Four watersheds namely Ballowal Saunkhari Watershed (BSW), Kular Watershed (KW), Sadh Di Khad Watershed (SDKW) and Takarala Watershed (TW) were selected for this investigation. Four land use systems were identified in each of the four watersheds selected in the Kandi area were: cultivated land use system (CS), undisturbed land use system (US), pasture land use system (PS) and forest land use system (FS).

The major soils of Kandi area are loamy sand to sandy loam with low to medium water holding capacity. The soils are mostly non-saline with pH varying from 7.5-8.0. Soils are very deep with no root-restricting layer. Crop lands (CS) are characterized by addition of chemical fertilizers and farm yard manure whereas, forest lands (FS) are characterized by regular addition of organic matter from leguminous tree species of *subabul* (*Leucaena leucocephala*), *kikker* (*Acacia catechu*), *kair* (*Acacia catechu* Wild) and *tahli* (*Dalbergia sissoo*) existing in the watershed. On the other hand pasture (PS) and undisturbed (US) lands are characterized by poor grass stands (except Kular watershed). Also, these land use systems are located on highly degraded site of the watersheds where erosion is a severe problem. The physico-chemical properties of different watersheds (BSW, SDKW, KW and TW) are presented in Table 1. Both the BSW and TW watersheds had higher clay (18.60 to 23.80 and 15.90 to 20.60%, respectively), higher organic matter (0.16 to 0.41 and 0.20 to 0.52%, respectively) and more cation exchange capacity (11.80 to 15.20 and 9.70 to 13.60 Cmol kg^{-1} soil, respectively), with the result these land use systems are associated with rich concentrations of available and total Zn, Cu, Fe and Mn. The physico-chemical properties of CS, PS, US and FS under different watersheds are given in Table 2. Both CS and FS in BSW, SDKW and TW and PS and FS in KW reported higher clay content of organic matter as these land use systems are located on small slopes compared with other systems.

Soil samples (0-15 cm depth) were collected from each spot. 10 to 15 randomly selected soil samples were taken under each land use system in each watershed. Profile samples were also collected from one spot in each land use system. These surface as well as profile samples were analyzed for available Zn, Cu, Fe and Mn content as described by Lindsay and Norvell (1978) whereas, the total content of Zn, Cu, Fe and Mn was determined with the method described by Page *et al.* (1982).

To assess the soil quality and sustainability of the selected land use systems contents of available Zn, Cu, Fe and Mn were used. The absolute values of each soil quality parameters were converted into the indicator values (Gomez *et al.*, 1996). The indicator value of each soil quality parameter for particular land use system indicated their individual contribution of particular soil attribute towards the sustainability of particular land use system. Then an average value of all the soil quality parameters was calculated individually for Zn, Cu, Fe and Mn parameters by taking an arithmetic average of all parameters in each land use system. Each value was individually divided by average value. A higher magnitude after division indicated an important role played by particular soil quality parameter in enhancing the sustainability of land use system. A value of one or more than one of these averages represents a positive contribution towards sustainability of land use system. Whereas, an average value less than one indicates its role in reducing the sustainability of a particular land use system.

Results and Discussion

Surface and profile distribution of available Zn, Cu, Fe and Mn

The surface distribution of Zn, Cu, Fe and Mn is affected by many factors like clay and organic matter content in different land use systems. The data presented in Table 3 clearly evinced that in BSW significantly higher levels of available Zn, Cu, Fe and Mn were observed in FS and CS as compared to in PS and US. In the FS organic carbon was significantly correlated with available Zn (0.47**), available Fe (0.66**) and available Mn (0.67**), respectively. In KW significant coefficients of correlation between available Zn and OC (0.37*) and available Mn and OC (0.57**) were observed in PS. In fact, in KW these land use systems existed on highly eroded and degraded site of the watershed. The results pertaining to available Zn, Cu, Fe and Mn showed that FS and PS possess better soil quality compared to CS and US. In SDKW significant coefficients of correlation of organic carbon were observed with available Zn (0.48**), available Mn (0.67**) and available Fe (0.66**) in FS, respectively. The results pertaining to available micronutrients revealed that soils in FS and CS were better and more sustainable, whereas, soils in PS and US were less sustainable. In TW Significant coefficients of correlation of organic carbon with available Zn (0.47**), available Fe (0.66**) and available Mn (0.62**) were observed in FS. The various results regarding trend of available Zn, Cu, Fe and Mn distribution in surface soils of different land use systems was reported. BSW: CS > FS > PS > US, KW: PS > FS > US > CS, SDKW: CS > FS > US > PS and TW: CS > FS > US > FS. The results related to available micronutrient status revealed that soils in FS and CS were of better quality as compared to other two land use systems (US and PS). These results are in agreement with those obtained by Franzluebbers and Hons (1996), Reeves (1997), Bellaki and Badanur (1997), and Rattan *et al.* (1999).

The profiles of four land use systems in different watersheds did not show any regular trend with respect to distribution of available micronutrients. In BSW, C_3 depth in CS (68-100 cm), US (75-100 cm) and FS (51-73 cm) and C_5 depth in PS (90-112 cm) and FS (90-112 cm) possessed higher levels of available micronutrients (Table 4) whereas, in KW, C_3 depth in CS (68-95 cm), US (51-75 cm) and FS (38-61 cm) and C_5 depth in CS (117-136 cm) and FS (79-104 cm) possess higher levels of available micronutrients (Table 5). In SDKW C_4 depth in CS (112-135 cm) and PS (82-108 cm), C_4 depth in US (45-69 cm) and PS (82-108 cm) and CS (112-135 cm) possessed higher levels of available micronutrients (Table 6). On the other hand, in TW, C_4 depth in CS (64-93 cm) and FS (102-119 cm), C_3 depth in US (89-98 cm) and PS (48-78 cm) possessed higher levels of available micronutrients (Table 7). These higher levels of available Zn, Cu, Fe and Mn in profiles of different land use systems were associated with higher content of clay and organic matter (Table 2). The CS and FS in BSW have higher levels micronutrients followed by PS and US. In KW lower levels of available Zn, Cu, Fe and Mn were reported because CS is practiced on relatively sandy texture soils located on terrace land, which is under severe water erosion. Both US and FS in SDKW showed low values of micronutrients due to undulating topographical constraints and poor management. Both FS and US in TW have their existence on leveled lands whereas, the other two systems were located on undulating topography. These higher levels of available Zn, Cu, Fe and Mn in BSW, KW, and TW were associated with higher level of clay content and regular addition organic matter (Table 1). These observations are similar to those reported by Carter and Rennie (1982), Sharma *et al.* (1992), Reganold and Palmer (1995), Sharma *et al.* (1999), Stockfisch *et al.* (1999) and Sawhney *et al.* (2000).

Surface and profile distribution of total Zn, Cu, Fe and Mn

In BSW the effect of different land use systems on total Zn, Cu, Fe and Mn content and their distribution in surface soils evinced that in this watershed significantly higher levels of total Zn, Cu, Fe and Mn were observed in FS and CS as compared to those in PS and US (Table 3). The total micronutrient content in FS and CS was correlated with clay content and organic carbon. On the basis of total micronutrient content of soils, it is observed that soils in FS and CS had higher content compared with PS and US and soil are of better quality and these results are supported by Bellaki and Badanur (1997), Rattan *et al.* (1999), Carter and Rennie (1982), Sharma *et al.* (1992), Reganold and Palmer (1995), Sharma *et al.* (1999), Stockfisch *et al.* (1999) and Sawhney *et al.* (2000). In KW the total content of Zn, Cu, Fe and Mn and their distribution in surface soils showed that both FS and PS had significantly higher levels of total Zn, Cu, Fe and Mn compared with CS and US. In this watershed both CS and US had lower levels of total Zn, Cu, Fe and Mn, which is attributed to their existence (Table 3) in KW on highly eroded and degraded site of the watershed. The higher content of total Zn, Cu, Fe and Mn in FS and PS were associated with clay and organic mater and these results were supported by Reeves (1997), Bellaki and Badanur (1997) and Rattan *et al.* (1999). In SDKW the total Zn, Cu, Fe and Mn content in surface and (0-15 cm) layer revealed that FS and CS in this watershed possessed significantly higher levels of total Zn, Cu, Fe and Mn compared with PS and US. Both PS and US have lower levels of total micronutrients because, these land use systems existed on highly eroded and degraded site of the watershed. Similar observations were reported by Franzluebbers and Hons (1996) and Rattan *et al.* (1999). In TW the effect of different land use systems on total Zn, Cu Fe and Mn content and their distribution in surface soils revealed that both FS and CS in this watershed possessed significantly higher levels of total Zn, Cu, Fe and Mn (Table 3) compared with PS and US. The micronutrient status of PS and US was low because of their existence on highly eroded and degraded site of the watershed. These observations were similar to that reported by Bellaki and Badanur (1997) and Rattan *et al.* (1999). The overall trend of total micronutrients in surface soils of different land use systems under four watersheds showed similar trend for profiles as reported. BSW: CS > FS > PS > US, KW: PS > FS > US > CS, SDKW: CS > FS > US >PS and TW: CS > FS > US > FS.

In profiles of different land use systems in BSW the content of total micronutrients increased with depth in some layers, but it did not show any regular distribution. The data showed that C_3 layer in CS (68-100 cm), US (75-100 cm) and FS (51-73 cm), C_4 layer in CS (100-123 cm), and C_5 in PS (90-112 cm) and FS (90-112 cm) possess the highest levels of total micronutrients at different depths (Table 4). The total Zn, Cu, Fe and Mn content in different land use systems in KW (Table 5) revealed that profiles of FS and PS have higher levels micronutrients followed by CS and CS. In fact in KW, C_3 layer in CS (68-95 cm), US (51-75 cm) and FS (38-61 cm), C_4 layer in CS (68-95 cm), PS (90-111) and FS (61-79 cm), and C_5 layer in CS (117-136 cm) and FS (79-104 cm) possessed higher levels of total micronutrients. The low content in this watershed is attributed that cultivation in this watershed is practiced on relatively sandy texture soils located on terrace

Table 1. Range of basic soil properties of different watersheds in Kandi region of Punjab

Parameter	Watershed			
	BSW (*15)	KW (*15)	SDKW (*15)	TW (*15)
Sand (%)	56.10-64.60	68.90-80.40	65.90-80.10	62.10-68.00
Silt (%)	16.80-20.20	11.60-16.80	11.10-19.40	13.80-20.40
Clay (%)	18.60-23.80	9.10-14.30	8.80-14.70	15.90-20.60
pH (1:2)	7.63-7.86	7.70-8.15	7.78-7.82	7.64-7.95
EC (dS m^{-1})	0.14-0.24	0.10-0.22	0.11-0.18	0.19-0.26
Organic carbon (%)	0.16-0.41	0.08-0.26	0.04-0.38	0.20-0.52
$CaCO_3$ (%)	2.15-2.25	1.57-2.15	1.56-2.45	2.15-2.60
CEC (Cmol kg^{-1})	11.80-15.20	8.50-8.70	8.20-8.80	9.70-13.60

Ballowal: Saunkhari Watershed, KW: Kular Watershed, SDKW: Sadh Di Khad Watershed: TW: Takarala Watershed, *Number of surface samples analyzed.

Table 2. Range of some basic soil properties in four land use systems

Indicators	Land use systems			
	CS (*15)	US (*15)	PS (*15)	FS (*15)
BSW				
Sand (%)	55.6-66.8	69.6-70.2	68.9-71.8	56.9-68.9
Silt (%)	16.6-21.6	11.3-12.5	12.5-13.8	16.8-18.9
Clay (%)	19.6-22.8	16.8-18.9	15.8-16.9	19.8-21.6
pH (1:2)	7.65-7.86	7.65-7.72	7.68-7.78	7.65-7.69
EC (dS m^{-1})	0.12-0.24	0.14-0.16	0.15-0.16	0.15-0.16
Organic carbon (%)	0.28-0.45	0.15-0.29	0.16-0.25	0.35-0.46
KW				
Sand (%)	56.5-64.6	64.6-68.3	54.6-67.5	55.8-58.9
Silt (%)	16.8-18.7	10.3-13.4	16.8-18.6	15.8-16.7
Clay (%)	18.9-20.6	15.6-18.6	18.9-19.8	18.9-22.5
pH (1:2)	7.50-7.68	7.56-7.72	7.64-7.89	7.64-7.68
EC (dS m^{-1})	.016-0.26	0.13-0.15	015-0.18	0.16-0.19
Organic carbon (%)	0.26-0.42	0.15-0.28	0.29-0.44	0.36-0.44
SDKW				
Sand (%)	54.8-55.9	69.9-71.2	68.8-70.2	58.9-59.6
Silt (%)	15.8-18.6	11.5-13.8	12.8-16.8	15.9-16.8
Clay (%)	19.4-21.6	16.8-17.9	15.3-17.6	18.9-21.8
pH (1:2)	7.56-7.62	7.64-7.66	7.65-7.69	7.56-7.65
EC (dS m^{-1})	0.13-0.16	0.15-0.16	0.14-0.19	0.13-0.22
Organic carbon (%)	0.32-0.46	0.16-0.19	0.17-0.25	0.36-0.45
TW				
Sand (%)	56.8-59.8	68.6-72.8	68.6-70.8	55.9-57.8
Silt (%)	15.6-18.9	12.6-14.8	11.9-14.9	15.8-16.7
Clay (%)	18.4-19.8	15.9-18.9	14.9-16.8	18.9-19.5
pH (1:2)	7.64-7.68	7.66-7.0	7.65-7.66	7.42-7.58
EC (dS m^{-1})	0.13-0.19	0.16-0.19	0.16-0.19	0.15-0.18
Organic carbon (%)	0.29-0.41	0.12-0.18	0.15-0.19	0.38-0.45

CS- Cultivated land use system, US- Undisturbed land use system, PS- Pasture land use system, FS- Forest land use system, *Number of soil samples analyzed.

land, which is under severe water erosion. Also the clay content and organic matter of these soils is less as compared to BSW and TW (Table 1). Carter and Rennie (1982), Sparling (1992) Sawhney *et al.* (1992), Patriquin *et al.* (1993), Stockfisch *et al.* (1999) and Maddonni *et al.* (1999) also reported similar observations. In SDKW, C_4 layer in CS (112-135 cm), C2 layer in US (45-69 cm), C_4 layer in PS (82-108 cm) and C_3 layer in FS possessed higher levels of micronutrients (Table 6). In this watershed (SKDW), both FS and CS showed edge of total micronutrients over PS and US as FS and CS have their existence on leveled lands whereas, the other two systems are located on undulating topography. In TW total micronutrients content is associated with C_3 (US and PS), C_4 (CS and FS) and C_5 (CS) depths under various land use systems (Table 7). These higher levels of total Zn, Cu, Fe and Mn were associated with higher level of clay content in profile and regular addition organic matter at the surface (CS and FS). Similar observations were reported by Carter and Rennie (1982), Reganold and Palmer (1995), Sharma *et al.* (1999), Stockfisch *et al.* (1999) and Maddonni *et al.* (1999).

Sustainability of land use systems

The data presented in Table 8 show that among micronutrient indicators of soil quality, highest average index was observed in FS (1.20) compared with CS (1.19) indicating that these land use systems are more sustainable with respect to micronutrient

Table 3. Available and total micronutrient status of four land use systems in four watersheds

Indicators	BSW				KW			
	CS	US	PS	FS	CS	US	PS	FS
Available Zn (mg kg^{-1})	0.84	0.58	0.64	0.96	0.62	0.67	0.88	0.86
Available Cu (mg kg^{-1})	0.58	0.36	0.40	0.56	0.28	0.28	0.52	0.54
Available Fe (mg kg^{-1})	9.36	6.56	7.42	9.40	7.42	7.56	9.24	9.64
Available Mn (mg kg^{-1})	12.96	7.80	8.36	11.80	8.68	8.92	10.24	10.42
Total Zn (mg kg^{-1})	89.7	75.3	74.5	82.6	70.6	74.5	92.8	86.4
Total Cu (mg kg^{-1})	27.6	22.9	24.5	26.7	26.5	29.3	25.4	26.4
Total Fe (%)	3.42	2.56	2.64	3.62	2.42	2.30	3.28	3.48
Total Mn (mg kg^{-1})	695	572	586	684	564	592	685	694
	SDKW				TW			
Available Zn (mg kg^{-1})	1.20	0.92	0.68	1.12	0.98	0.58	0.48	0.86
Available Cu (mg kg^{-1})	0.56	0.42	0.34	0.48	0.42	0.38	0.36	0.38
Available Fe (mg kg^{-1})	9.78	7.96	7.36	8.92	9.42	8.50	7.78	8.42
Available Mn (mg kg^{-1})	9.46	7.60	7.92	9.10	8.72	8.56	7.98	8.46
Total Zn (mg kg^{-1})	88.6	72.4	65.4	77.6	78.6	64.7	63.7	80.4
Total Cu (mg kg^{-1})	27.8	24.3	22.8	25.8	25.4	18.7	17.8	25.9
Total Fe (%)	3.27	2.96	2.63	3.42	3.19	2.32	2.18	3.12
Total Mn (mg kg^{-1})	681	634	548	667	698	536	534	669

CS: Cultivated land use system, US: Undisturbed land use system, PS: Pasture land use system, FS: Forest land use system *Number of soil samples analysed.

Table 4. Soil quality indicators inprofile underdifferentland use system in Ballowal - Saunkhari Watershed

	CS						US					
Horizon depth (cm)	0-23	23-40	40-68	68-100	100-123	–	0-18	18-40	40-75	75-110	110-134	–
Horizon designation	A1	C1	C2	C3	C4	–	A1	C1	C2	C3	C4	–
Available Zn (mg kg^{-1})	0.68	0.40	0.34	0.36	0.32	–	0.54	0.28	0.26	0.40	0.28	–
Available Cu (mg kg^{-1})	0.34	0.28	0.18	0.24	0.16	–	0.26	0.20	0.14	0.18	0.12	–
Available Fe (mg kg^{-1})	8.86	9.72	8.36	7.80	7.72	–	6.80	6.60	7.62	6.80	5.66	–
Available Mn (mg kg^{-1})	9.96	9.18	7.36	9.34	9.10	–	8.52	7.90	8.68	7.92	4.76	–
Total Zn (mg kg^{-1})	70.8	72.6	54.0	96.6	74.2	–	64.5	42.6	52.7	60.6	52.3	–
Total Cu (mg kg^{-1})	16.8	20.6	18.6	26.8	24.2	–	22.4	52.4	14.6	18.2	10.2	–
Total Fe (%)	2.46	2.98	2.14	2.95	2.62	–	1.62	1.42	1.46	1.78	1.67	–
Total Mn (mg kg^{-1})	696	741	652	818	754	–	576	584	662	784	746	–
	PS						FS					
Horizon depth (cm)	0-14	14-38	38-51	51-73	73-90	90-112	0-14	14-38	38-51	51-73	73-90	90-112
Horizon designation	A1	C1	C2	C3	C4	C5	A1	C1	C2	C3	C4	C5
Available Zn (mg kg^{-1})	0.62	0.38	0.34	0.23	030	0.34	1.10	0.66	0.59	0.64	0.36	0.45
Available Cu (mg kg^{-1})	0.28	0.20	0.18	0.12	0.13	0.14	0.38	0.20	0.20	028	0.13	0.18
Available Fe (%)	7.36	6.92	7.10	6.62	6.42	6.86	9.53	6.46	4.88	5.98	4.15	5.81
Available Mn (mg kg^{-1})	8.24	7.30	7.86	6.25	6.90	7.68	11.96	8.90	7.84	7.98	6.12	6.33
Total Zn (mg kg^{-1})	76.4	50.0	47.6	37.8	48.0	54.2	86.0	75.4	92.4	94.3	58.5	66.3
Total Cu (mg kg^{-1})	20.6	14.8	10.8	12.1	8.7	10.4	28.4	22.3	32.6	40.3	20.6	22.7
Total Fe (%)	1.58	1.46	1.34	1.62	1.47	1.96	3.52	22.6	2.62	2.96	2.10	2.72
Total Mn (mg kg^{-1})	595	656	586	463	567	610	691	700	828	854	750	838

Table 5. Soil quality indicators in profile underdifferent land use system in Kular Watershed

	CS						US					
Horizon depth (cm)	0-25	25-55	55-68	68-95	95-11	117-136	0-15	15-28	28-51	51-75	75-116	
Horizon designation	A1	C1	C2	C3	C4	C5	A1	C1	C2	C3	C4	–
Available Zn (mg kg^{-1})	0.60	0.38	0.32	0.44	0.22	0.30	0.64	0.30	0.18	0.27	0.14	–
Available Cu (mg kg^{-1})	0.26	0.28	0.18	0.20	0.12	0.16	0.30	0.18	0.16	0.18	0.12	–
Available Fe (mg kg^{-1})	7.56	5.60	5.82	5.30	5.32	5.64	6.72	5.86	4.46	5.10	4.80	–
Available Mn (mg kg^{-1})	8.42	7.86	6.90	4.36	4.76	4.82	8.92	9.70	8.14	10.12	6.10	–
Total Zn (mg kg^{-1})	66.5	58.4	72.5	63.8	70.6	68.4	71.6	54.3	86.2	104.2	88.6	–
Total Cu (mg kg^{-1})	25.3	14.0	22.0	18.4	18.6	22.8	23.4	18.3	22.6	28.6	20.5	–
Total Fe (%)	2.30	2.46	2.62	2.28	2.52	3.10	2.03	2.16	2.62	2.76	2.48	–
Total Mn (mg kg^{-1})	536	625	743	715	736	875	578	547	694	726	593	–
	PS						FS					
Horizon depth (cm)	0-8	8-20	20-50	50-90	90-11	–	0-7	7-23	23-38	38-61	61-79	79-104
Horizon designation	A1	C1	C2	C3	C4	–	A1	C1	C2	C3	C4	C5
Available Zn (mg kg^{-1})	0.78	0.64	0.48	0.26	0.28	–	0.92	0.84	0.64	0.72	0.46	0.34
Available Cu (mg kg^{-1})	0.48	0.24	0.22	0.18	0.24	–	0.64	0.68	0.40	0.38	0.28	0.22
Available Fe (mg kg^{-1})	8.92	7.36	8.52	6.16	7.14	–	9.48	8.10	6.42	7.45	6.20	5.86
Available Mn (mg kg^{-1})	10.06	10.42	11.16	8.27	9.82	–	10.18	11.86	10.80	11.35	9.32	8.14
Total Zn (mg kg^{-1})	86.9	68.4	40.6	71.8	84.3	–	86.4	72.3	76.8	80.1	70.3	52.8
Total Cu (mg kg^{-1})	23.6	22.5	18.7	23.8	24.7	–	27.3	18.9	13.6	17.8	16.5	13.6
Total Fe (%)	3.42	3.50	2.94	3.76	3.81	–	3.49	2.84	2.95	3.10	3.36	2.86
Total Mn (mg kg^{-1})	665	736	676	718	758	–	693	676	600	755	725	622

availability in BSW. The lowest micronutrient availability index values in the same watershed in PS (0.78) and US (0.80) indicate these land use systems are not sustainable as sustainability index (SI) is less than one (SI <1) whereas, in KW the highest average index was shown by FS (1.14) compared with PS (1.11) among chemical indicators of soil quality. This indicates that these land use systems are more sustainable with respect to micronutrient availability. Whereas, the micronutrient availability index values were lower in US (0.83) and CS (0.82). On the other hand, in SDKW, CS showed the highest sustainability index (1.18) based on indicator of the quality as well. FS recorded a value of 1.08 amongst different indicators of soil quality. The data presented in Table 7 revealed that in TW the highest average index value based on micronutrient indicators of soil quality was higher for CS (1.15) followed by FS (1.05). On the other hand, PS (0.87) and US (0.96) land use systems showed average index values less than unity. Similar trend of index values was observed for second sampling. Index value >1 recorded for cultivated and FS indicated that the systems are sustainable in TW. Values less than 1, as observed in PS and US indicated that these systems are not sustainable. These sustainability index values were supported by Gomez *et al.* (1996) and Lal (1998).

The overall sustainability indices of land use systems under different watersheds were also compared (Table 8). Some of the land use systems in different watersheds were sustainable (S*) whereas, others were non-sustainable (NS**). The data showed that FS (S*) and CS (S*) were sustainable in BSW, SDKW and TW, whereas PS (S*) and FS (S*) were sustainable KW. Other land use systems were non sustainable (NS**) in the respective watershed. Similar observations that FS was more sustainable than CS followed by PS and US were reported by Lal (1989), Gomez *et al.* (1996), Karlen *et al.* (1997) and Campbell *et al.* (1998)

Distinct land use systems exist under different watersheds in Kandi region of Punjab. CS and FS in the BSW, SDKW and TW had significantly higher levels of available and total Zn, Cu, Fe and Mn compared with PS and US. The higher levels of Zn, Cu, Fe and Mn in CS were due to addition of fertilizers and farm yard manure whereas, higher levels of micronutrients in FS were

Table 6. Soil quality indicators in profile under different land use system in Sadh Di Khad Watershed

	CS					US					
Horizon depth (cm)	0-16	16-41	41-74	74-11	112-13	0-19	19-45	45-69	69-99	99-120	120-135
Horizon designation	A1	C1	C2	C3	C4	A1	C1	C2	C3	C4	C5
Available Zn (mg kg^{-1})	1.14	0.68	0.24	0.28	0.36	0.96	0.42	0.36	0.52	0.56	0.36
Available Cu (mg kg^{-1})	0.48	0.26	0.20	0.12	0.12	0.28	0.22	0.18	0.22	0.20	0.12
Available Fe (mg kg^{-1})	9.86	7.14	4.72	5.10	6.84	7.84	7.10	6.12	5.80	5.10	5.72
Available Mn (mg kg^{-1})	9.30	10.64	8.42	8.16	8.96	7.56	7.36	7.84	4.30	4.38	5.76
Total Zn (mg kg^{-1})	84.5	62.6	64.8	87.3	98.4	80.3	64.1	100.5	84.5	86.3	98.5
Total Cu (mg kg^{-1})	29.8	20.4	16.3	22.4	31.8	25.6	19.3	31.4	22.6	16.1	24.8
Total Fe (%)	3.48	3.40	3.12	3.46	3.88	3.12	3.25	3.73	3.19	3.54	3.76
Total Mn (mg kg^{-1})	698	742	756	814	894	685	672	844	736	764	792
	PS					FS					
Horizon depth (cm)	0-23	23-44	44-56	56-82	82-108	0-10	10-30	30-61	61-76	76-114	114-137
Horizon designation	A1	C1	C2	C3	C4	A1	C1	C2	C3	C4	C5
Available Zn (mg kg^{-1})	0.72	0.38	0.56	0.42	0.54	1.22	0.84	0.40	0.48	0.34	0.34
Available Cu (mg kg^{-1})	0.34	0.22	0.18	0.16	0.20	0.48	0.22	0.24	0.31	0.18	0.12
Available Fe (mg kg^{-1})	7.86	5.60	6.14	5.20	5.78	9.38	8.10	6.12	7.68	6.64	5.86
Available Mn (mg kg^{-1})	8.06	9.86	10.92	7.60	8.92	10.16	9.80	10.00	11.50	9.30	8.86
Total Zn (mg kg^{-1})	67.3	76.5	94.5	76.1	86.4	81.5	50.3	78.5	88.6	56.5	44.3
Total Cu (mg kg^{-1})	24.9	16.8	21.6	13.8	10.9	26.1	22.3	18.3	22.1	16.5	19.5
Total Fe (%)	2.96	3.58	3.74	3.37	3.67	3.56	2.96	2.76	3.74	2.35	2.76
Total Mn (mg kg^{-1})	557	672	716	615	735	675	604	715	826	714	663

Table 7. Soil quality indicators inprofile under different land use system in Takarala Watershed

	CS						US				
Horizon depth (cm)	0-14	14-34	34-48	48-64	64-93	93-115	0-26	26-55	55-89	89-98	98-118
Horizon designation	A1	C1	C2	C3	C4	C5	A1	C1	C2	C3	C4
Available Zn (mg kg^{-1})	1.16	0.72	0.58	0.52	0.46	0.40	0.60	0.38	0.30	0.38	0.24
Available Cu (mg kg^{-1})	0.46	0.18	0.18	0.22	0.16	0.18	0.36	0.18	0.16	0.22	0.12
Available Fe (mg kg^{-1})	9.56	7.36	5.38	6.21	5.43	6.10	8.56	5.42	5.28	6.56	5.48
Available Mn (mg kg^{-1})	8.60	10.60	10.84	7.96	8.66	8.95	8.76	9.72	6.12	7.68	6.32
Total Zn (mg kg^{-1})	79.6	54.5	64.8	60.3	63.8	66.6	72.5	64.6	40.3	44.4	38.2
Total Cu (mg kg^{-1})	28.0	25.3	22.2	16.4	30.1	12.9	20.5	24.6	18.5	23.6	25.7
Total Fe (%)	3.25	2.98	2.76	2.42	3.00	3.64	2.38	2.46	2.30	2.96	2.18
Total Mn (mg kg^{-1})	705	584	566	552	612	719	536	686	638	678	588
	PS						FS				
Horizon depth (cm)	0-20	20-36	36-48	48-78	78-10	106-13	0-20	20-40	40-67	67-10	102-11
Horizon designation	A1	C1	C2	C3	C4	C5	A1	C1	C2	C3	C4
Available Zn (mg kg^{-1})	0.48	0.20	0.34	0.28	0.16	0.24	0.92	0.84	0.62	0.68	0.72
Available Cu (mg kg^{-1})	0.38	0.24	0.28	0.18	0.16	0.12	0.36	0.30	0.18	0.12	0.16
Available Fe (mg kg^{-1})	8.14	7.16	6.42	5.80	5.61	6.49	8.56	5.72	6.10	6.40	6.96
Available Mn (mg kg^{-1})	8.10	7.42	7.36	6.82	6.41	6.86	8.34	7.41	6.84	7.72	7.76
Total Zn (mg kg^{-1})	64.6	44.3	40.3	38.6	34.5	38.9	92.8	65.3	54.8	63.6	70.3
Total Cu (mg kg^{-1})	18.6	20.5	16.3	13.7	12.8	17.5	265.3	22.6	18.5	12.6	118
Total Fe (%)	2.14	1.72	1.63	1.53	1.42	1.47	3.16	2.98	2.08	2.95	3.38
Total Mn (mg kg^{-1})	538	593	637	764	572	614	684	710	590	628	674

Table 8. Indicator values of sustainability under different land use systems in four land use systems in four watersheds

Indicators	CS	US	PS	FS	CS	US	PS	FS
	BSW				KW			
Available zinc (mg kg^{-1})	1.09	0.76	0.84	1.26	0.81	0.88	1.15	1.13
Available copper (mg kg^{-1})	1.26	0.78	0.87	1.22	0.62	0.62	1.15	1.20
Available iron (mg kg^{-1})	1.14	0.80	0.91	1.15	0.86	0.88	1.08	1.12
Available manganese (mg kg^{-1})	1.27	0.76	0.82	1.16	0.99	0.94	1.08	1.10
Overall indicator value	1.19	0.78	0.86	1.20	0.82	0.83	1.11	1.14
Sustainability	S	NS	NS	S	NS	NS	S	S
	SDKW				TW			
Available zinc (mg kg^{-1})	1.21	0.93	0.69	1.13	1.31	0.78	0.64	1.16
Available copper (mg kg^{-1})	1.26	0.94	0.76	1.08	1.14	1.03	0.97	1.03
Available iron (mg kg^{-1})	1.15	0.94	0.87	1.04	1.10	1.00	0.91	0.99
Available manganese (mg kg^{-1})	1.12	0.90	0.93	1.07	1.04	1.02	0.95	1.01
Overall indicator value	1.18	0.93	0.81	1.08	1.15	0.96	0.87	1.05
Sustainability	S	NS	NS	S	S	NS	NS	S

S- Sustainable, NS- Non-sustainable.

due to the regular addition of organic matter in the form of leaf litter. In BSW, SDKW and TW, PS and US exhibited low magnitude of soil quality indicators and thus were not sustainable. Similarly, based on soil samples drawn from profiles of CS and FS in BSW, KW and TW showed higher levels of Zn, Cu, Fe and Mn compared with US and PS. Higher levels of soil quality parameters in profile were associated with higher contents of clay and organic matter. The magnitude of soil quality parameters decreased with depth in all the land use systems falling under different watersheds. The increases of available and total Zn, Cu, Fe and Mn in some layers in profile were associated with clay and organic matter. Sustainability indices worked out for micronutrients indicators, were found to be more than unity in case of forest and cultivated land use systems lying under BSW, SDKW and TW, thereby proving that these systems are sustainable under soil and climatic conditions of 'Kandi' area of Punjab.

References

Bellakki, M.A. and Badanur, V.P. 1997. Long-term effect of integrated nutrient management on properties of vertisol under dry land agriculture. *Journal Indian Society of Soil Science* 45: 438-442.

Bhadraray, S., Rao, Y.S., Ahmed, N. and Dutt, O.M. 1999. Available nutrient status of a Typic Ustochrept as influenced by two irrigated and rainfed tropical agro-silvicultural plantations. *Indian Journal of Agrilcultural Sciences* 69(8): 555-559.

Bhardwaj, V. and Omanwar, P.K. 1994. Long-term effects of continuous rotational cropping and fertilization on crop yield and soil properties-II. Effects on EC, pH, organic matter and available nutrients of soil. *Journal Indian Society of Soil Science* 42: 387-392.

Campbell, C.A., McConkey, B.G., Biederbeck, V.O., Zentner, R.P., Curtin, D. and Peru, M.R. 1998. Long-term effects of tillage and fallow-frequency on soil quality attributes in a clay soil in semiarid southeastern Saskatchewan. *Soil and Tillage Research* 46: 135-144.

Carter, M.R. and Rennie, D.A. 1982. Changes in soil quality under zero tillage farming systems: Distribution of microbial biomass and mineralizable C and N potentials. *Canadian Journal of Soil Science* 62: 587-597.

Doran, J.W. and Gregorich, E.G. 2002. Soil quality and sustainable agriculture. In *Encyclopedia of Soil Science* (Ed. R. Lal), pp. 42-78. Marcel Dekker, New York.

Franzluebbers, A.J. and Hons, F.M. 1996. Soil profile distribution of primary and secondary plant available nutrients under conventional and no-tillage. *Soil and Tillage Research* 39: 229-239.

Gomez, A.A., Kelly, D.E.S., Syers, J.K., Coughlan, K.J. and Doran, J.W. 1996. Measuring sustainability of agricultural systems at the farm level. In *Methods for Assessing Soil Quality* (Eds. J.W. Doran and A.J. Jones), pp. 401-410. Soil Science Society of America, Special Publication 49, Madison, Wisconsin, USA.

Hargrove, W.L., Touchton, J.T. and Gallaher, R.N. 1982. Effect of tillage practices on fertility status of an acid soil double-cropped to wheat and soyabean. *Agronomy Journal* 78: 684-687.

Horne, D.J., Ross, C.W. and Hughes, K.A. 1992. Ten years of maize – oats rotation under three tillage systems on a silt loam in New Zealand: I.A. comparison of some soil properties. *Soil and Tillage Research* 22: 131-143.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. and Schuman, G.E. 1997. Soil quality: A concept, definition and framework for evaluation. *Soil Science Society of America Journal* 61: 4-10.

Katyal, J.C. and Sharma, B.D. 1991. DTPA-extractable and total Zn, Cu, Mn and Fe in Indian Soils and their association with some soil properties. *Geoderma* 49: 165-179.

Lal, R. 1989. Conservation tillage for sustainable agriculture: Tropics versus temperate environments. *Advances in Agronomy* 42: 185-197.

Lindsay, W.L. and Norvel, W.A. 1978. Development of DTPA soil test for zinc, copper, iron and manganese. *Soil Science Society of America Journal* 42: 421-428.

Maddonni, G.A., Urricariet, S., Ghersa, C.M. and Lavado, R.S. 1999. Assessing soil quality in Rolling Pampa, using soil properties and maize characteristics. *Agronomy Journal* 91: 280-287.

Page, A.L., Miller, R.H. and Keeney, D.R. 1982. *Methods of Soil Analysis.* Part 2, 2nd edition. ASA, Madison, Wisconsin, USA.

Patriquin, D.G., Blaikie, H., Patriquin, M.J. and Yang, C. 1993. On-farm measurements of pH, electrical conductivity and nitrate in soil extracts for monitoring coupling and decoupling of nutrient cycles. *Biology and Agricultural Horticulture* 9: 231-272.

Prasad, B. and Sinha, M.K. 1981. The relative efficiency of zinc carriers on growth and zinc nutrition of corn. *Plant and Soil* 62: 45-52.

Prasad, B., Singh, A.P. and Sinha, M.K. 1984. Effect of poultry manure as a source of Zn, Fe and as complexing agent on Zn and Fe availability and crop yield in calcareous soil. *Journal Indian Society of Soil Science* 32: 519-521.

Rattan, R.K., Neelam-Saharan and Datta, S.P. 1999. Micronutrient depletion in Indian soils: Extent, causes and remedies. *Fertilizer News* 44(2): 35-40.

Reeves 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research* 43: 131-167.

Reganold, J.P. and Palmer, A.S. 1995. Significance of gravimetric versus volumetric measurements of soil quality under biodynamic, conventional and continuous grass management. *Journal of Soil and Water Conservation* 50(3): 298-305.

Rhoton, F.E. and Lindbo, D.L. 1997. A Soil depth approach to soil quality assessment. *Journal of Soil and Water Conservation* 52(1): 66-72.

Sawhney, J.S., Verma, V.K. and Jassal, H.S. 2000. Soil physiographic relationship in south-eastern sector of submontane tract of Punjab. *Agropedology* 10: 6-15.

Sawhney, J.S., Verma, V.K., Sharma, B.D. and Sharma, P.K. 1992. Pedogenesis in relation to physiography in semiarid and arid tract of Punjab, India. *Arid Soil Research and Rehabilitation* 6: 93-103.

Sharma, B.D., Sidhu, P.S. and Nayyar, V.K. 1992. Distribution of micronutrients in arid zone soils of Punjab and their relation with soil properties. *Arid Soil Research and Rehabilitation* 6: 233-242.

Sharma, B.D., Jassal, H.S., Sawhney, J.S. and Sidhu, P.S. 1999. Micronutrient distribution in different physiographic units of the Siwalik hills of the semi-arid tract of Punjab, India. *Arid Soil Research and Rehabilitation* 13: 1-12.

Singh, B., Singh, Y., Sadana, U.S. and Meelu, O.P. 1992. Effect of green manure, wheat straw and organic manures on DTPA extractable Fe, Mn, Zn and Cu in a calcareous sandy loam soil at field capacity and under waterlogged conditions. *Journal Indian Society of Soil Science* 40: 114-118.

Singh, G. and Tilak, K.U.B.S.R. 1998. Biological approach for secondary and micronutrients acquisition. *Fertilizer News* 43(10): 35-38.

Sparling, G.P. 1992. Ratio of microbial biomass to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Australian Journal of Soil Research* 30: 195-07.

Sparling, G.P., Shepherd, T.G. and Kettles, H.A. 1993. Changes in Soil Organic C, microbial C and aggregate stability under continuous maize and cereal cropping, and after restoration to pasture in soils from Manawatu region, New Zealand. *Soil and Tillage Research* 24: 225-241.

Stockfisch, N., Forstreuter, T. and Ehlers, W. 1999. Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. *Soil and Tillage Research* 52: 91-101.