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Impact of temporal change of land use and cropping system on some soil properties in northwestern parts of Indo-Gangetic Plain

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Soil series representing different physiographic units were studied to know the impact of temporal change in land use and cropping system on some soil properties in the northwestern parts of the Indo-Gangetic Plain. The dynamics in land use and cropping system for the period 1983–84, 1996–97 and 2007–2008 and change in soil properties for the period 1983 and 2008 were studied. In Singhpur soil series developed on Shiwalik hills, the soil organic carbon (SOC) content decreased from 0.69% in 1983 to 0.40% in 2008 on account of increased deforestation and soil erosion. However, no significant changes were observed in soil pH and electrical conductivity (EC). In Manjuwal (upper piedmont plain) and Mandiani series (lower piedmonts) slight changes in SOC, pH, EC and calcium carbonate were found. In Naura series (normal soils), occurring in the old flood plain, SOC content of surface soils increased to >1.0% in 2008 compared to 0.41% in 1983 because of shifting of cropping system of maize–wheat to high biomass-producing cropping system (rice–wheat, rice–potato/mustard/peas/sunflower) and addition of fertilizers under high management practices. The soil pH and EC decreased slightly during 1983 to 2008. Similar results were also observed in Bhaura series (salt-affected soils) and Bairsal series in recent flood plains. Thus, the land use and cropping system in less-intensive cultivated areas of Shiwalik hills and piedmonts do not have much influence on the soil properties. However, in intensively cultivated areas of old and recent flood plains, where high biomass-producing rice–wheat system replaced wheat–maize system, the soil properties had changed to a large extent.

Keywords: Land-use dynamics, physiographic units, rice–wheat cropping system, soil quality parameters.

IN the northwestern parts of the Indo-Gangetic Plains, maize–wheat and cotton–wheat cropping systems were prevalent before the green revolution. After the green revolution era, particularly during the last 3–4 decades (from 1980 to 2010) rice–wheat cropping system became dominant in this region. This system has become popular

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among the farmers because of high economic returns from high-yielding varieties of these crops[1]. In Punjab, the acreage under rice and wheat crops stands at 2.6 and 3.4 m ha respectively. Some studies have shown that continuous rotation of cereal–cereal (rice–wheat) cropping system has resulted in negative impacts in organic carbon (OC) content[2], while other studies have shown its positive impact on OC[3,4]. Cultivation of rice on light-textured soils in recent/active flood plains has resulted in lowering of the water table[5,6], creation of hard pan in the subsoils, increase in soil organic carbon (SOC)[7], and increase in selenium toxicity which adversely affects human as well as animal health[8, 9].

Soil erosion by seasonal streams (choes) in the northeastern parts of the district, especially Balachaur tehsil, low water-holding capacity in steeply sloping lands in the foothills of the Siwaliks, sandy soils of choes and recent/active flood plains[10,11], and small land-holding size are the other major problems in the area. This has been reflected in slow growth rate in the agriculture sector. However, these studies are mostly confined to one-time database (2007–2008) without considering the impact of temporal change of the cropping system on soil properties and/or soil quality parameters.

Keeping the above facts in mind, a case study of Shahid Bhagat Singh Nagar (SBS Nagar) (erstwhile Nawanshahr), representing an agriculturally important district of Punjab, India was undertaken to know the impact of the dynamics of cropping system on soil properties that is important for plant growth and soil health.

SBS Nagar is a newly formed district, carved out from Jalandhar and Hoshiarpur districts of Punjab. It came into existence as Nawanshahr district in 1995 and was later renamed as SBS Nagar district in 2008. It is located between 30°58′0″–31°17′0″N lat. and 75°47′20″–76°31′20″E long. and covers an area of 124,561 ha. It is a tract of undulating plain adjoining the Siwaliks in the northeast, old flood plain (old river terraces) in the central part and active flood plain (adjoining Sutlej River) in the south. SBS Nagar is surrounded by four districts, namely Jalandhar in the west, Roop Nagar (Ropar) in the east, Hoshiarpur in the north and Ludhiana in the south.

The district is broadly divided into seven physiographic divisions[12]: (i) Shiwalik hills, (ii) piedmont plain, (iii) old flood plain, (iv) old flood plain with channels/levees, (v) upper recent flood plains, (vi) lower recent flood plain, and (vii) active flood plain. General slope of the district is from northeast to southwest. The elevation ranges from 243 (lowest point near Beghowal village) to 540 m amsl (highest point near Sekhowal village). The northeastern area of the district forms a part of the Shiwalik system which has deposits of alluvial detritus derived from sub-aerial wastes of the middle and upper Himalaya. Geologists argue that these deposits belonged to the Pleistocene and Holocene periods[13]. There are several choes in the area which originate from the Shiwaliks. The piedmont plain formed by deposition of numerous seasonal streams is merged into the alluvial plain of the Sutluj in the south and southwest.

The climate of the district is tropical steppe, hot and semi-arid with severe summers and winters. In summer, mean maximum and mean minimum temperatures are 41° and 26°C respectively, while in winter the corresponding figures are 19°C and 6°C respectively. The mean annual air temperature is 23.3°C, and the difference between mean summer and mean winter temperature is more than 5°C. Hence, the district qualifies for 'hyperthermic' temperature regime. The average annual rainfall in the district is 700 mm and 79% of the rainfall is contributed by the southwest monsoon. Generally, rainfall in the district increases from southwest to northeast. The moisture regime of the district qualities as 'ustic'. The length of growing period (LGP) of the district varies from 180 to 210 days.

The change in land use was computed based on secondary data available for the years 1983–84, 1996–97 and 2007–2008, and primary data collected from sampled farming households representing soils of different series and landforms.

The timescale data of soil properties were taken from soil resource data by NBSS&LUP for 1983 (unpublished) and recent soil resource data generated in 2008 (ref. 14). The change in cropping system data was also collected for the corresponding years. The change in quantitative values of soil chemical properties, viz. pH, electrical conductivity (EC), OC and $CaCO_3$ was calculated for the corresponding years as stated above. In some soils, present status of soil compactness as indicated by increased bulk density was also observed. The impact of change in cropping system (land use) on soil properties was inferred for the above-mentioned periods.

The dynamics in land use for the district was studied on a temporal scale for the periods 1983–84, 1996–97 and 2007–2008 (Figure 1). Data indicated that the area under rice crop increased from 15% in 1983–84 to 22% in 1996–97 and 30% in 2007–08. The area under wheat decreased from about 44% in 1983–84 to 31% in 1996–97 and increased to 42% in 2007–08. On the other hand, the area under maize crop decreased from 21% during 1983–84 to about 9% in 1996–97, and continued the same acreage in 2007–08. The area under sugarcane crop also increased from 5% in 1983–84 to 9% in 1996–97 and again decreased to 3% during 2007–08. The area under fodder and vegetables also showed an increasing trend. The increase in area under rice crop is mainly on account of decrease in area under maize crop in the corresponding period. However, decrease in percentage area under sugarcane crop may be due to the non-performing sugarcane mills.

Table 1 presents the temporal change in soil properties of different soil series representing different physiographic units for Singhpur soil series (Shiwalik hills), Manjuwal (upper piedmont plain), Mandiani soil series (lower piedmont plain), Naura, Bhaura series (old flood plain) and Bairsal series (recent/active flood plain). The change in soil properties in each soil series representing different physiographic units is described below.

Soils developed on the Shiwaliks are mostly under scrubs and subtropical forests. These soils experienced severe to very severe erosion due to steep slopes and unconsolidated materials. Several schemes have been implemented to restore the soils by adopting soil and water conservation measures. According to the observations and interactions with different development agencies operating in the area, it is found that the intensity of biomass has increased since the last few decades on account of change in land use. Loss of nutrients from topsoil is prevalent on account of soil erosion. Singhpur series is the dominant soil series occurring in the Shiwaliks. These soils are very deep, excessively drained, light olive brown to very pale brown, loamy sand to sandy loam, calcareous on 30–45% slope, subjected to severe erosion and classified as Typic Ustorthents. The soil properties studied during 1983 and 2008 revealed that SOC content in surface soils decreased from 0.69% in 1983 to 0.40% in 2008 (Table 1). This declining trend was also observed in subsurface soils during the same period. It may be due to continuous deforestation and increasing grazing activities in the area. The man-made activities of levelling the hills for terrace formation may also expose subsurface soils, resulting in low OC. Soil pH in surface soils decreased slightly from 8.4 in 1983 to 8.0 in 2008. This declining trend in pH was also observed in the subsurface soils in the same period. Similar trends have been observed in EC, wherein it decreased from 0.16 dS m^{-1} in 1983 to 0.12 dS m^{-1} in 2008 in the surface soils and from an average of 0.14–0.12 dS m^{-1} in subsurface soils during this period. The calcium carbonate content also decreased from 2.05% in 1983 to 0.54% in 2008 in surface soils, while in the subsurface soils, it increased from an average value of 4.08% to 11.7% in the same period.

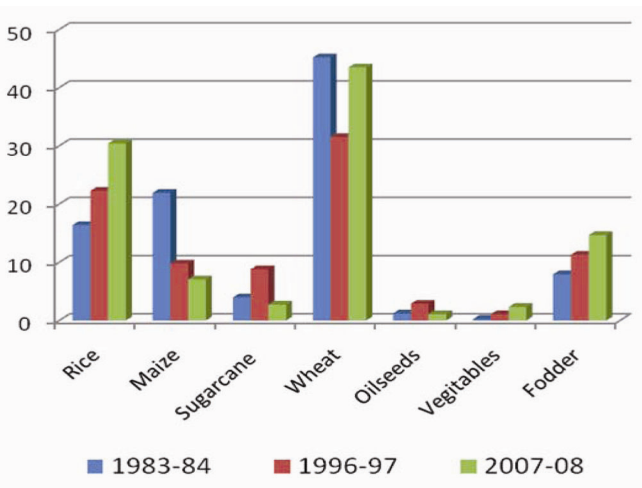

Figure 1. Changes in cropping pattern in Shahid Bhagat Singh Nagar district, Punjab, India. (Source: Chief Agriculture Officer, Shahid Bhagat Singh Nagar district.)

The soils of the upper piedmont plain are subjected to severe erosion during rainy season due to several choes in the area. Manjuwal series is the dominant soil series occurring in this region. These soils are very deep, somewhat excessively drained, yellowish-brown to dark yellowish-brown, sandy on 5–8% slope and subjected to moderate erosion (Typic Ustipsamments). The soil properties studied during 1983 and 2008 revealed that OC content in surface soils increased from 0.14% in 1983 to 0.20% in 2008 (Table 1). In subsurface soils, OC content was almost similar during both the periods. The increase in OC in surface soils may be due to addition of biomass by bringing the soils under cultivation after reclamation of severely eroded seasonal streams, i.e. choe areas. Soil pH in the surface soils decreased from 7.7 in 1983 to 6.9 in 2008. The declining trend was also observed in the subsurface soils in the same period. An increasing trend in case of EC was observed in both surface and subsurface soils. No change was observed in calcium carbonate as the soils are non-calcareous.

The soils of the lower piedmont plain are subjected to severe erosion during rainy season on account of 'choes'. However, intensity is relatively low compared to soils of the upper piedmont plain. The area is represented by Mandiani soil series. These soils are very deep, somewhat excessively drained, brown to yellowish-brown, sandy, calcareous on 3–5% slope and subject to moderate/slight erosion (Typic Ustipsamments). Soil OC in the surface layer increased from 0.21% in 1983 to 0.30% in 2008, while in subsurface layers there was a decreasing trend in the same period with negligible difference. Soil pH in the surface soils decreased from 8.6 in 1983 to 7.9 in 2008. The same trend was observed in subsurface soils (8.8 to 8.3) during this period. EC in the surface soils as increased from 0.06 dS m^{-1} in 1983 to 0.21 dS m^{-1} in 2008, while in subsurface soils no drastic change was observed in EC during the same period. Calcium carbonate in the surface soils increased from 1.85% in 1983 to 3.38% in 2008, while the reverse trend was observed in subsurface soils in the same period.

The old flood plain is the most stable landform in the district. It is intensively cultivated for rice, wheat, sugarcane, potato, sunflower and oilseed crops. The soils are silty clay loam to clay loam. Perceptible changes have been observed in this area. Rice crop has replaced the maize and groundnut crops and presently, the dominant cropping system is rice–wheat. The area is represented by Naura and Bhaura soil series and classified as Alfisols and Inceptisols respectively.

The Naura series soils are very deep, moderately well-drained, brown to dark greyish-brown, loam to clay

Table 1. Comparison of some properties of soils in different physiographic units with temporal change in Shahid Bhagat Singh Nagar district, Punjab, India during 1983 and 2008

1983						2008					
Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (%)	$CaCO_3$ (%)	Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (%)	$CaCO_3$ (%)
Singhpur series (Shiwalik hills) – Typic Ustorthents											
A1	0–11	8.4	0.16	0.69	2.05	A1	0–20	8.0	0.12	0.4	0.54
C1	12–26	8.2	0.13	0.41	3.64	C1	20–50	8.1	0.11	0.2	5.63
IIC2	26–61	8.3	0.15	0.36	6.87	IIC2	50–77	8.1	0.12	0.2	13.77
IIC3	61–115	8.5	0.13	0.34	7.49	IIC3	77–100	8.3	0.11	0.1	9.00
IIC4	115–135	8.3	0.14	0.30	3.54	IIC4	100–135	8.3	0.14	0.2	12.69
IIC5	135–172	8.6	0.11	0.13	0.67	IIC5	135–165	8.2	0.17	0.2	17.78
Manjuwal series (upper piedmont plain) – Typic Ustipsamments											
A1	0–12	7.7	0.06	0.14	Nil	A1	0–19	6.9	0.16	0.2	Nil
C1	11–27	7.8	0.04	0.14	Nil	C1	19–50	7.1	0.04	0.1	Nil
C2	27–59	7.8	0.05	0.09	Nil	C2	50–80	7.0	0.03	0.08	Nil
C3	59–88	8.1	0.04	0.04	Nil	C3	80–115	7.9	0.08	0.08	Nil
C4	88–115	8.4	0.09	0.10	Nil	C4	115–142	7.9	0.08	0.04	Nil
C5	115–172	9.0	0.06	0.04	Nil	C5	142–170	8.0	0.08	0.02	Nil
Mandiani series (lower piedmont plain) – Typic Ustipsamments											
A1	0–13	8.6	0.06	0.21	1.85	Ap	0–15	7.9	0.21	0.30	3.38
C1	13–40	8.8	0.07	0.09	8.98	A1	15–42	8.3	0.11	0.09	3.24
C2	40–70	8.8	0.07	0.04	5.00	C1	42–76	8.3	0.09	0.02	4.14
C3	70–100	8.8	0.08	0.03	7.30	C2	76–110	8.3	0.10	0.02	3.69
C4	100–160	8.8	0.12	0.04	4.10	IIC3	110–145	8.3	0.10	0.01	4.05
Naura series (old flood plain) – Udic Haplustalfs											
Ap	0–13	7.2	0.27	0.41	Nil	Ap	0–19	7.0	0.37	1.08	Nil
Bw1	17–39	7.4	0.25	0.29	Nil	Bw1	19–28	7.1	0.1	0.31	Nil
Bwt1	39–78	7.5	0.24	0.29	Nil	Bwt1	48–74	7.1	0.1	0.10	Nil
Bwt2	78–105	7.7	0.18	0.25	Nil	Bwt2	74–104	7.0	0.06	0.10	Nil
Bwt3	105–129	7.7	0.28	0.23	Nil	Bwt3	104–132	7.0	0.06	0.07	Nil
BC	129–160	7.6	0.28	0.25	Nil	BC	132–152	nd	nd	nd	nd
Bhaura series (old flood plain) – Typic Halaquepts											
Ap	0–25	8.3	0.5	0.64	2.45	Ap	0–19	7.9	0.22	0.72	1.35
Bw1	21–55	8.5	0.28	0.12	0.68	Bw1	19–43	8.3	0.18	0.36	1.13
Bw2	55–87	8.3	0.24	0.18	2.85	Bw2	43–68	8.0	0.13	0.36	0.45
Bw3	87–120	8.2	0.39	0.10	4.44	Bw3	68–125	8.1	0.14	0.27	0.68
Bw4	120–160	8.3	0.41	0.16	1.59	Bw4	125–150	8.0	0.10	0.23	0.45
Bairsal series (recent flood plain) – Typic Ustifluvents											
Ap	0–13	9.4	0.63	0.29	0.28	Ap	0–19	8.8	0.88	1.05	7.5
A12	13–30	10.0	1.0	0.16	0.91	A12	19–35	9.5	0.60	0.25	7.65
IIC1	30–55	10.0	1.4	0.08	0.96	IIC1	35–65	9.5	0.52	0.15	7.56
IIC2	55–81	9.9	1.1	0.14	0.57	IIC2	65–100	9.4	0.44	0.12	6.98
IIC3	81–118	9.6	0.8	0.12	0.39	IIC3	100–127	9.6	0.78	0.27	6.08
IIC4	118–150	9.3	0.5	0.12	5.41	IIC4	127–150	9.7	0.78	0.32	7.2

loam/silty clay loam on 0–1% slope (Udic Haplustalfs). The results indicated that OC increased from 0.41% in 1983 to 1.08% in the surface layer in 2008 (Table 1). However, the trend was reversed in the subsurface soils. The increase in OC in surface soils may be due to increasing biomass due to change in cropping system (from maize–wheat to rice–potato, rice–wheat/sunflower/mustard/peas) and addition of fertilizers under high management practices. Similar results were also reported by various other studies[15–19]. The earlier studies reported that OC content was high on surface layers, which decreased with depth due to further addition of biomass in the surface layers[20–22]. The lower OC content in the lower layers during 2008 may be blocking of translocation of organic matter due to the formation of impervious layer below the surface having higher bulk density (1.8 g cm^3). Similar results were also reported by other studies[23–26]. Decreasing trend in pH was observed in the surface soils (7.3 in 1983 to 7.0 in 2008). This trend was also perceptible in the subsurface soils. EC increased slightly in surface soils during 2008 compared to 1983, which may be due to the use of chemical fertilizers causing the build-up of salts. However, in the subsurface layers, EC was low in 2008 compared to 1983.

The Bhaura series soils are very deep, moderately well-drained, greyish-brown, and loam to clay loam/silty clay loam on 0–1% slope (Typic Halaquepts). These are salt-affected soils which were under natural grasses and vegetation. Recently, these soils have been reclaimed and brought under cultivation. The status of soil properties during 1983 and 2008 (Table 1) indicated that OC was higher in the surface and subsurface soils during 2008 compared to 1983. Soil pH of surface soils reduced from 8.3 in 1983 to 7.9 in 2008. The same trend was also observed in the subsurface soils. This may be on account of reclamation of salt-affected soils. EC of surface soils was higher (0.50 dS m^{-1}) in 1983 compared to 2008 (0.22 dS m^{-1}). The same trend was observed in the subsurface soils. Calcium carbonate content of the surface soils was 2.45% during 1983 and reduced to 1.35% during 2008. Similar trends were observed in the subsurface soils.

Soils occurring on recent flood plain are not fully developed. These soils are highly variable and their properties are not as stable as soils in the old flood plain. Previously, these soils were cultivated for maize, groundnut, pulses and oilseed crops. Presently, they have been put under rice–wheat cropping system after land-levelling. Bairsal series is the dominant soil series found in the area. These soils are very deep, well-drained, brown to dark yellowish brown, sandy loam to loam on 0–1% slope (Typic Ustifluvents). Higher OC was observed (1.05%) in surface soils in 2008 compared to 1983 (0.29%). However, in subsurface soils, OC content was slightly higher in 2008 compared to 1983 (Table 1). Soil pH of surface soils decreased from 9.4 in 1983 to 8.8 in 2008. Similar trends were found in the subsurface soils. The drop in pH may be due to replacement of maize–wheat cropping system by rice–wheat system and adopting suitable reclamation measures. EC of surface soils increased from 0.63 dS m^{-1} in 1983 to 0.88 dS m^{-1} during 2008. This trend was reversed in the subsurface soils. Calcium carbonate content both in surface and subsurface soils drastically increased during 2008 compared to 1983.

From the above studies, it may be concluded that the land use and cropping system in less-intensive cultivated areas of the Shiwalik hills do not have much influence on the soil properties. On the other hand, in intensively cultivated areas of piedmont plain, and old and recent flood plains where high-biomass rice–wheat cropping system has replaced the low biomass-producing maize–wheat system, the soil properties had changed to greater extent. There has been an increase in the soil OC and a decrease in the pH and EC in the surface soils. In addition, the improved management practices in the intensively cultivated areas have further changed the soil properties. In the changing scenario there is need for such studies in more extensive areas, including additional soil parameters and other natural resource indicators using geo-referencing database for more precise and site-specific results. This will help to develop eco-friendly, sustainable land use and cropping systems.

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