# Assessment of Soil Physico-Chemical Properties after Conversion of Sand Dunes into Arable Land in  Hot Semi-Arid Climatic Conditions of Punjab

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**Abstract**: The study aimed to assess changes in soil organic carbon (SOC) stock and physico-chemical properties of soil in semi-arid regions after 30 years of continuous rice-wheat cultivation. The SOC stock in the surface soil enhanced by 279% and in the subsurface soil by 54% compared to the SOC stock in the sand dunes. Furthermore, in the topsoil, prolonged cultivation of the rice-wheat system resulted in an increase of 84%, 132%, 121%, and 377% in the levels of sulphur, zinc, copper, and iron, respectively. This enhancement was also evident in the subsoil, with respective increases of 35%, 81%, 6%, and 266% in sulphur, zinc, copper, and iron content. However, continuous cultivation of rice-wheat system resulted in depletion of available manganese by 62% in topsoil despite of the positive impacts of continuous rice-wheat cultivation. Therefore, further research is needed to study the changes in microbial flora, an important soil quality indicator, in order to gain more comprehensive and relevant information about the effects of continuous cultivation of different cropping systems on soil health.

**Keywords**: Sand dune, SOC, Rice-wheat, Continuous cultivation

Understanding the formation and persistence of soil organic matter (SOM) is crucial for maintaining the sustainability of arable soils (Lal 2009). Soil organic carbon (SOC) is a vital indicator of soil quality and contributes to enhancing microbial processes, cation exchange capacity, water holding capacity, and infiltration rate through the soil profile. It also reduces soil bulk density and cohesion, ultimately enhancing crop productivity (Schillaci et al 2017). Recent attention has been focused on understanding the controls of terrestrial carbon storage due to concerns over rising atmospheric $CO_2$ concentration and its implications for global climate change. Soil organic carbon (SOC) is particularly important as it represents the largest stock of terrestrial carbon and has the potential to act as either a $CO_2$ source or sink (Moharana et al 2021). Arid and semi-arid lands are characterized by higher temperatures, low and irregular precipitation, low surface water availability, marginal soil health, and limited vegetation diversity (Acosta-Rangel et al 2019). Despite their low soil organic carbon (SOC) content, these areas store 16% of the total carbon in the soil globally. Long-term studies across various land use and management systems have demonstrated the potential for SOC sequestration in cultivated lands (Ghimire et al., 2015)eroded lands (Shukla and Lal, 2005a), and severely disturbed and reclaimed mine-lands (Nyamadzawo et al., 2008) through improved management practices. Fixing atmospheric carbon in soils (soil carbon sequestration) is the key to enhancing soil quality and curbing global warming. The rice-wheat cropping system in South Asia accounts for 27 and 16% of global rice and wheat production, respectively, and sustains more than 129 million farmers, most of whom are smallholders. However, rice and wheat yield trends in this region have slowed or stagnated due to the impacts of climate change, and these negative impacts are projected to worsen over the coming decades (Ishtiaque et al 2024). The impact of conversion of sand dunes to stabilized cultivated arable land under semi-arid condition of Indo Gangetic plain in surface and sub-surface soil is very limited. Thus, there is strong need to assess the impact of land use change on SOC stock and soil physico-chemical properties of *Inceptisols* in the IGP of India, which may help us to better understand the effect of long-term cultivation of rice-wheat system on soil quality and global climate change. Thus, the main objective of the current study was to analyse the long-term impact of conversion of sand dunes to cultivable arable land on soil organic carbon stock.

## MATERIAL AND METHODS

**Site description:** The research was conducted in the Faridkot district, situated in the southwestern region of Punjab, India (30°21′59" to 30° 49′ 52″ N and 74°28′12″ to 75°03′22″ E). Encompassing a total area of 1418.60 km2, the district experiences a predominantly semi-arid climate characterized by intense summers, a brief monsoon season, and cold winters. The cold season spans from November to March, followed by the summer season lasting until the end of June. The period from July to mid-September constitutes the southwest monsoon season. The district records an

average annual rainfall of 449 mm, with approximately 78 percent occurring during the monsoon months of July to September. The average elevation of the district is 196 meters and t is situated on the Punjab Plains, forming part of the greater Satluj Ganga plain in a macro-regional context. The area generally exhibits a low-lying flat topography that slopes towards the southwest, with a few linear depressions occupied by paleo-bluff and paleo channels near Pakka and southeast of Kamiyana Villages, as well as sand dunes concentrated in the northwestern and southern parts of the study area. Due to the exceptionally flat topography, there is not much of a developed drainage system. The soil classes found in the study region were loams, loamy sand, sandy to fine sandy loams, and silty loam, with loam sand as a predominant class within the study area.

**Soil sampling:** The soil samples from surface (0-15 cm) and sub-surface (15-30 cm) were collected from 20 different sites under two different land use patterns viz. sand dunes and already stabilized cultivable land under rice-wheat crop rotationduring April 2022. The geographical coordinates of the sampling points were recorded using a handheld geographical positioning system. Soils were sampled from each depth at 8 random points on each sampling site by a soil sampling auger. The sampled soils were composited and were treated as one. The total 80 soil samples (40 surface and 40 sub-surface soil samples of both sand dunes and rice-wheat crop rotation) was brought into the laboratory The samples were air dried, grinded and sieved with a 2.0 mm sieve and stored for analysis.The soil sample core of surface and sub-surface soil was also sampled from the field to calculate the bulk density and calculate the total porosity of the soil.

**Soil analysis:** Walkley Black oxidizable soil organic carbon (WB-SOC) was analyzed by oxidizing 2 g soil with potassium dichromate in the presence of concentrated sulfuric acid (Walkley and Black, 1934). The well-established, coremethod was used to measure the bulk density of the surface and subsurface soil (Bandyopadhyay et al 2012). The particle density of both surface and surface soil was assumed to be 2.65 Mg m$^{-3}$ to further calculate the total pore space of the soil (Eq.1).

$$Total\ soil\ porosity(\%) = \left[1 - \left(\frac{\rho b}{\rho s}\right)\right] * 100$$

Where, $\frac{\rho b}{\rho s} = bulk density / particle density$  [1]

The plant available sulfur in soil was analyzed turbidimetrically at 420nm wavelength on spectrophotometer (Chesnin and Yenin 1951). Thecationic micronutrients (Zn, Fe,Cu and Mn) were analyzed on ICP-OES following the procedure of Lindsay and Norvell 1978.The SOC stock of surface and sub-surface soil was calculated (Eq. 2) from respective soil organic carbon concentration and soil bulk density.

C stocks (Mg ha$^{-1}$)=SOC (%) × Bulk density (Mg m$^{-3}$)× soil depth (cm)  [2]

**Data analysis:** The descriptive statistics, correlation and linear regression for soil physico-chemical properties were evaluated at significance level of $p<0.005$ and $p<0.001$usingSPSS 25.0 Software SPSS Inc., Chicago, IL, USA)

## RESULTS AND DISCUSSION

**Descriptive statistic:** In surface soil the SOC stock in both sand dune and rice-wheat cropping system was highly variable and ranged from1.13 to 4.08 Mg ha and 6.14 to 13.40 Mg ha$^{-1}$, respectively (Table 1, 2). The SOC stock in rice-wheat system in subsurface soil ranged from 3.69 to 10.63 Mg ha$^{-1}$ and averagely decreased by 27 % incomparison to surfacesoil which might be accredited to greater root biomass addition in surface soil owing to shallow root system of paddy (Moharana et al 2021). The average decrease in soil organic carbon (SOC) stock ranged from 26 to 41% in sub-surface soil compared to surface soil in a rice-based cropping system, as reported by Meetei et al (2020).

**Bulk density and total soil porosity:** In the topsoil of sand dunes, the bulk density ranged from 1.55 to 1.70 Mg m-3, and the total soil porosity ranged from 35.90% to 41.70%. In contrast, the topsoil under a rice-wheat system exhibited a bulk density ranging from 1.49 to 1.65 Mg m$^{-3}$ and a total soil porosity ranging from 37.85 to 43.83% (Table 1). Over time, the cultivation of rice and wheat resulted in a 3% reduction in soil bulk density in the topsoil and a 15% increase in the subsurface soil compared to sand dunes. The subsurface compaction beneath the puddled zone, attributed to aggregate disruption, has emerged as a significant constraint for sustainable productivity in the Indo-Gangetic Plain (IGP) (Singh et al 2018). The improvement of total soil porosity in top soil under rice-wheat system was due to decrease in bulk density and increase is surface soil organic carbon content. The significant positive correlation existsbetween total soil porosity and SOC(Fukumasu et al 2022) and these relations are well established at field scale (Jarvis et al 2017).

**Sulphur and cationic micronutrient:** The long-term cultivation of rice-wheat for 30 years has enhanced the sulphur, zinc, copper and iron by 84, 132, 121 and 377% in surface soil and 35,81,6and 266% in subsurface soil respectively. Beside the positive impact of 30-year long term cultivation of rice-wheat, manganese (Mn) content in surface soil reduced by 62% but enhanced by 306% in subsurface soil (Table 1, 2). The intensive agriculture and skewness toward high-analysis fertilizers have gradually depleted the

soil of available micronutrients in the surface soil. Furthermore, continuous intensive rice-wheat cultivation leads to the formation of subsurface hardpan, thereby reducing DTPA-extractable Mn (Balloli et al 2000). The continuous flooding in paddy might have led to the leaching of Mn which resulted in high available Mn content in subsurface soil with respect to the surface soil (Narender et al 2018). The substantial variability within the study area could be

**Table 1.** Descriptive statistics for surface soil (0-15 cm)of sand dune and rice-wheat system in the south-western district of Punjab

| Major land use | Soil physico-chemical properties | Central tendency | | | Dispersion | | | | | Distribution | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Median | Mode | Minimum | Maximum | SE | SD | CV (%) | Skewness | Kurtosis |
| Sand Dune | SOC stock (Mgha$^{-1}$) | 2.65 | 3.03 | 1.13 | 1.13 | 4.08 | 0.47 | 1.15 | 43.30 | -0.45 | -1.33 |
| | Bulk density (Mgm$^{-3}$) | 1.62 | 1.62 | 1.55 | 1.55 | 1.70 | 0.03 | 0.06 | 4.02 | 0.14 | -2.18 |
| | Total Porosity (%) | 38.80 | 38.50 | 36.20 | 35.90 | 41.70 | 0.98 | 2.40 | 6.20 | 0.24 | -1.74 |
| | Zn (ppm) | 0.51 | 0.50 | 0.31 | 0.31 | 0.77 | 0.08 | 0.19 | 36.70 | 0.25 | -2.17 |
| | Cu (ppm) | 0.35 | 0.36 | 0.24 | 0.24 | 0.45 | 0.03 | 0.07 | 20.70 | -0.17 | 0.42 |
| | Fe (ppm) | 3.96 | 3.30 | 2.11 | 2.11 | 7.05 | 0.81 | 1.97 | 49.80 | 0.91 | -0.76 |
| | Mn (ppm) | 2.26 | 2.37 | 0.83 | 0.83 | 3.84 | 0.42 | 1.04 | 46.10 | 0.42 | 1.04 |
| | S (ppm) | 14.86 | 14.72 | 5.28 | 5.28 | 27.59 | 3.00 | 7.36 | 49.50 | 0.85 | 2.08 |
| Rice-wheat | SOC stock (Mg ha$^{-1}$) | 8.27 | 7.29 | 6.14 | 6.14 | 13.40 | 1.14 | 2.80 | 33.90 | 1.52 | 1.74 |
| | Bulk density (Mg m$^{-3}$) | 1.58 | 1.59 | 1.60 | 1.49 | 1.65 | 0.02 | 0.05 | 3.30 | -0.90 | 2.16 |
| | Total Porosity (%) | 40.39 | 40.33 | 37.85 | 37.85 | 43.83 | 0.80 | 1.96 | 4.90 | 0.92 | 2.36 |
| | Zn (ppm) | 1.19 | 0.95 | 0.10 | 0.10 | 3.49 | 0.50 | 1.24 | 1.19 | 1.59 | 2.79 |
| | Cu (ppm) | 0.77 | 0.81 | 0.50 | 0.50 | 0.99 | 0.07 | 0.18 | 0.77 | -0.55 | -0.46 |
| | Fe (ppm) | 18.89 | 15.26 | 4.11 | 4.11 | 34.56 | 5.09 | 12.48 | 18.89 | 0.48 | -1.62 |
| | Mn (ppm) | 0.86 | 0.57 | 0.28 | 0.28 | 2.41 | 0.33 | 0.80 | 0.86 | 1.94 | 3.90 |
| | S (ppm) | 27.35 | 28.36 | 14.29 | 14.29 | 38.64 | 3.43 | 8.40 | 27.35 | -0.38 | 0.25 |

**Table 2.** Descriptive statistics for sub-surface (15-30cm) of sand dune and rice-wheat system in the south-western district of Punjab

| Major land use | Soil physico-chemical properties | Central tendency | | | Dispersion | | | | | Distribution | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Median | Mode | Minimum | Maximum | SE | SD | CV (%) | Skewness | Kurtosis |
| Sand Dune | SOC stock (Mg ha$^{-1}$) | 2.74 | 2.67 | 1.14 | 1.14 | 4.56 | 0.51 | 1.25 | 45.70 | 0.24 | -0.96 |
| | Bulk density (Mg m$^{-3}$) | 1.58 | 1.63 | 1.40 | 1.40 | 1.69 | 0.05 | 0.12 | 7.80 | -0.85 | -1.22 |
| | Total porosity (%) | 40.40 | 38.90 | 36.20 | 36.21 | 47.27 | 1.89 | 4.63 | 11.50 | 0.72 | -1.41 |
| | Zn (ppm) | 0.71 | 0.32 | 0.30 | 0.28 | 2.42 | 0.35 | 0.85 | 35.00 | 2.33 | 5.49 |
| | Cu (ppm) | 0.57 | 0.40 | 0.30 | 0.30 | 1.05 | 0.13 | 0.32 | 56.40 | 0.98 | -1.38 |
| | Fe (ppm) | 4.19 | 3.50 | 2.16 | 2.16 | 9.36 | 1.09 | 2.67 | 63.70 | 1.92 | 4.01 |
| | Mn (ppm) | 0.68 | 0.74 | 0.34 | 0.34 | 0.91 | 0.08 | 0.20 | 29.40 | -1.01 | 1.02 |
| | S(ppm) | 19.42 | 14.87 | 6.69 | 6.69 | 45.57 | 6.15 | 15.08 | 77.60 | 1.21 | 0.89 |
| Rice-wheat | SOC stock (Mg ha$^{-1}$) | 6.34 | 5.91 | 3.69 | 3.69 | 10.63 | 1.02 | 2.50 | 39.50 | 1.04 | 1.01 |
| | Bulk density (Mg m$^{-3}$) | 1.81 | 1.81 | 1.66 | 1.66 | 1.94 | 0.04 | 0.10 | 5.30 | -0.22 | 0.38 |
| | Total Porosity (%) | 31.81 | 31.62 | 26.85 | 26.85 | 37.52 | 1.49 | 3.64 | 11.40 | 0.37 | 0.56 |
| | Zn (ppm) | 1.29 | 1.30 | 0.64 | 0.64 | 1.90 | 0.20 | 0.49 | 38.30 | -0.094 | -1.73 |
| | Cu (ppm) | 0.60 | 0.60 | 0.32 | 0.32 | 0.98 | 0.10 | 0.25 | 41.80 | 0.369 | -0.88 |
| | Fe (ppm) | 15.32 | 8.79 | 2.26 | 2.26 | 41.43 | 6.43 | 15.76 | 40.20 | 1.12 | -0.08 |
| | Mn (ppm) | 2.76 | 2.09 | 0.86 | 0.86 | 5.94 | 0.88 | 2.15 | 77.70 | 0.71 | -1.44 |
| | S (ppm) | 26.21 | 21.63 | 18.98 | 18.98 | 40.07 | 3.59 | 8.79 | 33.50 | 1.09 | -0.84 |

attributed to the implementation of diverse soil management practices, encompassing disparities in fertilizer application and other agricultural management practices (Behera et al 2016). The continuous paddy cultivation for 15 years and soils with high SOC content resulted in high soil total and available sulphur pools of the soil (Zhou et al 2024). The diminished level of soil organic carbon (SOC) within sand dunes can be attributed to limited vegetation cover. The exposure of soils to intense solar radiation leads to the oxidation of SOC (Pandey et al 2010).

**Correlation and Linear regression between SOC stock, BD, total soil porosity, sulphur and cationic micronutrients:** The analysis revealed negative correlation between soil organic carbon (SOC) stock and bulk density in both surface soil (-0.513) and sub-surface soil (-0.649), regardless of the land use pattern. This correlation was statistically significant (Table 3) whereas the change in SOC stock could explain 27% and 21% variation in bulk density of surface and subsurface soil, respectively (Fig. 1A) and these results are in agreement with results of Yu et al (2014). Changes in land use invariably result in alterations to soil physical and chemical properties. (Sun et al 2011). The increase in soil porosity and significant positive correlation coefficient of 0.345 and 0.549 for surface and subsurface soil, respectively with SOC stock explained the decrease in bulk density under continuous rice-wheat cultivation for 30
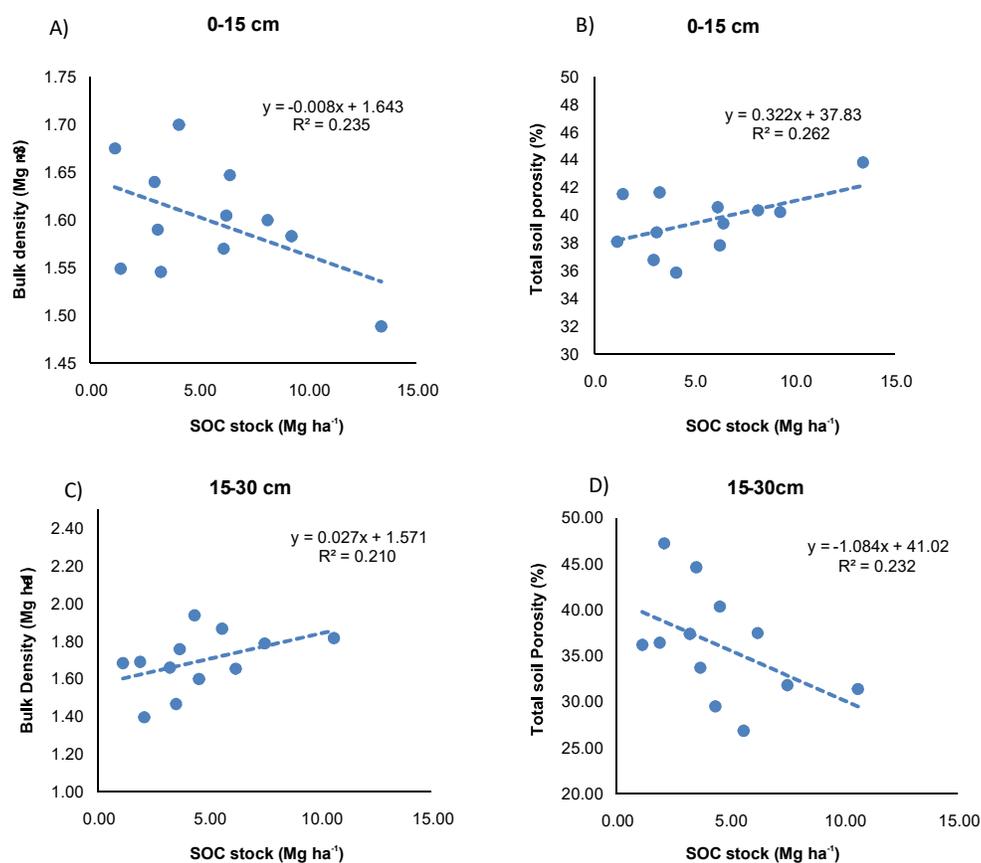


**Fig. 1.** Relationship of SOC stock (Mg ha$^{-1}$) with bulk density and total soil porosity in surface (A and B) and sub-surface (C and D) soil in south-western district of Punjab

**Table 3.** Quantifying the relationship between soil organic carbon (SOC) stock in both surface and sub-surface soils with the physico-chemical properties of soil in South western district of Punjab

| SOC | BD | Total porosity | Zn | Fe | Cu | Mn | S |
|------|--------|-----------------|-------|---------|--------|-------|-------|
| 0-15 | -0.513* | 0.345* | 0.112 | 0.939** | 0.580* | 0.077 | 0.169 |
| 15-30 | -0.649 | 0.549 | 0.163 | 0.551 | 0.199 | 0.154 | 0.214 |

*and **Correlation is significant at the $p<0.05$ and $p<0.01$

years (Table 3). In surface soil the SOC stock explained 26% and in subsurface soil 23% variation in total soil porosity. Whalen et al (2003) explained decrease in bulk density with increasing SOC content could be related to the increase in soil porosity and soil aggregate stability. The relationship of SOC stock withsulphur, Zn, Mn except Fe and Cu was significant but with low correlation coefficient. The low correlation for, Zn and Mn might be related to the formation of strong bond of the former with OM which might have affected the availability of Zn and Mn. The significant strong correlation of 0.939 between SOC stock and Fe might have resulted from reduced condition in paddy and high microbial activity owing to high organic matter (OM) availability in soil (Dhaliwal et al 2019).The increase in available Cu in surface and subsurface soil with increasing SOC stock could be explained from the fact that Cu has greater affinity to form strong inner sphere complex with SOM (Boudesocque et al 2007) and adsorption of $Cu^{2+}$ ions on OM influence the bioavailability of Cu (Matijevic et al.2014).

## CONCLUSION

The conversion of sand dunes into cultivable arable land significantly improved SOC stock and physico-chemical properties of the soil except the Mn content, a major micronutrient in rice-wheat cropping systemin both surface and subsurface soil. The formation of hard pan due to puddling in rice resulted in high bulk density in subsurface soil. The wide variation in crop and nutrient management practices had resulted in high coefficient of variation >35% for SOC stock, sulphur and cationic micronutrients. SOC stock was negatively correlated with bulk density in both soil depths and positively correlated with S and cationic micronutrients. Thus, there is need to further study the soil inorganic carbon dynamics, change in microbial flora, a major soil quality indicator to get the realistic and more relevant information on the effect of continuous cultivation of rice-wheat cropping system on the total soil organic carbon stock and soil health.

## AUTHOR'S CONTRIBUTION

Harinder Singh designed, supervised and recorded the data of the experiment. Gagandeep Dhawan wrote the original draft of manuscript, reviewed and edited the manuscript. Mandeep Singh analysed and investigated the data and also helped in writing the manuscript. All authors read and approved the final manuscript

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