JEB®

Journal of Environmental Biology

p-ISSN: 0254-8704 • e-ISSN: 2394-0379 • CODEN: JEBIDP
Journal website : www.jeb.co.in ★ **E-mail :** editor@jeb.co.in

Triveni Enterprises
(Educational Services Set-up)

Original Research

DOI : http://doi.org/10.22438/jeb/44/2/MRN-4023

Improvement in soil fertility under long-term intensive irrigated agriculture Punjab (North-west India) scenario

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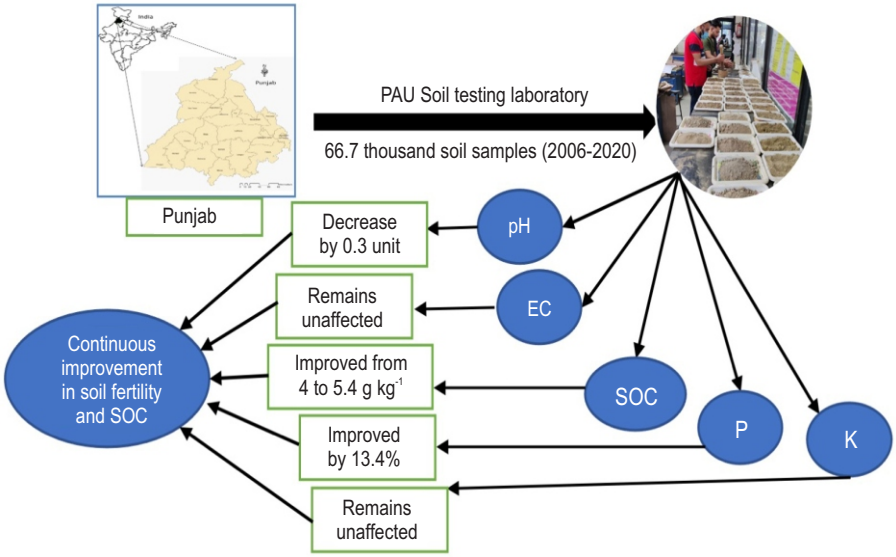
Received: 09.11.2021 *Revised*: 18.04.2022 *Accepted*: 02.09.2022

Abstract

Aim: The objective of this study was to monitor the changes in soil fertility parameters of Punjab soils for the last 15 years (2005/06 to 2019/20) and to estimate the contribution of rice-wheat system to soil carbon sequestration.

Methodology: This investigation is based on 66.7 thousand surface (0-15 cm) soil samples that were received in the Soil Testing Laboratory, Department of Soil Science and were analyzed for different fertility parameters such as pH, EC, organic carbon, phosphorous and potassium following standard protocols.



Results: Analysis of soil fertility parameters data of last 15 years indicated positive trends of change in soil pH (7.7 to 7.4), organic carbon (4.0 to 5.4 g kg^{-1}) and available P (9.9 to 15.4 mg kg^{-1}). These changes are very much synchronised with increase in average rice-wheat yield trend (7.99 to 9.38 t ha^{-1}) in the State of Punjab. Intensive cultivation also helped in higher soil carbon sequestration (3.73 t ha^{-1}).

Interpretation: There is an indication of improved soil fertility/health, including increased soil carbon sequestration in the Indian Punjab. The long-term trends of change in different soil fertility parameters will help to regulate the fertilizers usage to sustain the soil health as well as crop yields in this region.

Key words: Intensive agriculture, Punjab, Rice-wheat cropping system, Soil organic carbon, Soil pH

How to cite : Singh, K., D. Singh, A.S. Toor, O.P. Choudhary and S. Chandel: Improvement in soil fertility under long-term intensive irrigated agriculture–Punjab (North-west India) scenario. *J. Environ. Biol.*, **44**, 229-237 (2023).

Introduction

The Indian Punjab, the part of the Indo Gangetic Plains, is separated from the Ganga basin by the flood plains of the Ghaggar River. It covers a total geographical area of 5.036 million ha with approximately 83 per cent of the cultivated area. Indian Punjab having only 1.5 percent of the geographical area of the country produces about 21 percent of wheat, 11 percent rice and 13 percent cotton of the total production under these crops during 2019/20 (Statistical Abstracts of Punjab, 2020). The cropping intensity in Punjab state was 191 percent during 2019/20 which indicates tremendous pressure on the nutrient reserves of the soils and hence, demands replenishment (Sharma *et al.,* 2016; Statistical Abstracts of Punjab, 2020). Rice-wheat cropping system is the major crop rotation in the Indo-Gangetic plains of Punjab. Continuation of rice-wheat system for several years has already imposed major threats to ground water (decline in water Table). Rice-wheat cropping system is an exhaustive feeder of soil nutrients. Many researchers have raised the question on the sustainability, yield stagnation, soil degradation and atmospheric pollution under this system (Ladha *et al.,* 2003; Bhandari *et al.,* 2002; Bijay-Singh *et al.,* 2008). There is a general perception that the excessive use of straight nitrogenous and phosphatic fertilizers are deteriorating the fertility status of Punjab soils.

After the green revolution in 1960s, high yielding varieties requiring more fertilizers being followed in the state resulted in a gradual increase in the rice-wheat cropping system. Even after application of balanced fertilizer recommendations, a negative balance of the main nutrients still persist (Singh *et al.,* 2004). Different research studies (Srivastava, 1998; Duxbury 2001; Ladha *et al.,* 2003; Singh and Grover, 2011) have also concluded that continuous application of nitrogenous fertilizers has depleted soil organic matter, resulting in the inherent loss of native soil N, available P as well as available K and collapse of beneficial microbial communities. The loss of nutrients due to removal/burning of paddy/wheat straws from the fields further indicate deterioration of soil health. However, contrary to this, Benbi and Brar (2009) observed overall positive effect of intensive cultivation of rice-wheat cropping rotation for over a period of 25 years in Punjab on the soil properties. They observed a decrease in soil pH by 0.8 units, an increase of 38 per cent in soil organic carbon and 1.5-fold increase in available phosphorus during 1980/81 to 2005/06 that led to improved carbon restoration, a favourable pH environment and amelioration of the soil salinity.

Soil fertility is acquiring more recognition as soil health is gaining more attention as key to sustainable development. Soil health degradation jeopardize sustainability of agriculture and environmental quality (Chandel *et al.,* 2017). Soil organic matter is the most important driver for soil health as it plays a significant role in carbon storage and nutrient release (Schutte *et al.,* 2014; Spiegel *et al.,* 2018). Although there is a general perception, of deterioration of the fertility status of agricultural soils in Punjab, yet there has been a consistent increase in total productivity in the rice-wheat system over the years. Most of the statements about the deteriorating soil fertility of Punjab are mainly based on the findings of several researchers mostly operating from outside the state and relying on only short-term investigation or staggered data. Such a contrasting ground scenario needs to be verified from the long-term ground truth. Accordingly, a study was planned with the objective to monitor the changes in soil fertility parameters of Punjab soils for the last 15 years to estimate the contribution of rice-wheat cropping system in carbon sequestration.

Materials and Methods

Study area: The Indian Punjab covers an area of 5.036 M ha and lies between 29° 32' 31.563" and 32° 34' 39.658" N latitudes and 73° 53' 13.453" and 76° 56' 40.597" E longitudes.

Soil sampling and analyses: Soil samples (0-15 cm) received from the farmers in Soil Testing Laboratory, PAU, Ludhiana for soil fertility evaluation and fertilizer recommendations for the period 2005/06 to 2019/20 were analyzed for different soil fertility parameters. During the last 15 years, a total of 66.7 thousand soil samples were received from entire state of Punjab were analyzed in the laboratory. Before analysing, the soil samples of plough layer were dried under shade and passed through 2 mm sieve after grinding. Parameters such as soil pH (Thomas, 1996), electrical conductivity (Thomas, 1996), soil organic carbon (Walkley and Black, 1934), available phosphorous (Olsen *et al.,* 1954) and available potassium (Merwin and Peech, 1950) were determined as per the standard procedures.

The samples received during each year were categorized in to different groups, on the basis of their analysis value. The pH of the soil samples was categorized into normal (6.5–8.7), alkaline (8.7–9.3) and alkali (> 9.3), EC was grouped into low (< 0.8 dSm^{-1}) and high (> 0.8 dSm^{-1}) categories. Soils containing organic carbon less than 4.0 g kg^{-1} were classified as low, 4.0-7.5 g kg^{-1} as medium and greater than 7.5 g kg^{-1} as high. Regarding available phosphorous, soils containing less than 5 mg P kg^{-1} were categorized as low, 5–9 mg P kg^{-1} as medium and greater than 9 mg P kg^{-1} as high category (Sadana, 2007). Similarly, for available potassium, soils withless than 55 mg K_2O kg^{-1} were categorized as low, 55-134 mg K_2O kg^{-1} as medium and more than 134 mg K_2O kg^{-1} into high category (Muhr *et al.,* 1965).

Statistical analyses: Weighted arithmetic mean for each analysed soil parameter was computed for each year to assess the effect of agricultural management practices on soil quality over a period of 15 years. The weighted arithmetic mean for a given soil parameter was calculated using Eq. 1.

$$\bar{X} = \frac{1}{n}\sum x_i \times w_i \text{ ---------- eq. 1}$$

Here, $\bar{X}$= weighted arithmetic mean for a given soil parameter, X such as pH, EC, SOC, P or K;

xi = middle value of X in the i^{th} category;

wi= weight, *i.e.,* the number of samples falling into the i^{th} category;

n= total no. of soil samples analyzed in that particular year.

In the highest category, the middle value for a parameter was selected on the basis of its maximum soil test value acquired during that particular year. The middle values selected for the highest category were 9.6 for pH, 0.12 dSm^{-1} for EC, 9.5 g kg^{-1} for SOC, 25 mg P kg^{-1} for available P and 220 mg K_2O kg^{-1} for available K.

The trend analysis of soil organic carbon in relation to crop productivity and time was determined by linear function in MS Excell (Gomez and Gomez, 1976). The level of significance was tested at 5 percent probability ($P < 0.05$) for the regression coefficient. Carbon inputs into the soil were computed based on rice and wheat grain yields, by taking a grain: straw ratio 1:2.2 for rice and 1:1.5 for wheat (Benbi and Brar, 2009) and concentration of the carbon in stubble, root biomass and rhizodeposition. As per the reports of Kukal *et al.* (2008) for rice and Gajri and Parihar, 1985 for wheat in the region, roots constitute 10 percent of the above-ground biomass for wheat and 15 percent for rice. Stubble and rhizodeposition account for 2.5 and 15 percent of the total aboveground biomass, at maturity harvest for rice. Similarly, wheat contributes 3.0 and 12.6 per cent stubble and rhizodeposition, respectively of the total above ground biomass for wheat (Majumder *et al.,* 2007). The concentration of carbon in stubble, root biomass and rhizodeposition are 38.1, 41.2 and 74 percent for rice and 35.2, 39.1 and 74.0 percent for wheat, respectively (Majumder *et al.,* 2007). Contribution of the rice-wheat system in carbon sequestration was calculated according to the above mentioned share in roots, stubble and rhizopedopsition.

Potassium balance: Potassium balance was calculated using the data from the statistical abstract of Punjab by employing following equation

Potassium Balances= Total Input (K through Fertilizer application + K in rain water+Seed K + K in Irrigation water) - Total Output (Total grain and straw uptake)

Data on soil fertility parameters were analysed for descriptive and trend analysis in the MS excel.

Results and Discussion

Soil reaction (pH) data of the samples collected in soil testing laboratory during the period of last 15 years (2005/06 to 2019/20) were grouped into three categories viz normal (pH 6.5-8.7) those are best suitable for plant growth and do not need any amendment, alkaline (pH 8.8-9.3) require organic/green manuring for normal plant growth and alkali (pH > 9.3) require reclamation with amendment (gypsum),is depicted in Fig. 1. The distribution frequency of soil pH in various categories indicated an increase in number of samples in the normal category (91.5 to 95.6 per cent) with a corresponding decrease in number of samples in the alkaline (6.9 to 3.5 per cent) and alkali (1.6 to 0.8 per cent) categories during 2005/06 to 2019/20, respectively (Fig. 1a). The weighted average of soil pH decreased from 7.7 in the year 2005/06 to 7.4 in the year 2019/20 (Fig. 1b). The decrease in soil pH by 0.3 units and increase in number of samples in the normal category may be due to the combined effect of increase in area under cultivation of low land rice during this period from 26.42 to 29.2 lakh ha (Statistical Abstract of Punjab, 2020).

This may be attributed to intensive agriculture that contributed more root biomass, hence more organic acids in the soils, continuous use of urea fertilizer having acidic residual effect and continued reclamation of alkali soils in the state. In addition to this, when an aerobic soil is submerged, its pH decreases during the first few days, subsequently reaches a minimum, and then, a few weeks later, increases asymptotically to a fairly stable value of 6.7–7.2 (Ponnamperuma, 1972). The overall effect of submergence is to bring the soil pH near to neutrality, *i.e.,* to increase the pH of acid soils and to depress the pH of alkaline and alkali soils. In Indian Punjab, the decrease in soil pH towards near neutrality has positive implications for phosphorus and micronutrients availability in soils. Generally, P availability is maximum in the pH range 6.5–7.5 and the availability of Zn, Cu, Fe and Mn also increases with the drop down of soil pH (Neina, 2019; Miller, 2016). Earlier, Benbi and Brar (2009) also observed a decline in soil pH by 0.8 units (8.5 to 7.7) during a period of 25

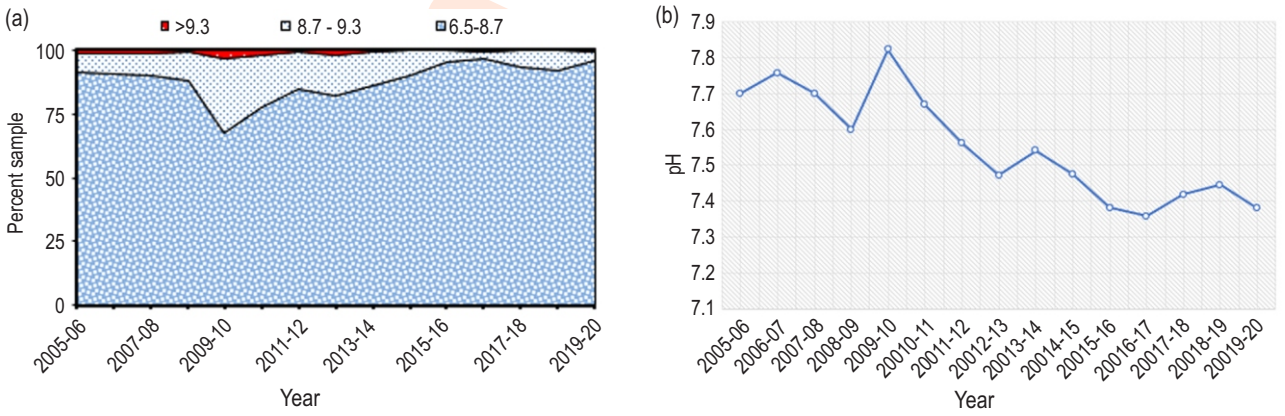


Fig. 1: Status of pH (a) percentage of samples falling under different categories and (b) weighted average, during 2005/06 to 2019/20 in the soils of Punjab, India.

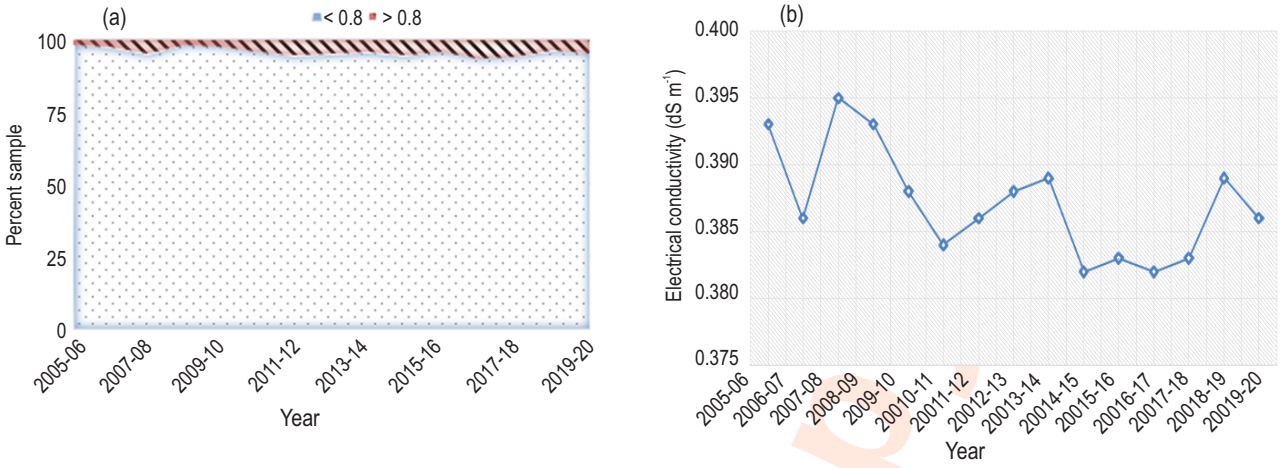


Fig. 2: Status of electrical conductivity (dS m^{-1}) in the soils of Punjab, India (a) percentage of samples falling under different categories and (b) weighted average, during 2005/06 to 2019/20.

years in the state. The number of samples with higher category (pH >9.3; alkali) progressively decreased from 1.6 to 0.8 percent in 2005/06 to 2019/20 (Fig. 1b). This could be due to gypsum application in alkali soils and low land rice cultivation. Submergence of alkali soils help to leach the soluble salts to deeper layers along with significant decrease in pH (Chhabra, 2002). In the second category, *i.e.,* the pH range of 8.7–9.3 (alkaline), there was a consistent increase in number of samples from 6.9 percent in 2005/06 to 29.1 percent in 2009/10. Thereafter, the number of samples in this category gradually decreased. Considering the soil pH data reported by Benbi and Brar (2009) and thereafter the soil pH data beyond 2006 in the present study, there was an indication of increase in the number of samples in alkaline category from 1999 to 2010, which could be due to the increased withdrawal of underground water to supplement the water requirement of increasing area under the paddy crop. As a result, the water table in the state especially in the central alluvial plain zone has gone deeper (Singh and Kumar, 2007). Due to increased withdrawal and declining water table, farmers started lowering their tube wells into the deeper strata by using submersible pumps. Lower layers of the strata in these alluvial plains have salt impregnations; as a result, water quality of some of the areas which were earlier normal had started deteriorating (Kumar *et al.,* 2014). This deteriorating quality of underground water may have resulted in increase in the soil samples in the pH range of 8.7–9.3 (alkaline) till 2011. After 2010-11, however, there was continuous decline in the number of soil sample in this category. Soils having pH > 8.7 needs special attention by way of regular use of farm yard manure or green manuring to bring down the pH.

Excess of dissolved salts in soils create hindrance in the normal nutrient uptake process by imbalance of ions, antagonistic and osmotic effects. During 2005/06 to 2010/11, approximately 98 percent of the tested soil samples were free from salinity (Fig. 2a). Approximately 2 percent of the soil samples were having EC > 0.8 dS m^{-1}. During 2010/11 to 2019/20, there was a marginal fluctuation in the number of samples in this category between 4 to 6 percent. Overall, the weighted mean of the soil EC for the state remained unaffected (Fig. 2b). So, soils of Punjab do not have salinity problem, as indicated from low EC.

The percentage of samples with soil organic carbon under low (< 4.0 g kg^{-1}), medium (4.0 to 7.5 g kg^{-1}) and high (>7.5 g kg^{-1}) category in the Punjab soils during 2005/06 to 2019/20 is shown in Fig. 3a. The percent samples under low category SOC decreased with a corresponding increase in the medium and high category of SOC, indicating improvement in the soil organic carbon status of Punjab soils. The percent samples under high and medium SOC category increased from 5.0 to 15.6 and 45 to 52.3, respectively from 2005/06 to 2019/20. Correspondingly, the number of samples under low category decreased from 55.5 to 26 percent for the same period. The weighted average for SOC increased from 0.41 to 0.54 per cent during 2005/06 to 2019/20 (Fig. 3b). This indicates that soils earlier falling in the low category of SOC have shifted to medium or high SOC category. Earlier, Benbi and Brar (2009) also observed similar trend of shifting in SOC of Punjab soils during 1981 to 2005. Practices such as improved balanced fertilizer application, manure/compost and residue incorporation enhance build up of SOC and carbon storage (Biswas and Benbi 1997; Kimble *et al.,* 2002; Nayak *et al.,* 2012).

The relationship between weighted SOC and number of years of rice-wheat cropping system through the period of 2005/06 to 2019/20 was linear (Fig. 3b).

$$SOC = 3.805 + 0.131 * \text{number of years} \quad (R^2 = 0.77)$$

The increase in the SOC perfectly matched with the increase in the rice-wheat production as well as productivity over the years (Fig. 3b). The total production showed a linear relationship with the number of years, *i.e.,* Total production (Rice + Wheat) = 25.6 + 0.38 × Number of Years (R^2 = 0.66) is depicted in Fig. 3b. The intensive cropping system in the area added more

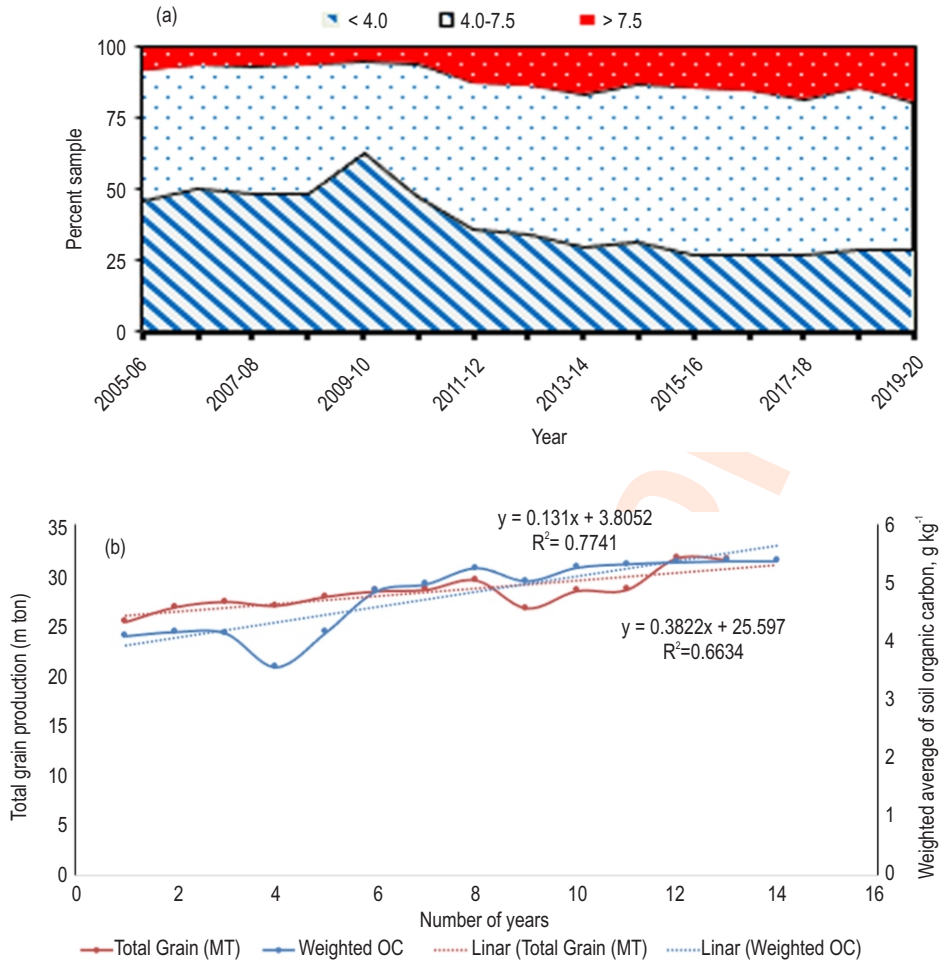


Fig. 3: Status oforganic carbon (g kg^{-1}) in soils of Punjab, India (a) percentage of samples falling under different categories and (b) weighted average of soil organic carbon and total rice-wheat grain production, during a period of 15-year, viz. 2005 to 2020.

above and below-ground biomass to the soil with each increasing year and that resulted in progressive hike in the SOC. After green revolution, high yielding varties requiring more fertilizers being followed in the state resulted in a gradual increase in the rice-wheat cropping system and its yield. Higher plant biomass results in addition of more root biomass residues (Jat *et al.,* 2014; Sapkota *et al.,* 2017) that improves the level of SOC. Bhattacharya *et al.* (2007) and Benbi and Brar (2009) gave an account of increase in SOC stock in 25 years (1980-2005) in semi-arid tropics and Indo Gangetic plains, respectively. Better agricultural management practices and intensive cultivation of optimally fertilized rice-wheat system led to increased levels of SOC. However, Ladha *et al*., (2003) reported static behaviour of soil organic carbon for 25-30 years in the northwest India based on the findings of long term fertility experiments on rice-wheat cropping system. The increase in the SOC may also be due to submerged conditions under rice for nearly 3-4 months. High moisture promotes plant dry matter production and poor aeration inhibits faster organic matter decomposition, as anaerobic condition inhibits the microbial activity in such kind of soil. Poorly drained soils, therefore, accumulate more levels of organic matter (Jenkinson 1988; Kögel-Knabner *et al.,* 2010). Kukal *et al.* (2008) also reported that continuous cultivation of rice-wheat cropping system improved SOC by 1.7 to 6.2 g kg^{-1} compared to maize-wheat. Further increase in SOC may also be ascribed to more root biomass and crop stubbles due to gradual increase in cropping intensity from 186 % in 2005 to 190.8 % in 2021 (Ministry of Agriculture and Farmers Welfare, 2021). Fig. 4 indicates that a significant increase in the SOC ($p < 0.003$) with increase in overall rice-wheat productivity over the study period explained about 68.4 % of the variations.

The total rice-wheat production in the state increased from 25.3 to 31.5 MT during 2005/06 to 2019/20 (Fig. 3b). The SOC linearly increased with an increase in the total grain yield (Fig. 3b). One ton increase in the productivity of rice-wheat system in one hectare results in 1.44 ton increase in SOC per hectare, assuming the

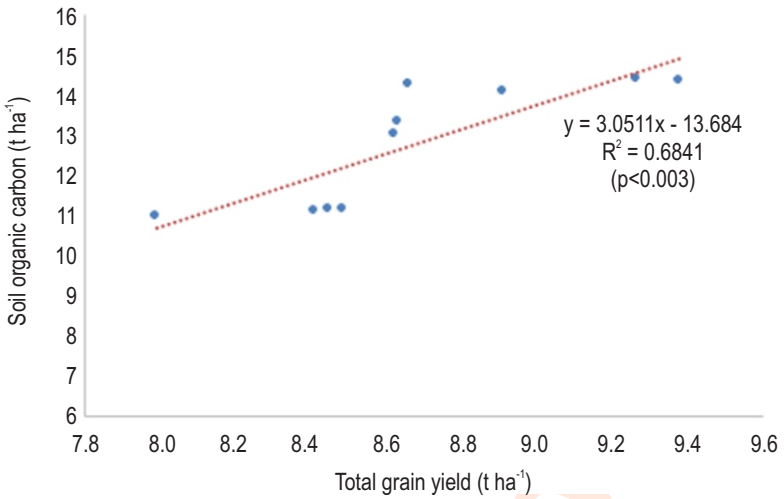


Fig. 4: Soil organic carbon stocks (0-15 cm depth) as affected by total grain yield, during 2005/06 to 2019/20 in the soils of Punjab, India.

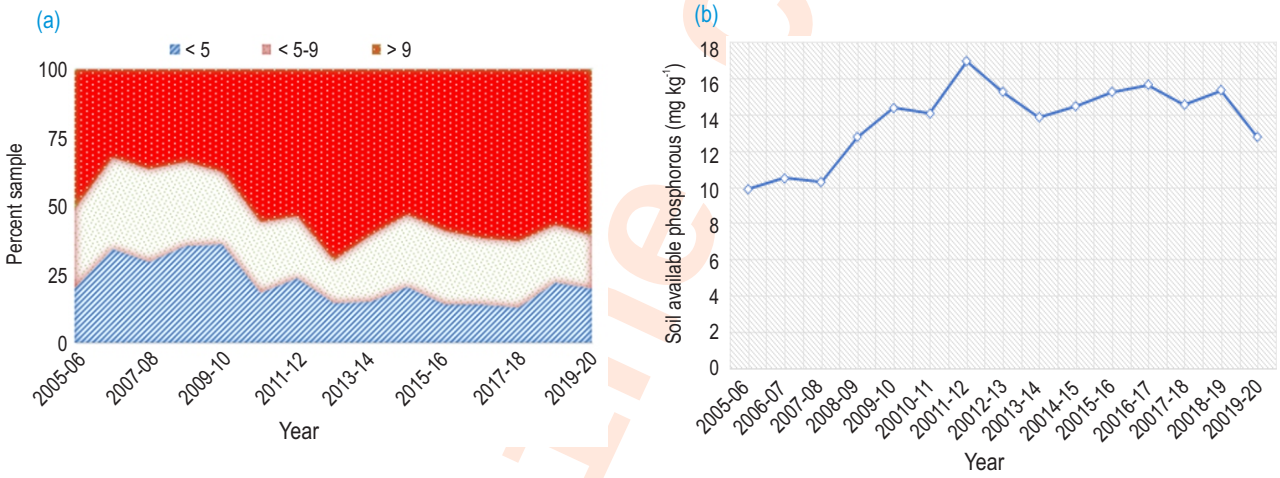


Fig. 5: Status of available phosphorous (mg kg^{-1}) in the soils of Punjab, India (a) percent samples falling under different categories and (b) weighted average, during 2005/06 to 2019/20.

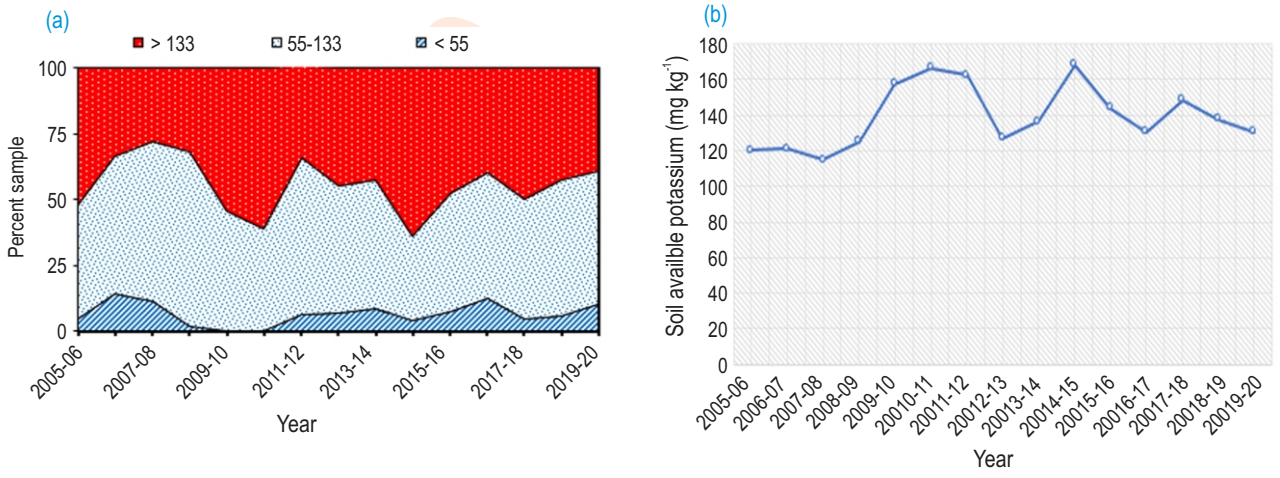


Fig. 6: Status of available potassium (mg kg^{-1}) in the soils of Punjab, India (a) percentage of samples falling under different categories and (b) weighted average, during 2005/06 to 2019/20.

Table1: Average grain yield (rice and wheat, t ha^{-1}), estimated carbon input through root biomass, stubble and rhizodeposition (t ha^{-1}) during 2005/06 to 2019/20

Parameter(s)	Rice	Wheat	Total
Grain yield	3.95 (± 0.15)	4.64 (±0.31)	8.59 (±0.41)
Root carbon	0.70 (±0.03)	0.45 (±0.03)	1.16 (±0.04)
Stubble carbon	0.11 (±0.001)	0.12 (±0.01)	0.23 (±0.01)
Rhizodeposition	1.26 (±0.05)	1.08 (±0.07)	2.34 (±0.11)
Total carbon input	2.07 (±0.08)	1.66 (±0.11)	3.73 (±0.17)

Figures in parenthesis indicate standard deviation

bulk density of 1.5 Mg m^{-3} for surface soils as per the regression equation (Fig. 4).

SOC (t ha^{-1}) = 3.0511 × Total Grain Yield (t ha^{-1}) - 13.684
R^2 = 0.684 (p <0.003)

For 15 years (2005/06 to 2019/20), based on the mean rice-wheat yield of 8.59 t ha^{-1}, the estimated belowground carbon inputs could be 3.73 t ha^{-1} contributed by both both rice (2.07 t C ha^{-1}) and wheat (1.66 t C ha^{-1}). Root, stubble and rhizodeposition contributed 1.16, 0.23 and 2.34 t C ha^{-1}, respectively to the below ground carbon in the rice-wheat cropping system (Table 1). The results further indicate that rice contributes more towards total below ground biomass C (55.5 %) compared to wheat (44.5 %). Out of that, contribution of rhizodeposition was more (60 to 65 %), compared to roots (27 to 33 %) and stubbles (5.3 to 7 %) in rice - wheat, system. Cereals transfers approximately 20-30 percent of the assimilated C back to the soil (Kuzyakov and Domanski, 2000). Considering half the amount of C is subsequently found in roots and approximately 1/3rd in CO_2 evolved from the soil by root respiration and microbial utilization of root borne organic substances (Benbi and Brar, 2009), our data from 2005/06 through 2019/20 indicates that approximately 26.8 percent of C transported into the soil accumulated in the surface plough layer. These estimates can give an insight for C input and accumulation balance under intensive cultivation of rice-wheat system in Punjab soils. Considering the below ground biomass including stubbles, estimated (3.29 t ha^{-1}) in the earlier study by Benbi and Brar (2009) during 1981/82 to 2005/06, an improvement to the tune of 13.4 percent was observed during the study period of 2005/06 to 2019/20. This enhanced the carbon sequestration, mainly attributed to better crop productivity, more belowground soil carbon and lower decomposition of SOM under submerged anaerobic conditions in rice. Apparently, intensive cultivation in Punjab soils can result in more soil C sequestration.

With regards to available phosphorus, the results indicated that the number of samples in high category of Olsen P (>9 mg kg^{-1}) increased spontaneously throughout the study period (Fig. 5a) with a corresponding decrease in the number of soil samples in 5-9 mg P kg^{-1} (medium) and <5 mg P kg^{-1} (low) category. The number of soil samples in high category increased from 32 percent in 2005/06 to 62 percent in 2019/20. In the medium category, the number of samples decreased from 33 percent in 2005/06 to 19 percent in 2019/20. Correspondingly, the number of samples in the low category of P decreased from 34 percent in 2005/06 to only 20 percent in 2019/20. The weighted mean for available P in soils showed an increasing trend from 9.9 mg P kg^{-1} in 2005/06 to 15.4 mg P kg^{-1} in 2019/20 with about 1.5 fold increase in 15 years period (Fig. 5b). This data of soil testing laboratory corresponds well with the observations from several long-term experiments and both indicate a considerable build-up in available P in the soils of Punjab (Benbi and Biswas, 1999). Therefore, Punjab Agricultural University advises the farmers that if the recommended dose of phosphatic fertilizer has already been applied to the preceding wheat crop, application of phosphatic fertilizer to paddy can be omitted without any yield penalty (Kumar and Kaur, 2022). Increase in soil available P level to 8 mg kg^{-1} or more can also lead to the risk of environmental problems associated with the loss of P from agricultural soils via downward leaching beyond the active root zone (Aulakh *et al.,* 2007) and further prediction of its downward movement to groundwater or flowing laterally into streams in Punjab. So, there is an urgent need to regulate P application rates to achieve high fertilizer P use efficiency and for environmental safety.

The available potassium in the soil samples from 2005/06 to 2019/20 are depicted in Fig. 6. This clearly shows that there was not much difference in the potassium content (across various categories) of Punjab soils during the last 15 years of study. In the low category (≤55 mg K_2O kg^{-1}), the per cent number of samples did not show much variation over the years, while for medium (55-133 mg K_2O kg^{-1}) and high (>133 mg K_2O kg^{-1}) categories, relatively more variation was observed. Earlier also, Benbi and Brar (2009) did not observe much variation in the potassium content of Punjab soils from 1981/82 to 2005/06. The percent number of samples in low category of K ranged from 0.09 to 14.02, for medium category from 32.0 to 66.07 and for high category from 28.22 to 64.0 in different years (Fig. 6a). There was lesser change in soil available potassium, in spite of generally low addition of K fertilizers. Which could be due to the contribution of large amounts of potassium from irrigation water (paddy-wheat system) and the K-bearing minerals (Illite and Biotite) in soils. The average K content in groundwater of Punjab is about 6.2 mg l^{-1} (Brar and Chhiba, 1997). Twenty irrigations (each of 5 cm depth) to rice add about 27-94 kg K ha^{-1}, whereas 4 irrigations (each of 7.5 cm depth) to wheat add 8-28 kg K ha^{-1} (Hundal *et al.,* 2009). Balance

Table 2: Yearly potassium balance in rice-wheat system during 2005/06 to 2019/20

Year(s)	Mean grain K uptake (kg ha^{-1})		Mean Straw K uptake (kg ha^{-1})		Total K output*	Total K input*	Annual K balance
	Rice	Wheat	Rice	Wheat	Rice+Wheat	Rice+Wheat	
2005-06	16.9	15.7	159.4	69.0	261.0	115.8	-145.1
2006-07	17.0	15.8	159.8	69.5	262.0	112.7	-149.3
2007-08	17.6	16.9	166.0	74.3	274.9	112.6	-162.3
2008-09	17.6	16.7	166.2	73.6	274.2	115.1	-159.1
2009-10	17.6	16.2	165.7	71.1	270.5	117.2	-153.3
2010-11	16.8	17.6	158.2	77.4	270.0	117.0	-153.0
2011-12	16.4	19.1	154.6	84.1	274.2	114.6	-159.6
2012-13	17.5	17.7	165.2	77.9	278.4	110.8	-167.6
2013-14	17.3	18.8	163.3	82.8	282.2	110.8	-171.4
2014-15	16.8	16.1	158.6	71.0	262.6	111.5	-151.1
2015-16	17.4	17.2	164.2	75.6	274.4	117.5	-156.9
2016-17	18.2	18.9	171.4	83.3	291.8	113.7	-178.1
2017-18	19.1	19.0	180.4	83.8	302.3	114.0	-188.3
2018-19	18.1	19.5	170.7	85.6	293.9	114.2	-179.7
Average	17.5	17.5	164.5	77.1	276.6	114.1	-162.5

*Potassium inputs are through fertilizers, rainfall, irrigation and seed

sheet of potassium in rice-wheat system in Punjab indicates negative balance in soils of Punjab (Table 2) attributed to more removal of potassium compared to addition.

Analysis of soil fertility parameters of last 15 years (2005/06 to 2019/20), depicted no adverse effect of major intensive cropping system rice-wheat, on SOC and other major soil properties of Punjab. Decrease of 0.3 units in soil pH towards neutrality indicates positive implications on the availability of nutrients. In-spite of intensive cultivation with cropping intensity > 180 % in the state, organic carbon content of the soils showed significant improvement from 4.0 to 5.4g kg^{-1}, probably due to contributions from the root and above ground biomass including stubbles along with improved carbon sequestration in the surface soils to the tune of 13.4%. Build-up of residual phosphorus (about 1.5-fold) indicates an urgent need to educate Punjab farmers for rational use of P application. In-spite of large removal of potassium by the crops, soils did not show any change in the potassium status. Overall, there is an indication of improvement in the general soil fertility parameters and carbon sequestration during the study period. However, regular monitoring of soil fertility parameters in the state is required to define/revise fertilizer recommendations in future and sustain agriculture in Punjab.

Acknowledgments

Authors are grateful to the Head, Department of Soil Science for providing the facilities to conduct the soil analysis and anonymous reviewers and R & D Team of *Journal of Environmental Biology* for their valuable suggestions and comments.

Authors' contribution: K. Singh, D. Singh: Preparation of the first draft, Data compilation and Proofreading; **A.S. Toor, O.P. Choudhary:** Improvement in the first draft of the MS, Strengthening of the MS and Proofreading; **S. Chandel:** Data compilation, manuscript writing and proofreading.

Funding: Not applicable.

Research content: The research content of manuscript is original and has not been published elsewhere.

Ethical approval: Not applicable.

Conflict of interest: There is no conflict of interest.

Data availability: Not applicable.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology*.

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