



Impact of Long-Term Application of Patranala Sewage on Carbon Sequestration and Heavy Metal Accumulation in Soils

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There is a gradual decline in good quality irrigation water for crop production. Farmers are forced to use poor quality water for crop production in peri-urban areas. Among the wastewater, sewage water generally contains higher amount of plant nutrients and dissolved organic matter. A case study was conducted to investigate the impact of untreated sewage water application on physicochemical properties and carbon sequestration in soil. For this purpose, peri-urban agricultural lands irrigated with sewage water from Patranala, Bhopal were selected. Such lands around both sides of the Patranala were being irrigated with sewage water for more than last 50 years. The soil samples were collected at various soil depths *i.e.*, 0-15, 15-30, 30-45 and 45-60 cm from these fields; and sampling points were at about 2 km intervals along the channel direction and also at the distance interval of about 0.5, 1.0, 1.5 and 2.0 km away from the sewage carrying channel. The soil microbial population and enzymatic activities were considerably higher in the sewage irrigated fields as compared to those in tubewell irrigated area. Concentrations of heavy metals in surface soils were also higher in sewage irrigated fields. Maximum soil organic carbon (SOC) contents were found in surface layer (0-15 cm), which decreased with depth at all the locations. Net stock of carbon in upper 60 cm of the soil depth was higher in sewage irrigated lands as compared to those irrigated with tubewell water. Thus, long-term application of sewage water for crop production enhanced sequestration of sewage borne carbon in soil profile, which otherwise could pollute the surface water bodies and emit in the atmosphere as greenhouse gases. However, heavy metals build-up in the sewage irrigated area is a major concern.

Key words: Carbon sequestration, heavy metals, plant nutrient, sewage irrigation

Due to rapid increase in population, and expansion of industrial sectors, there has been a reduction in the per capita availability of fresh water. Agriculture sector in India is consuming major fraction of fresh water resource, which however, is decreasing rapidly. India is having only 4% of global fresh water resource, but sustaining 16% of world population (Meena *et al.* 2016). Thus, there is a huge pressure on natural resources, especially water and land. Considerable part of fresh water resource is used for household activities, which released as sewage effluent after serving the purpose. Approximately 15,644 million liters per day (MLD) sewage is generated from Indian metropolitan cities (CPCB 2013). As per predictions by National Commission of Integrated Water Resource Development, the fresh water requirement for domestic and municipal by 2025 and 2050 will be

55 and 90 Bm³, respectively in India (NCIWRD 1999).

The use of sewage water for crop production are followed mostly in developing countries to fulfill the water requirement in water scarce areas. Sewage water supplies soil organic matter (SOM) and plant nutrients *i.e.*, nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magnesium (Mg), zinc (Zn), copper (Cu), iron (Fe), nickel (Ni), *etc.* (Saha *et al.* 2017). It enhances soil organic carbon (SOC) and soil fertility status, which helps in improving crop yields. Long-term irrigation with sewage water accumulates significant amount of heavy metals namely chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), Zn, Cu and Ni in soil which reach the human body *via* food chain (Dotaniya *et al.* 2017a). Use of tannery effluent mixed sewage water for crop production in Kanpur, raised Cr concentration in soil by 28-30 times (Dotaniya *et al.* 2017b). Adverse effect

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Table 1. List of villages using Patranala sewage water for irrigation

S. No.	Village	S. No.	Village	S. No.	Village
1	Khushipura	16	Ghashipura	31	Fatehpur
2	Nishatpura	17	Isalamnagar	32	Kadhahiya
3	Karaiya	18	Bherupura	33	Kirat Nagar
4	Sajidabad	19	Kanchbavli	34	Barkhedhi Abdulla
5	Kolua Kalan	20	Golkhedhi,	35	Karond Khurd
6	Khejrabaramad	21	Kalyanpura	36	Kayampur
7	Bhanpur	22	Khamkheda	37	Khejra
8	Shabri Nagar	23	Rusalli Beldar	38	Pipaliya Jumardar
9	Malkhedhi	24	Sumerkhedi	39	Cheel Kheda
10	Rusalli Khedi	25	Kala Pipal	40	Bhensh Kheda
11	Pipliya Bajkhan	26	Rasla Khedi	41	Jhirniya
12	Ghatkhedi	27	Mungalia Khurd	42	Chhatri
13	Sattikhedi	28	Agaria	43	Neenond
14	Devalkhedi	29	Chanched, Kanera	44	Hindola
15	Shyampur	30	Momanpur	45	Sukalia

of heavy metal on soil microbial activities and its related nutrient transformation process have long been recognized (Dotaniya *et al.* 2017c; Dotaniya and Pipalde 2018). The concentration and type of heavy metals present in sewage water are affected by its source of generation and extent of mixing with industrial effluent. A high accumulation of Cu (150-450 mg kg⁻¹) due to use of wastewater reduced the dehydrogenase, catalase and urease activities in soil (Wyszkowska *et al.* 2009); and also reduced the crop yield and quality. In addition to supply water for irrigation, sewage effluent also supplies SOC and substantial amount of plant nutrients. The SOC is considered an important constituent for good soil health and therefore a key factor for agricultural crop production and soil microorganisms diversity. Increasing or maintaining SOC in soil enhances microbial biomass which, in turn, facilitates mineralization of plant nutrients for crop uptake. Increasing the carbon sequestration of the soil through different process can also counter the global climate change. The available pool of C *i.e.* labile C is easily available to microbes as a source of food material, but is also converted to CO₂ a greenhouse gas (GHG) in the process to reach the atmosphere (Lal 2014). Therefore, in order to mitigate the emission of GHG, it is always desirable to reduce the mineralization of SOC or to sequester the C in the biologically resistant pool. Untreated sewage water contains considerable amount of dissolved and particulate organic C, which is considerably different from organic manure use in agricultural land in terms of both size fraction and chemical nature. Therefore, C accumulation pattern in sewage irrigated area is expected to be different from non-sewage irrigated area. In this backdrop, a

study was undertaken to investigate long-term use of sewage water as irrigation on soil physicochemical properties and SOC accumulation in different soil depths.

Materials and Methods

Crop history and location

The sewage water is being used for irrigation purpose for more than 50 years by farmers' of the study area due to ease of availability. The crops grown in these areas are mainly maize, rice, wheat and vegetables *i.e.* lettuce, coriander, radish, cabbage, cauliflower, bhindi, brinjal, chilli and fruit orchards *i.e.* citrus, mango and kinnow. This sewage channel, supply sewage water for irrigation in 45 villages mentioned in table 1.

All the farmers of above mentioned villages are getting good crop yield and easy approach to market. The sewage water supplies good amount of plant nutrients *i.e.*, organic carbon, N, P, S and micronutrients (Saha *et al.* 2016) leading to improved crop yields. During the interaction meetings, farmers informed about saving of more than 50% of recommended fertilizers doses without any harmful effect on crops because of sewage irrigation as was observed in earlier experiment (Saha *et al.* 2010).

Weather conditions

The meteorological data indicated that the minimum temperature (4.8 °C) was in the month of December and the maximum temperature (41.3 °C) in the end of June, 2014 (Fig. 1). The rainfall pattern also varied largely with the maximum rainfall (70.8 mm) in the month of July, and followed by August

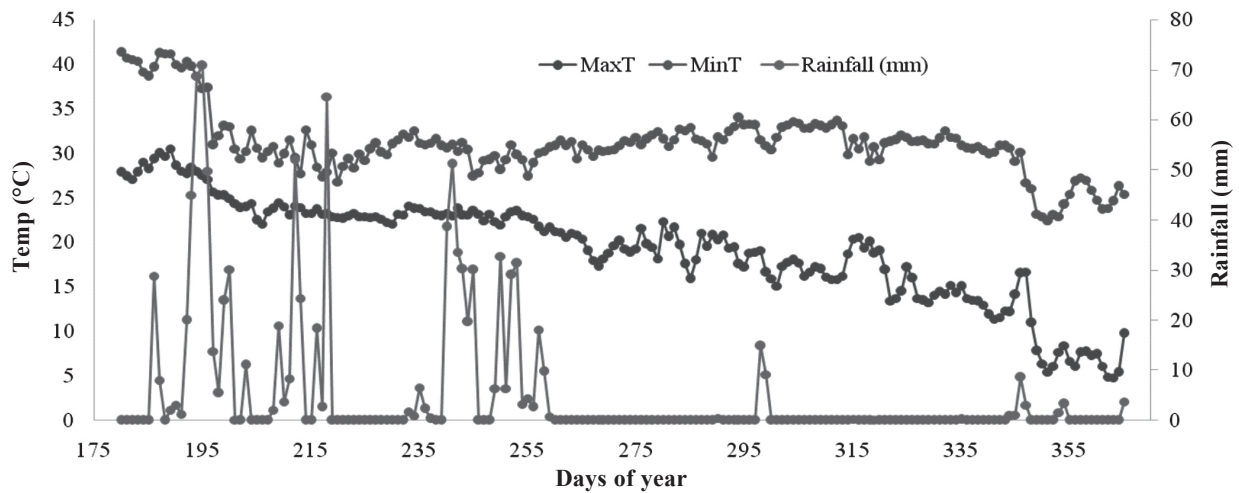


Fig. 1. Meteorological data during the sampling

and September and few rains in the months of October, November and December. These weather data indicated the pattern of sewage water used during non-rainy months for crop production. Increase in volume and flow of water in sewage channels due to rainfall might have diluted the concentration of heavy metals and plant nutrients present in sewage water as observed by Velusamy and Kannan (2016). This sewage water was a good source of irrigation for the cultivation of *rabi* crops during post-rainy days in this areas but higher concentration of heavy metals could be a major concern. Long-term application of such wastewater accumulated significant amount of heavy metals in soil and might affect the crop yield and quality.

Soil and sewage water sampling and analysis

Geo-referenced sewage and soil samples were collected from the sewage irrigated area around Patranala of Bhopal city (Madhya Pradesh). The samples of sewage water were collected for analysis of their chemical properties. For this, one set of sewage water was acidified with concentrated nitric acid @ 3-4 mL L⁻¹ to prevent precipitation of metals present in water and was kept for heavy metal analysis. Another set of sewage water was used for the estimation of organic carbon (OC), pH, electrical conductivity (EC) and available plant nutrients. In sewage water, physicochemical properties were analyzed as per the standard methods mentioned by Singh *et al.* (2005).

Soil profile sampling and analysis

For assessing C sequestration, soil samples were

collected from different depths (0-15, 15-30, 30-45 and 45-60 cm) at agricultural fields at the interval of 2 km along the Patranala; and at 0.5, 1.0, 1.5 and 2.0 km interval in perpendicular distance away from sewage channel (Fig. 2). Soil samples were collected from a total of 45 sampling points in sewage irrigated peri-urban areas and from 8 sampling points in tubewell irrigated fields of adjoining area. The collected soil samples were kept in plastic bags with proper tagging like sampling time, crop history, number of sewage irrigation and other related information. In the laboratory, soil samples were air-dried, ground with wooden pestle and mortar and passed through a 2-mm sieve and were analyzed for physicochemical properties as per methods mentioned in Singh *et al.* (2005). The SOC stock was calculated with the help of bulk density and C content in different soil depths. The biochemical activities in soil like dehydrogenase activity (DHA) was measured as outlined by Casida *et al.* (1964); fluorescein di-acetate hydrolytic activity (FDA) was measured by Adam and



Fig. 2. Collection of soil and sewage samples

Duncan (2001) method and alkaline phosphatase activity was measured by Tabatabai and Bremner (1969) method. The microbial biomass (bacteria, fungi and actinomycetes population) was also assessed with the help of standard procedure. For total heavy metals contents, soil and sewage water samples were digested with aqua-regia (75% concentrated HCl: 25% concentrated HNO₃) and measured with the help of inductively coupled plasma-optical emission spectrophotometer (ICP-OES; Perkin Elmer Precisely Optima 2100 DV).

Statistical analysis

The random sample data on SOC under different depth has been analyzed for the statistical significance and comparison along with different depth by using the two sample (small) t-test statistics at 5% level of significance. The statistical analysis of the data were performed with the help of SAS-9.3 version.

Result and Discussion

Physicochemical properties of sewage water

The pH range of sewage was 7.4-8.5 which indicated neutral to slightly alkaline reaction. However, EC varied from 0.36 to 0.62 dS m⁻¹. The total organic carbon varied widely from 98 to 235 mg L⁻¹ with an average value of 214 mg L⁻¹. Available N, available P and available K were in the range of 21-29, 19-23 and 17-24 mg L⁻¹, respectively. The nutrients content in sewage water can vary with the source and extent of sewage addition, merging of channels from different origin during the flow and the weather conditions during the sample collection. Saha *et al.* (2016) reported the high manurial value in the sewage irrigated field as well as in sewage water used for irrigation purpose. Higher pH and EC depends on the source of sewage and additional mixing of intermittent small channels into the sewage

channel. Meena *et al.* (2016) reported that sewage water contained significant amount of OC in effluent and it is increasing the soil fertility levels during the crop production.

Heavy metal content in sewage water

The result indicated that the concentrations of metals were low in all the sampling points (Table 2). The Cu concentration was lower at source point and increased with increasing the distance up to Islam Nagar and thereafter it was almost constant. The Cd concentration was almost equal in all the sampling points. The irregular pattern of Pb concentration in soils was observed; whereas, Cr concentration was higher in upstream samples collected up to Islam Nagar. The Ni and Zn concentrations were higher up to Bhanpur Bridge and subsequently, reduced up to Halali Dam. The heavy metals (except Cu and Zn) in tubewell water samples were found below the detection limits of ICP-OES (Table 2). The concentrations of heavy metals in the sewage water samples were in the safe range as per the wastewater standard for irrigation described by FAO (1985). The seasonal variation affected the heavy metals concentration in sewage effluent. In rainy season, dilution effect affected the total metal concentration by increasing the volume of water (Velusamy and Kannan 2016). The concentration of metal and other plant nutrients found more in May-June months as compared to rainy months.

Heavy metal content in soil

The results showed that average values of heavy metals in sewage water irrigated soils were 61.5, 3.94, 11.8, 41.9, 47.1 and 64.7 mg kg⁻¹ for Cu, Cd, Pb, Cr, Ni and Zn, respectively (Fig. 3). However, in tubewell water irrigated soils, the average metals contents were 28.7, 1.28, 11.2, 23.9, 23.0 and 40.1 mg kg⁻¹ for Cu, Cd, Pb, Cr, Ni and Zn, respectively. The continuous

Table 2. Heavy metal content in sewage water

Points	Cu	Cd	Pb	Cr	Ni	Zn
	(µg L ⁻¹)					
Source point to before Bhanpur bridge	2	1	14	9	17	37
Bhanpur bridge to highways crossing	6	1	13	6	13	29
Highways crossing to Islam Nagar	11	1	11	6	3	3
Sumer khedi to Agariya	12	1	9	1	2	5
Agariya to Cheelkhedi	11	1	7	0	1	6
Cheelkhedi to HalaliDam	14	1	15	1	4	8
Metal content in tubewell irrigated water	1	ND	ND	ND	ND	2
FAO (1985) standared for waste water (mg L ⁻¹)	0.2	0.01	5.0	0.1	0.2	2.0

ND-not detected

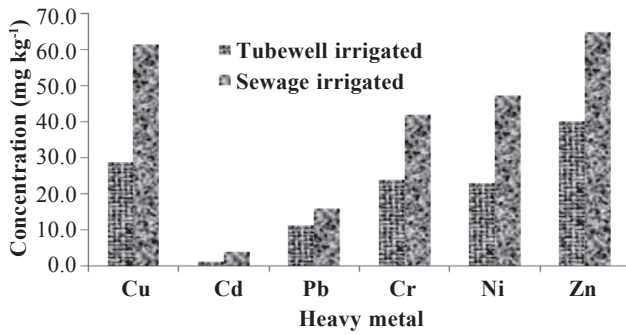


Fig. 3. Heavy metal concentration in sewage irrigated vs tubewell irrigated field

sewage water application for crop production resulted in accumulation of significant amount of heavy metals in the soil. The magnitude of increments in sewage contaminated soils were 2.14, 3.20, 1.41, 1.75, 2.04 and 1.61 times in case of Cu, Cd, Pb, Cr, Ni and Zn, respectively as compared to tubewell irrigated soils. The extent of accumulation of total heavy metals followed the sequence: Cd>Cu>Ni>Cr>Zn>Pb. The concentration of heavy metals were, however within the safe limit for crop cultivation (FAO 1985). The soil surface samples were collected and analyzed for the metal concentration with DTPA. The DTPA extracted metals represent the labile concentration of plant nutrients or heavy metals. The concentration of DTPA extractable Zn, Cu, Fe, Mn, Cd, Pb, Cr and Ni were 1.26, 4.53, 29.4, 11.3, 0.04, 1.45, 0.03 and 0.64 mg kg⁻¹ soil, respectively. The long-term application of sewage water, might have accumulated significant amount of metals in extractable fraction which could affect the soil and crop health (Narwal *et al.* 1993). Similar accumulation of heavy metals in soil in south-west Delhi due to effluent irrigation was observed by Gurjar and Yadav (2013). Yadav *et al.* (2002) reported that the long-term application of sewage water accumulated significant amount of heavy metals in soil. Some of the metals (Cu and Zn) increased many fold. The source and the mixing of household and

industrial channels also increased the availability of metals and other organic load in sewage water (Dotaniya *et al.* 2017b). Similar finding was also reported from peri-urban agricultural lands under the Keshopur effluent irrigation scheme (KEIS) of Delhi (Meena *et al.* 2016).

Soil organic carbon content

The SOC was higher in the upper layer (0-15 cm) of soil and lower in the deeper soil depths (Table 3). The average SOC in soils from 0.5 km away from the sewage channel was 11.7 g kg⁻¹ in 0-15 cm and 8.2 g kg⁻¹ in 45-60 cm depth; whereas, at 1.0 km distance the mean SOC was 10.5 g kg⁻¹ in 0-15 cm and 7.0 g kg⁻¹ in 45-60 cm soil depth. At 1.5 km away from sewage channel, the mean SOC of 11.1, 9.4, 8.5 and 7.6 g kg⁻¹ were measured in 0-15, 15-30, 30-45 and 45-60 cm depth, respectively. Mean SOC at 2 km away from the channel, were 10.3, 9.3, 8.5 and 7.4 g kg⁻¹ in 0-15, 15-30, 30-45 and 45-60 cm soil depth, respectively. The SOC values were 7.0, 5.5, 4.2 and 3.0 g kg⁻¹ in 0-15, 15-30, 30-45 and 45-60 cm, respectively in non-sewage irrigated fields, which was lesser than sewage irrigated soils. While moving away from the sewage channel, the accumulation rate of SOC showed decreasing trend. This might be due to less frequency of irrigations with sewage water. The nearby fields to Patranala might have receive more number of irrigation compared to far away fields. The SOC was also decreased with depth of the soil depths. The results thus showed that proximity of the sewage channel received more amount of sewage and more possibility to accumulation of SOC in a lower soil depths.

Carbon sequestration in soil profile

Carbon sequestration in sewage irrigated soils was calculated with the help of a standard procedure by taking soil bulk density values. The carbon sequestration values were more in the sewage irrigated

Table 3. Soil organic carbon (SOC) in various soil depths

Soil depth (cm)	Sewage irrigated field				Tubewell irrigated
	Distance away from sewage channel (km)				
	0.5	1.0	1.5	2.0	
	SOC (g kg ⁻¹)				
0-15	11.7 ^a	10.5 ^a	11.1 ^a	10.3 ^a	7.0 ^a
15-30	9.9 ^b	9.7 ^{ab}	9.4 ^{ab}	9.3 ^{ab}	5.5 ^b
30-45	9.3 ^{bc}	8.5 ^{bc}	8.5 ^b	8.5 ^{bc}	4.2 ^{bc}
45-60	8.2 ^c	7.0 ^c	7.6 ^b	7.4 ^c	3.0 ^c

Values followed by different letters or no same letter/letters in common column wise are significantly different at 5% level of significance

Table 4. Carbon sequestration potential of sewage irrigated fields

Distance from sewage channel (km)	SOC sequestration (tonnes C ha ⁻¹ 60 cm ⁻¹)	Increment (%)
0.5	85.2	71.5
1.0	77.4	55.9
1.5	81.2	63.4
2.0	79.4	59.9

field as compared to tubewell irrigated fields. The computed carbon sequestration in 60 cm soil depth was 85.2 tonnes C ha⁻¹ at 0.5 km and 79.4 tonnes C ha⁻¹ at 2 km horizontal distance from the sewage channel (Table 4). The maximum carbon sequestration was measured in upper part of soil depth (0-15 cm) at 0.5 km distance from the sewage channel; whereas, the minimum sequestration was measured in lower part of soil depth (45-60 cm) at 2 km away from the sewage channel. These data clearly point out the positive effect of sewage irrigation on carbon sequestration. Accumulated SOC at lower part of the soil depth have less chance to oxidation-mineralization due to less exposure to air and therefore, is expected to have higher residence time (Ashworth and Alloway 2004). Vertical movement of SOC in soil profiles are influenced by the soil properties (Yadav *et al.* 2002). Swell-shrink characteristics of the soils of study area facilitates migration of sewage carbon to lower soil depths.

Microbial population

The results showed that the population of microbial biomass was much higher in sewage irrigated soils compared to those from tubewell irrigated area (Table 5). The population of bacteria, fungi and actinomycetes in sewage irrigated fields were in the ranged of $4.6 \times 10^6 - 1.9 \times 10^7$, $7.0 \times 10^4 - 1.7 \times 10^5$, $4.0 \times 10^5 - 4.1 \times 10^6$ cfu g⁻¹ soil; whereas the same in tubewell irrigated fields were $1.7 \times 10^6 - 2.0 \times 10^5$, $2.0 \times 10^4 - 3.0 \times 10^4$ and $3.0 \times 10^4 - 2.9 \times 10^4$ cfu g⁻¹ soil, respectively. Thus, average population of bacteria, fungi and actinomycetes in sewage irrigated soils were significantly higher (1.3, 13.5 and 5.6 times, respectively) as compared to the tubewell irrigated area. The application of high volume of sewage water enhanced the SOC in soil, that might have acted as a food material for soil microorganisms (Saha *et al.* 2010). Later on, Saha *et al.* (2010) pointed out that use of Patranala sewage water enhanced the soil bacterial population as compared to groundwater

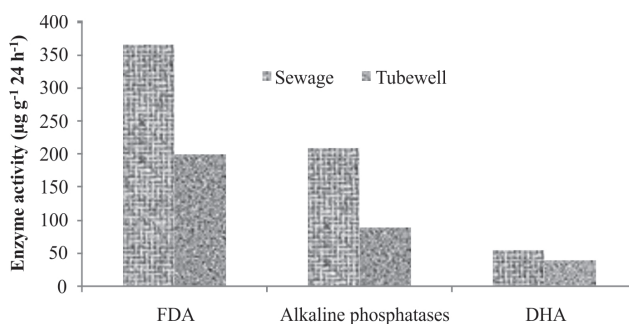
Table 5. Microbial population in sewage irrigated fields

Microbial population	Range (cfu g ⁻¹ soil)	
	Sewage irrigated soils	Tubewell irrigated soils
Bacteria	$4.6 \times 10^6 - 1.9 \times 10^7$	$1.7 \times 10^6 - 2.0 \times 10^5$
Fungi	$7.0 \times 10^4 - 1.7 \times 10^5$	$2.0 \times 10^4 - 3.0 \times 10^4$
Actinomycetes	$4.0 \times 10^5 - 4.1 \times 10^6$	$3.0 \times 10^4 - 2.9 \times 10^4$

irrigation. Similar type of study was also carried out and reported at Vishnupuri, Nanded by Sonune *et al.* (2015).

Enzymatic activities

The values of FDA, alkaline phosphates and DHA were 366, 209 and 55 µg g⁻¹ 24h⁻¹ in sewage irrigated surface soils and were 200, 90 and 38 µg g⁻¹ 24h⁻¹ in tubewell irrigated fields, respectively (Fig. 4). In the sewage irrigated field, higher amount of plant nutrients and organic matter enhanced the growth of soil biota and also enhanced the level of soil enzymes. These microorganisms promote various types of soil enzymatic activities and favourably influence the plant nutrient dynamics in soil. Levantesi *et al.* (2010) also observed increase in microbial count and activities of soil enzymes secreted by the elevated count of the microbial population in sewage irrigated crop fields. The higher availability of SOC and nutrient elements acts as source of carbon and energy for soil microbial biomass which was directly and indirectly responsible for the increase in soil enzymatic activities (Dotaniya *et al.* 2018).

**Fig. 4.** Effect of sewage and tubewell irrigation on soil enzymatic activities

Conclusions

Use of sewage water for irrigation supplied plant nutrients and supported profuse crop growth and yield. Long-term application of sewage water increased the organic matter status and accumulated heavy metals in the soils. The per cent increment of metals were 2.14, 3.20, 1.41, 1.75, 2.04 and 1.61 times for Cu,

Cd, Pb, Cr, Ni and Zn, respectively in sewage irrigated soils. Concentration of all the metals were however, in the safe limit for the cultivation of agricultural crops as per guidelines mentioned by FAO (1985). Sewage water needs proper pre-treatment before use in agricultural purpose. The microbial count was also higher in sewage irrigated agricultural fields. Long-term use of sewage water for irrigation stored more amount of carbon in soil and improved the soil fertility. This showed that the long-term use of sewage water is beneficial for soil health. However, a strict monitoring of metal accumulation in the soil has to be undertaken at periodic interval.

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