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REVIEW ARTICLE

PHYSICO-CHEMICAL STUDIES OF TANNERY WASTE AND SEWAGE SLUDGE TO ESTIMATE CARBON CONTENT IN AMENDED SOIL

*,[1]Neeraj Kumar, [1]Kushmander Singh, [2]Sangeeta Agarwal, and [3]Anil Kumar

[1]S.S.M.V. (PG) College, Shikarpur, Bulandshahr (India)
[2]S.S.V. (PG) College, Hapur, (India)
[3]Radio Tracer Laboratory, Division of soil Science and Agricultural Chemistry, I.A.R.I. New Delhi-12, India

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ABSTRACT

Sewage sludge generated from wastewater treatment plants are being merited greater attention in light of their potential for improving soil properties and for providing important nutrient and trace element supplements that are essential for plant growth. Because of the differences in sludge characteristics among sludges that undergo different levels of treatment as well as the extensive and variable nature of pollutant inputs to wastewater, the fertilizer potential and pollutant risk of sewage sludge intended for agricultural application has to be specifically evaluated for each sludge. Sewage sludge generated from seven wastewater treatment plants in Swaziland were analysed for a range of physico-chemical characteristics including organic matter, nutrients, cation exchange capacity, pH and trace elements. Despite the differences in sludge processing and sludge storage ages, the sludge samples generally show high levels of organic matter, nutrients and trace elements needed for plant growth. The potential risk of heavy metal toxicity was evaluated by comparing the levels of heavy metals in the sludge samples with widely quoted and well known regulatory limits of a number of countries and the levels were found to be within acceptable risk level with respect to agricultural application. Chrome tannery sludge applied to agricultural land may have benefits in terms of added N for crop growth. An experiment was designed to compare tannery waste with commercial N fertilizer and investigate the potential of the waste as an alternative or supplement to commercial fertilizer. Soils with 38% and 7% organic C and N content of 1.3% and 0.2%, respectively, were amended with lime, commercial N fertilizer, or tannery sludge containing 1.6% Cr. A portion of the tannery waste was supplemented with additional Cr(+3) salt before adding to the soils. The amended soils were analyzed for total Cr, ammonium acetate extractable Cr, selected nutrient and trace element concentrations. The tannery sludge increased soil pH, total Cr and N, S, Ca, P, Mg, and Na concentrations.

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INTRODUCTION

The alarmingly increasing urbanization and industrialization countrywide has generated enormous amount of inorganic and organic wastes posing to serious problem of safe disposal. Nearly 450 cities in India generate around 1200 tonnes of sewage sludge every day, although there exists a potential to produce 4000 tonnes of sludge per day (Kaul *et al*., 1989). Sewage sludge contains variable amounts of heavy metals like Pb, Cr, Ni, Cd etc. as well as essential plant nutrients like N,P,K,S, and Zn *etc*. Sewage sludge is generally disposed off or applied in agricultural lands as a source of plant nutrients. Long term application of sewage sludge has been reported to elevate concentrations of heavy metals in soils around Delhi (Bansal *et al.,* 1992), Calcutta (Adhikari *et al*., 1993) and Ludhiana (Arora and Chhibba. 1992). These metals once mixed into agricultural soils, do not leach appreciably and get accumulated in surface plough layer by adsorption or precipitation phenomenon (Leeper, 1978, Sakal *et al*., 1992). Thus, a limiting factor in the long term and indiscriminate use of sewage sludge on agricultural lands is the likelihood of excessive accumulation of heavy metals such as Zn, Cd, Pb, Cr, and Ni in the soil and resultant phytotoxicity. Tanning is one of the oldest industries in the world. During ancient times, tanning activities were organized to meet local demands of leather foot wears, and musical instruments (Durai and Rajasimman, 2011). Tanning is the chemical process that converts animal hides and skin into stable and imputrescible products called leather (Hayelom and Adhena 2014 and Giusy *et al*., 2013). The transformation of hides into leather is usually done by means of tanning agents and the process generates highly turbid, colored and foul smelling effluent (Hayelom and Adhena 2014 and Buljan and Kral. 2011). Two adopted methods for tanning of raw hide/skin are; vegetable tanning and chrome tanning. The production processes in a tannery categorize into four namely; Beam house operations, Tanyard operations, Post tanning operations and finishing operations (Durai and Rajasimman, 2011). The addition of biochar to contaminated soils is an effective method to immobilize heavy

***Corresponding author: Neeraj Kumar,**
S.S.M.V. (PG) College, Shikarpur, Bulandshahr (India)

metals and reduce bioavailability (Li *et al*., 2016; Yang *et al*., 2017). The capacity of biochar to adsorb heavy metals mainly depends on feedstock type and pyrolysis temperature (Luo *et al*., 2015; Keiluweit *et al*., 2010 and Mukherjee *et al*., 2011). A number of studies have described the effect of biomass type (such as agricultural waste, forestry waste, livestock and poultry waste, and municipal sludge) on the adsorption capacities of biochars, especially in terms of heavy metal adsorption; the results showed good application prospects with a significant difference in adsorption capacity of Pb, Cd, Cu, and Zn between different biochars (Xu *et al*., 2013, Wang *et al*., 2015 and Fristak *et al*., 2015). Pyrolysis temperature significantly influences pore size distribution, functional groups, elementary composition, and the pH value of biochar (Shaaban *et al*., 2013, Fu *et al*., 2012 and Yuan *et al*., 2015), thereby determining adsorption capacity of heavy metal from aqueous solutions and metal mobility in soils (Kim *et al*., 2013, Chen *et al*., 2014 and Melo *et al*., 2013). For example, the high Cr sorption (208 mg·kg−1) on sludge biochar in solution has been associated with low pyrolysis temperatures due to the high number of functional organic groups (Zhang *et al*., 2013).In contrast, only 32.3 mg·kg−1 of Cr has been shown to be immobilized in soil (Fang *et al*., 2016). The removal capacity for Cd (II) and Zn (II) by biochar in solution and soils improved with higher pyrolysis temperatures due to O-containing functional groups, but the effects achieved with liming were more pronounced due to precipitation of Cd or Zn (Melo *et al*., 2013). Based on previous research, the heavy metal adsorption capacity of biochar differs between solutions and soil environments. Compared with solutions, soil systems are extremely complex, making it difficult to demonstrate heavy metal immobility attributed to the biochar.

MATERIALS AND METHODS

Soil sampling: Bulk surface sample (0-15 cm) of soil (Typic Haplustept) was collected from the agricultural land. The processed soil sample was used for laboratory and pot culture studies. Some important physico-chemical characteristics of the experimental soil have been shown in Table 1a.

Sewage sludge: Bulk sewage sludge sample was collected from the Sewer Treatment Plant, Industrial Estate Okhla, New Delhi. It was air dried, ground to pass through 2 mm. sieve and mixed thoroughly before use. The solid and powdered forms of sewage sludge have been displayed through plate-1a. The important physico-chemical characteristics have been presented in Table 1.

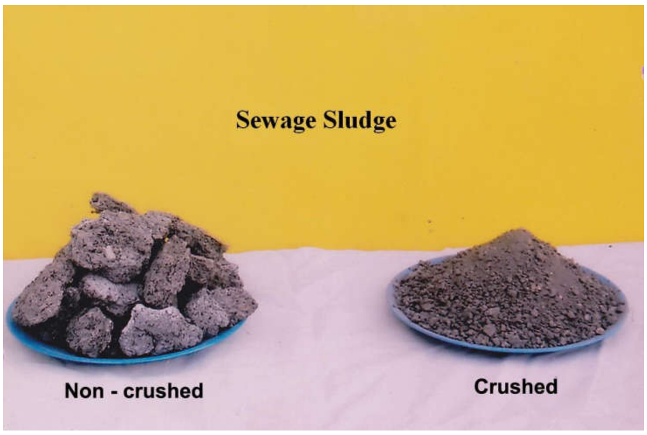

Table 1. Physico-chemical characteristics of the experimental sewage sludge, tannery waste and soil

Characteristics	Sewage sludge (Value)	Tannery waste (Value)	Soil (Value)
pH (Soil: water, 1:25)	7.1	7.6	7.8
EC (Soil:water, 1:2.5 d S m^{-1})	2.67	3.21	0.39
Mechanical analysis			
Sand (%)			44.3
Silt (%)			33.4
Clay(%)			20.6
$CaCO_3$(%)			1.7
Textural class			Loam
Organic carbon(%)	24.8	35.2	0.21
CEC [C mol (p$^+$) kg^{-1} soil			10.2
Available N (kg ha^{-1})			182
Available P (kg ha^{-1})			9.2
Available K (kg ha^{-1})			210
DTPA extractable heavy metal (mg kg^{-1}) in soil			
Cr			0.006
Ni			0.085
Pb			0.578
Nutrients in organic wastes			
N (%)	1.36	2.79	
P (%)	0.33	0.21	
K (%)	0.38	0.59	
SO_4(%)	0.62	2.08	
Heavy metal (mg kg^{-1}) in organic wastes			
Cr	35.96	364.5	
Ni	26.25	6.58	
Pb	74.30	17.66	
Zn	1178.20	154.20	
Fe	14300.00	880.8	
Mn	283.9	16.4	
Cu	206.90	8.80	
Cd	1.90	0.30	

Tannery waste: Bulk sample of tannery waste was collected from Tannery Industrial Area, Unnao (Kanpur), U.P. The non-crushed tannery waste was in the form of lumps of various sizes with majority size of 5 cm ×5 cm ×3 cm which were coal black in colour and leathery in touch giving out intense foul smell which took more than four months in drying. The dried clods/lumps were broken with hammer into small pieces of various dimensions. The crushed and non-crushed forms of tannery waste have been exhibited through plate-2b. Important physico-chemical characteristics of tannery waste have been shown in Table 1.

Analytical procedures used in the analysis of organic wastes, plant and soil have been shown in Table 2.

Table 2. Analytical procedures used in organic wastes, soil and plant analysis

Physico-chemical characteristics	Method/Instrument/reagent used	Reference
pH	In 1:2.5, soil-water suspension using combined electrode (glass and colomel)	Jackson (1973)
EC	In 1:2.5 soil-water suspension using conductivity bridge	Jackson (1973)
Mechanical analysis of soil	Bouyoucos hydrometer method	Day (1965)
Textural Class		USDA soil survey Staff (1966)
CEC	In NH_4OAC for leaching cations	Gillman (1979)
Organic carbon	Wet digestion method	Walklay and Black (1934)
Available nutrient in soil		
N	Alkaline permenganate method	Sabbiah and Asija (1956)
P	0.5 M-$NaHCO_3$ (pH 8.5)	Olsen *et al*. (1954)
K	1 N- NH_4 OAC (pH 7.0)	Hanway and Heidel (1952)
DTPA extractable heavy metal in soil (Cr, Ni and Pb)	0.05M-DTPA, 0.01M-$CaCl_2.H_2O$ and 0.1 M TEA and using ICAP-AES	Lindsay and Norwell (1978)
Total nutrients in organic wastes		
N	Diacid (HNO_3:$HClO_4$, 5:1) digestion	Kjeldahl procedure as described by Jackson (1967)
P	Do and using flame photometer	
K	Do using turbidity method	Koenig and Johnson (1942)
SO_4		
Total heavy metal in organic wastes (Cr,Ni, Pb, Fe, Cu, Zn, Mn, Cd)	Diacid (HNO_3:$HClO_4$, 5:1) digestion and using ICAP-AES	

Treatment details

***Organic Wastes*: Two**

- Sewage Sludge
- Tannery Waste

Levels of organic waste: Two

- 1.5% : 15 g of organic waste per kg soil
- 3.0 % : 30 g of organic waste per kg soil

Amendments: Four

- No amendment (organic waste alone)
- Calcium carbonate (5%): 50 g of $CaCO_3$ per kg soil
- Diammonium phosphate: 150g DAP (35.3mg P kg^{-1}) per kg soil
- Ethylene diamine tetra acetic acid (0.1%): 1 g EDTA per kg soil

Sampling stages: Two

- 6 months after application of treatments
- 12 months after application of treatments

Replications: Three

Experimental design: Completely Randomized Design (Factorial)

Treatments combination:

Upland soil conditions	*Submerged soil conditions*
T_1: Control	T_1: Control
T_2: Sewage Sludge (1.5%)	T_2: Sewage Sludge (1.5%)
T_3: Sewage Sludge (3.0%)	T_3: Sewage Sludge (3.0%)
T_4: Tannery Waste (1.5%)	T_4: Tannery Waste (1.5%)
T_5: Tannery Waste (3.0%)	T_5: Tannery Waste (3.0%)
T_6: Sewage Sludge (1.5%) + $CaCO_3$	T_6: Sewage Sludge (1.5%) + $CaCO_3$
T_7: Sewage Sludge (1.5%) + DAP	T_7: Sewage Sludge (1.5%) + DAP
T_8: Sewage Sludge (1.5%) + EDTA	T_8: Sewage Sludge (1.5%) + EDTA
T_9: Sewage Sludge (3.0%) + $CaCO_3$	T_9: Sewage Sludge (3.0%) + $CaCO_3$
T_{10}: Sewage Sludge (3.0%) + DAP	T_{10}: Sewage Sludge (3.0%) + DAP
T_{11}: Sewage Sludge (3.0%) + EDTA	T_{11}: Sewage Sludge (3.0%) + EDTA
T_{12}: Tannery Waste (1.5%) + $CaCO_3$	T_{12}: Tannery Waste (1.5% + $CaCO_3$
T_{13}: Tannery Waste (1.5%) + DAP	T_{13}: Tannery Waste (1.5%) + DAP
T_{14}: Tannery Waste (1.5%) + EDTA	T_{14}: Tannery Waste (1.5%) + EDTA
T_{15}: Tannery Waste (3.0%) + $CaCO_3$	T_{15}: Tannery Waste (3.0%) + $CaCO_3$
T_{16}: Tannery Waste (3.0%) + DAP	T_{16}: Tannery Waste (3.0%) + DAP
T_{17}: Tannery Waste (3.0%) + EDTA	T_{17}: Tannery Waste (3.0%) + EDTA

RESULTS

Data on soil organic carbon content as influenced by various treatments of organic wastes under upland soil moisture regime at 6 and 12 month incubation period have been shown in Table 3. A perusal of data on soil organic carbon content demonstrated in table 3 clearly indicated that various treatments of two organic waste and their levels with and without amendments significantly increased the soil organic carbon pool both at 6 and 12 month time after their application under upland soil moisture regime over control. The over all variation in soil organic carbon content brought about by various treatments ranged from 2.82 g kg^{-1} with T_5 to 6.78 g kg^{-1} with T_{14} treatments at 6 month and 2.20 g kg^{-1} with T_3 to 6.85 g kg^{-1} with T_{14} treatment at 12 month as against 1.27 g kg^{-1} at 6 month and 1.23 g kg^{-1} at 12 month recorded with control (T_1). Data further showed that the trend in the values of organic carbon content across the treatments at both period of incubation (6 and 12 month) was identical. However, all the treatments showed a slight decrease in organic carbon content at 12 month in comparison to 6 month incubation time except the treatments where 3.0% level of tannery waste was applied either alone (T_{14}) or along with amendments (T_{15}, T_{16} and T_{17}). The different treatments with 3.0% level irrespective of source of organic waste had significantly higher organic carbon content than the corresponding treatments with 1.5% level of organic waste at both the time interval of incubation.

Table 3. Soil organic carbon content under upland soil moisture regime as influenced by various treatments of organic wastes

Treatments	Soil organic carbon content (g kg^{-1})	
	6 Month	12 Month
T_1 Control	1.27	1.23
T_2 S.S. (1.5%)	2.89	2.35
T_3 S.S. (1.5%) + $CaCO_3$	3.04	2.20
T_4 S.S. (1.5%) + DAP	3.47	2.55
T_5 S.S. (1.5%) + EDTA	2.82	2.50
T_6 S.S. (3.0%)	4.52	3.85
T_7 S.S. (3.0%) + $CaCO_3$	4.80	3.37
T_8 S.S. (3.0%) + DAP	5.37	4.25
T_9 S.S. (3.0%) + EDTA	4.35	4.17
T_{10} T.W. (1.5%)	4.90	4.55
T_{11} T.W. (1.5%) + $CaCO_3$	4.06	3.95
T_{12} T.W. (1.5%) + DAP	3.92	3.25
T_{13} T.W. (1.5%) + EDTA	4.25	3.37
T_{14} T.W. (3.0%)	6.78	6.85
T_{15} T.W. (3.0%) + $CaCO_3$	4.68	5.82
T_{16} T.W. (3.0%) + DAP	4.35	5.27
T_{17} T.W. (3.0%) + EDTA	5.20	5.42
S.Em. (±)	0.192	0.245
C.D. (5%)	0.554	0.710

S.S. : Sewage Sludge, T.W. : Tannery Waste

Data pertaining to the effect of different treatments of organic wastes on soil organic carbon content under submerged soil moisture regime at 6 and 12 month incubation period have been presented in Table 4. A close examination of data on soil organic carbon content displayed in table 4 reveals that different treatments of organic wastes, their levels with and without amendments significantly enhanced the soil organic carbon pool at 6 and 12 month time after their application under submerged soil moisture regime over control. The overall variation in the values of soil organic carbon produced by various treatments under submerged soil moisture condition ranged from 3.20 g kg^{-1} with T_2 to 7.12 g kg^{-1} with T_{17} treatment at 6 month and from 2.20 g kg^{-1} with T_2 to 8.52 g kg^{-1} with T_{15} treatment at 12 month as against 1.50 g kg^{-1} at 6 month and 1.15 g kg^{-1} at 12 month observed with control (T_1).

It was further noticed that the treatments based on sewage sludge (T_2 to T_9) showed a slight decrease in organic carbon pool at 12 month period in comparison to their corresponding treatment at 6 month period. However, the trend in the values of organic carbon content across the treatments at 6 month as well as 12 month period was found identical. Data further showed that the treatments where tannery waste was applied at 3.0% levels (T_{14}, T_{15},T_{16} and T_{17}), exhibited a slight increase in organic carbon content at 12 month incubation time as compared to their corresponding treatments at 6 month time under submerged soil moisture condition. In general, treatments associated with 3.0% level, regardless of the source of organic waste, produced significantly higher organic carbon content over their corresponding treatments associated with 1.5% level of organic waste both at 6 and 12 month incubation time.

Table 4. Effect of various treatments of organic wastes on soil organic carbon content under submerged soil moisture regime

Treatments	Soil organic carbon content (g kg^{-1})	
	6 Month	12 Month
T_1 Control	1.50	1.15
T_2 S.S. (1.5%)	3.20	2.20
T_3 S.S. (1.5%) + $CaCO_3$	3.29	2.30
T_4 S.S. (1.5%) + DAP	3.95	2.62
T_5 S.S. (1.5%) + EDTA	3.35	2.32
T_6 S.S. (3.0%)	5.03	3.82
T_7 S.S. (3.0%) + $CaCO_3$	5.15	3.98
T_8 S.S. (3.0%) + DAP	6.53	4.63
T_9 S.S. (3.0%) + EDTA	5.25	4.00
T_{10} T.W. (1.5%)	4.67	4.75
T_{11} T.W. (1.5%) + $CaCO_3$	4.42	5.50
T_{12} T.W. (1.5%) + DAP	4.90	4.85
T_{13} T.W. (1.5%) + EDTA	4.27	5.05
T_{14} T.W. (3.0%)	5.90	7.12
T_{15} T.W. (3.0%) + $CaCO_3$	5.40	8.52
T_{16} T.W. (3.0%) + DAP	6.35	7.35
T_{17} T.W. (3.0%) + EDTA	7.12	7.70
S.Em. (±)	0.331	0.150
C.D. (5%)	0.958	0.433

Data on mean soil organic carbon content (g kg^{-1}) as influenced by various factors *viz*. organic wastes, their levels, amendments, soil moisture regimes and incubation period and their interactions have been displayed in interaction table 5a,b,c,d, e and Fig. 1. It is evident from the interaction table 5a that incubation of soil with two organic waste i.e. sewage sludge and tannery waste significantly enhanced the mean organic carbon pool over control. The magnitude of increase brought about by sewage sludge and tannery waste over control (1.29 g kg^{-1} mean organic carbon) were 107.75 and 314.72%, respectively. Between the two sources of organic waste, the tannery waste (5.35 g kg^{-1}) produced significantly higher mean organic carbon content (averaged over incubation time, level and soil moisture condition) in comparison to sewage sludge (3.68 g kg^{-1}). The tannery waste resulted 45.38% increase in soil organic carbon pool over sewage sludge. Data further showed that increasing the level of organic wastes from 1.5 to 3.0% significantly increased the mean organic carbon content from 3.64 to 5.39 g kg^{-1} as against 1.29 g kg^{-1} noticed with control. The extent of increase in mean soil organic carbon content due to the levels over control were 182.17 and 317.82% respectively. The rise in soil organic carbon content produced by 3.0% level over 1.5% level was 48.0%. The interaction between the levels and sources of organic waste was significant in relation to the mean organic carbon content. The incubation of soil with tannery waste at 1.5% level was as good as the incubation of Data on mean organic carbon content (averaged over incubation time, levels and amendments) under upland and submerged soil moisture regimes shown in interaction table 5b clearly indicate that submerged soil moisture condition (4.89 g kg^{-1}) had significantly higher mean organic carbon content as compared to upland soil moisture condition (4.15 g kg^{-1}). The individual effect of two organic waste has already been discussed in table 5a. The interaction effect of organic waste and soil moisture regime was significant with respect to mean soil organic carbon content (Table 5b). It is clear from the data presented in interaction table 5c that there was a significant decrease in mean organic carbon pool from 4.66 g kg^{-1} to 4.38 g kg^{-1} with the advancement of incubation time from 6 to 12 month, respectively. The interaction between the organic waste and incubation period was significant in respect of mean organic carbon content (Table 5c).

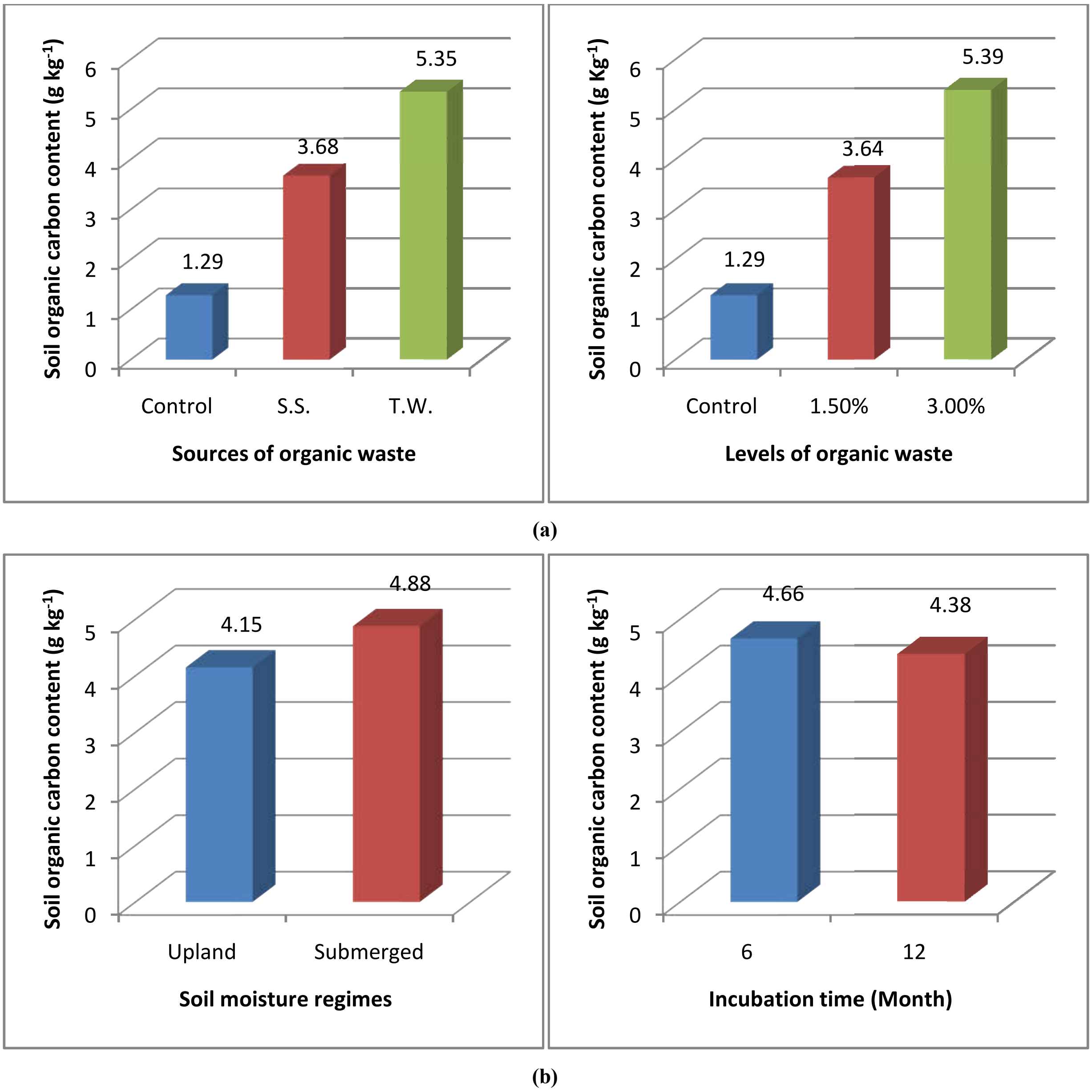

Fig. 1. (a) Effect of sources and levels of organic waste and (b) soil moisture regimes and incubation time on mean soil organic carbon content soil with sewage sludge at 3.0% level so far as the mean soil organic carbon content was concerned (Table 5a)

The interaction effect of soil moisture regime and incubation period was significant with respect to mean organic carbon content. The upland soil moisture regime (4.33 g kg^{-1}) at 6 month incubation time had significantly lower mean organic carbon content than the submerged soil moisture regime (4.79 g kg^{-1}) at 12 month incubation period (Table 5d). Data on mean organic carbon content (averaged over level, incubation time and soil moisture condition) presented in interaction table 5e clearly indicate that there was not any significant difference in the values of mean organic carbon content influenced by various amendments *i.e.* no amendment, $CaCO_3$, DAP and EDTA.

The corresponding values for mean organic carbon content due to different amendments were 4.45, 4.40, 4.59 and 4.50 g kg^{-1}, respectively. The interaction effect of organic waste and amendment was significant with respect to mean organic carbon content.

Table 5. Interaction effect of various factors on soil organic carbon content (g kg^{-1})

Table 5a. (Sources × Levels of organic waste)

Sources of organic waste	levels of organic waste		Mean
	1.5%	3.0%	
Sewage sludge	2.81	4.56	3.68
Tannery waste	4.47	6.23	5.35
Mean	3.64	5.39	

Control : 1.29 (g kg^{-1})

	SOW	L	SOW x L
S.Em.(±)	0.027	0.027	0.039
C.D. (5%)	0.095	0.095	N.S

Table 5b. (Sources × Soil moisture regimes)

Sources of organic waste	Soil moisture regimes		Mean
	Upland	Submerged	
Sewage sludge	3.53	3.85	3.69
Tannery waste	4.77	5.93	5.35
Mean	4.15	4.89	

	SOW	SMR	SOW x SMR
S.Em.(±)	0.031	0.031	0.044
C.D. (5%)	0.107	0.107	0.153

Table 5c. (Sources × Incubation time)

Sources of organic waste	Incubation time (Month) 6	12	Mean
Sewage sludge	4.19	3.19	3.69
Tannery waste	5.13	5.57	5.35
Mean	4.66	4.38	
	SOW	IT	SOW x IT
S.Em.(±)	0.024	0.024	0.035
C.D. (5%)	0.085	0.085	0.121

Table 5d. (Soil moisture regimes × Incubation time)

Soil moisture regime	Incubation Time (Month) 6	12	Mean
Upland	4.33	3.97	4.15
Submerged	4.98	4.79	4.88
Mean	4.65	4.38	
	SMR	IT	SMR x IT
S.Em.(±)	0.039	0.039	0.055
C.D. (5%)	0.135	0.135	N.S.

Table 5e. (Sources × Amendments)

Sources of organic waste	No amendment	With amendments $CaCO_3$	DAP	EDTA	Mean
Sewage sludge	3.23	3.51	4.17	3.59	3.87
Tannery waste	5.67	5.29	5.02	5.42	5.35
Mean	4.45	4.40	4.59	4.50	
	SOW		A		SOW x A
S.Em.(±)	0.058		0.082		0.117
C.D. (5%)	0.177		N.S.		0.35

DISCUSSION

The discussion deals with the soil incubation experiment conducted with the aim to observe the changes occurring in $K_2Cr_2O_7$ oxidisable soil organic carbon and DTPA extractable heavy metals (Cr, Ni and Pb) in soil at 6 and 12 month period after the addition of two levels (1.5 and 3.0%) of two organic wastes (sewage sludge and tannery waste) with and without three amendments ($CaCO_3$, DAP and EDTA) under upland as well as submerged soil moisture conditions. Both, sewage sludge and tannery waste-amended soils resulted in significant increase in $K_2Cr_2O_7$-oxidisable mean soil organic carbon content to the tune of 107.75 and 314.72 %, respectively over control. However, mean soil organic carbon was significantly higher in tannery waste-amended soil than in sewage sludge-amended soil. McGrath and Cegarra (1992) reported that the soils on plots that received inorganic treatment had a total organic carbon content just over 10 g kg^{-1}, where as in those to which sewage sludge @ 16.4 t ha^{-1} $year^{-1}$ had been added, the total organic carbon content increased from 10 g kg^{-1} initially to over 30 g kg^{-1} in 1960, before declining again to near 15 g kg^{-1} in 1983. Both, sewage sludge and tannery waste are the potential source of organic matter containing 24.8 and 35.2% carbon, respectively. Upon the decomposition of organic waste during the incubation period of 12 month, an increase in soil organic carbon is expected. The higher values of soil organic carbon noticed with tannery waste-treated soil may be ascribed to higher carbon content present in the tannery waste than that present in sewage sludge used in the investigation.

Increasing levels of organic waste significantly enhanced the mean soil organic carbon content over control. The 3.0% level caused 48% increase in mean soil organic content over 1.5% level of organic wastes. The progressive increase in mean soil organic carbon content may be attributed mainly to the graded increase in the amount of organic carbon added through the increasing levels of organic wastes. The incubation of soil with tannery waste at 1.5% level or with sewage sludge at 3.0% level, both were at par in relation to mean soil organic carbon content. The reason may be attributed to the lower carbon content, easily decomposable organic substances as well as faster mineralization rate of the added sewage sludge in comparison to the tannery waste, thus more loss of carbon occurred during the decomposition even at double rate of sewage sludge application (3.0%), thereby resulting mean soil organic carbon content comparable to that of tannery waste applied at 1.5% level.

The submerged soil moisture regime had significantly higher mean soil organic carbon content as compared to upland soil moisture regime. Jha and Rattan (2007) while studying the influence of moisture regimes and incorporation of crop residues on the mineralization of C and P in soil reported higher mineralization and loss of C as CO_2 under saturated moisture condition (20%) as compared to the standing water condition (18%). The two soil moisture regimes *i.e.* under upland and submerged soil differed considerably in their chemical, physico-chemical (soil reaction, temperature moisture, oxygen diffusion rate, redox potential *etc*.) and bio-chemical environment of the soil prevailed during the incubation of soil with organic wastes upto 12 month. The former soil moisture regime dominated by the aerobic conditions and higher redox potential promoted the growth of a wide variety of CO_2 producing soil microorganisms, thus favoured the higher mineralization rate of organic matter, whereas the latter soil moisture regime dominated by the anaerobic conditions and lower redox potential, supported only the methane producing hetrotrophs with few CO_2 producing microbes, thus resulted lower mineralization rate of organic matter. As a result, the loss of carbon as gaseous emissions (CO_2/CH_4) from the soil took place more from the former than from the latter. That is why, the upland soil moisture recorded lower mean soil organic carbon content than the submerged soil moisture regime.

Advancement in incubation time from 6 to 12 month decreased the mean soil organic carbon significantly. The results of the incubation study carried out for 64 days showed that the decomposition of organic matter as measured by CO_2 evolution, continued to take place, initially at faster rate followed by a slower but steady one (Jha and Rattan, 2007). The depletion in mean soil organic carbon content with the advancement in incubation time from 6 to 12 month may be explained as: the mineralization of organic matter during the incubation period as well as resultant loss of carbon as gaseous effluents (CO_2/CH_4) continued to occur throughout the incubation period upto 12 month. As a consequence, the total loss of carbon took place more at 12 month than at 6 month of incubation time, thus leading to the significant depletion in mean soil organic carbon at 12 month period of incubation. The upland soil moisture regime at 6 month incubation time exhibited significantly lower mean soil carbon content than the submerged soil moisture regime at 12 month of incubation period. The upland and submerged soil moisture regimes represent quite two distinct soil environments, differing in chemical, physco-chemical and biological aspects. The former regime was dominated by aerobic or oxidizing condition with higher redox potential and moisture at field capacity and adequate temperature, which promoted the growth of a wide variety of soil microorganism mainly CO_2 producing aerobes. Whereas the latter regime represented the anaerobic or reducing conditions with redox potential varying from +0.2 to –0.3V, stable or little variation in temperature and pH near to neutrality which supported only the CH_4 producing heterotrophs and a few anerobes producing CO_2 in smaller proportion. Thus, the mineralization of organic matter with the evolution of CO_2 and CH_4 and subsequent loss of carbon from the soil as gasseous emission took place at a much faster rate under the former regime than under the latter regime. Eventually, the mean soil organic carbon content under the upland soil moisture regime depleted significantly even at shorter time of incubation *i.e.* 6 months as compared to that noticed under submerged soil moisture regime at longer time of incubation *i.e.* 12 month.

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