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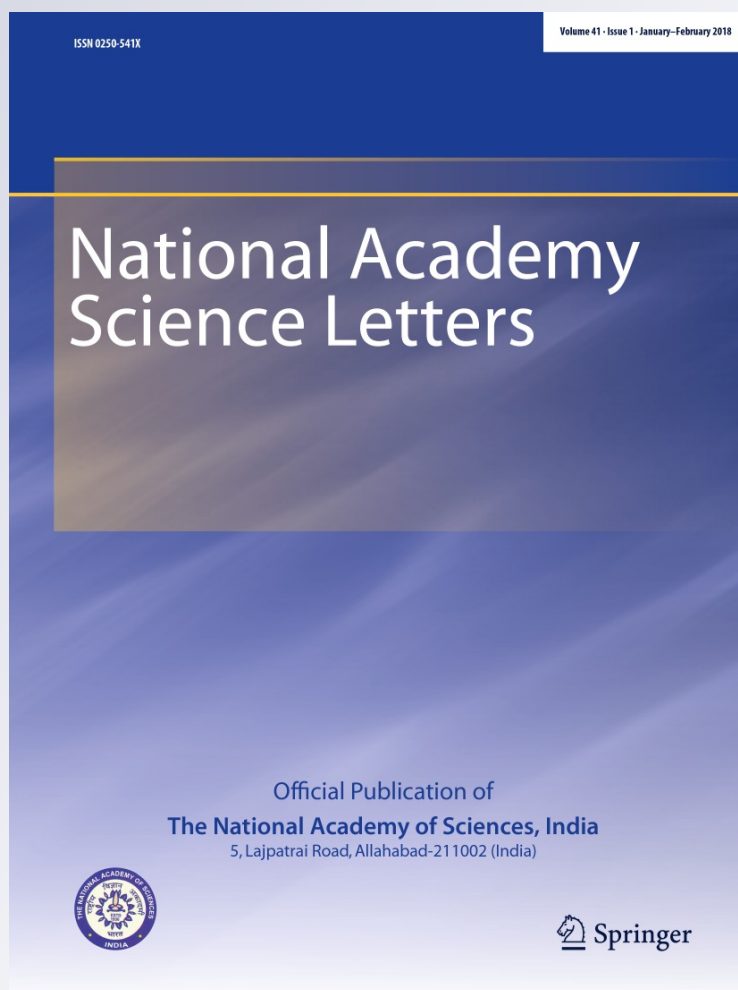
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# Soil Carbon Stability Assessment by Humus Desorption Using Simple First Order Exponential Equation in a Toposequence of Western Himalayan Region

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**Abstract** A chemical method based on batch desorption of adsorbed humus on clay-humus complex by sodium hydroxide-sodium pyrophosphate solution was used to assess the stability of humus C through the desorption rate constant using simple first order exponential equation in a toposequence of Western Himalaya region of India. The rate constant values were significantly ( $p < 0.0001$ ) higher in hill top ( $0.305 \text{ day}^{-1}$ ) and narrow valley ( $0.184 \text{ day}^{-1}$ ) than side slope ( $0.125 \text{ day}^{-1}$ ) and broad valley ( $0.11 \text{ day}^{-1}$ ) suggesting higher stability of soil C in side slope and broad valley. This variation implies that clay particles are active in binding humus C and soil texture plays an important role in stabilizing soil C.

**Keywords** Carbon · Himalaya · Humus · Stability · Toposequence

With the rising concerns of climate change and global warming, soils are considered as reservoir of carbon (C) having the potential to act as a source or sink of atmospheric  $\text{CO}_2$  through sequestration and releasing greenhouse gases [1]. Much research has been focused on soil C in relation to land use changes [2], soil depth [3] and toposequence [1]. C storage and its stability in soils indicates the potential of C sequestration [4] and is therefore important to assess the strength with which C is held by soil particles for soil quality and environmental related research. Very less studies has been reported on the capability of soils for stabilizing C with few methods for its assessment. Soil organic carbon (SOC) consists of fresh plant residues, root exudates, soil microbial residues and humus. Humus, a stable decomposition product of OM [5] may be best indicator to quantify the stability of soil C. The stability of humus C for a particular soil and its rate of release may differ depending on the associated particles [6] and may thus be affected by management practices, physiological locations, climate, soil type etc. Isolation of clay humus complex through ultrasonic vibrations has been followed for clay humus stability studies through determining the C content at different time interval, using simple first order exponential equation [7] and through humus desorption using linear combination of three first order equations [8]. In present study sodium hydroxide-sodium pyrophosphate were used to extract the humus from soil to assess soil C stability by humus desorption using simple first order exponential equation with an objective to elucidate the stability of soil C along a toposequence in Almora district of Uttarakhand, India.

Soil samples were collected from four pedons of distinct physiographic locations namely Airideo (P1)—hill top (2000 m amsl), Basauli (P2)—side slope (1400 m amsl), Someswar (P3)—broad valley (1200 m amsl) and Kosi

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(P4)—narrow valley (1100 m amsl) in Kumaon hill region of Western Himalayas, Almora district, Uttarakhand lying between 29°37'N to 29°49'N latitudes and 79°37'E to 79°44'E longitude. The climate was warm sub humid to humid and the mean annual precipitation (both rainfall and snowfall) ranged from 1100 to 1700 mm. Mean annual minimum and maximum temperature was about 2 and 24 °C respectively. The soil moisture and temperature regime were *udic* and *thermic*. The hill top (P1) had moderately dense forest dominated with pines and the side slope (P2) covered with mixed vegetation (Oaks and conifers). Broad valley (P3) and narrow valley (P4) were cultivated with paddy, jowar, bajra, maize, sunflower, wheat, mustard and horticultural plantation such as pears, plum and peach. From each land position, three soil profiles were mixed to make one composite soil sample from three different depths (D1, D2 and D3). Three composite samples representing three replications from each land position were collected.

To determine the stability, humus complex was extracted by shaking soil sample (5 g) with 100 ml of 0.1 M sodium hydroxide + 0.1 M sodium pyrophosphate for 2 h and centrifuged for 13 min @ 10,000 rpm [8]. Thus, in every 2 h the reacting solutions were replaced with fresh solution and repeated for 3 times (i.e. up to the 6 h). In this batch technique, the desorbed humus was removed every 2 h to avoid backward reaction, if any, so that the rate of release remained unaffected wherein re-adsorption of humus was avoided. The total organic carbon (TOC) of the soil and the C in the concentrated humus extracts (dried at 40 °C) were measured by reacting with acidified potassium

dichromate under external heat application following Schollenberger method [9] and back titrating unreacted potassium dichromate with ferrous ammonium sulphate. The absorbance of the extracts was also measured at 440 nm to obtain a linear regression relationship between the carbon concentration of the extracts and the absorbance ( $y = a x$ , where  $y$  was the carbon concentration of the extracts and  $x$  was absorbance). At the 8 h stage, when the C concentration in the extract was too less, this regression equation was used to determine the C concentration.

From the C concentration of the extract at different times, the cumulative desorption of humus C per unit amount of humus complex was determined and subtracted from the total C content of the soil to get C remaining at time  $t$  ( $C_t$ ). Carbon content of humus complex,  $C_t$ , at a time  $t$ , after desorption of humus from clay humus complex was fitted to a simple first order equation.

$$C_t = C_o \exp^{-kt}$$

Where,  $C_o$  is the initial C content and  $k$  is the humus desorption rate constant. Stability of the humus C was calculated from the reciprocal of the desorption rate constant ( $k$ ). Standard error of means (SE) was calculated from the rate constant of three replications.

A two way analysis of variance (ANOVA) as completely randomized design (CRD) was followed to statistically analyze the effects of profile and soil depths to compare the significance of the rate constant and TOC using SAS software version 9.2 (SAS Institute).

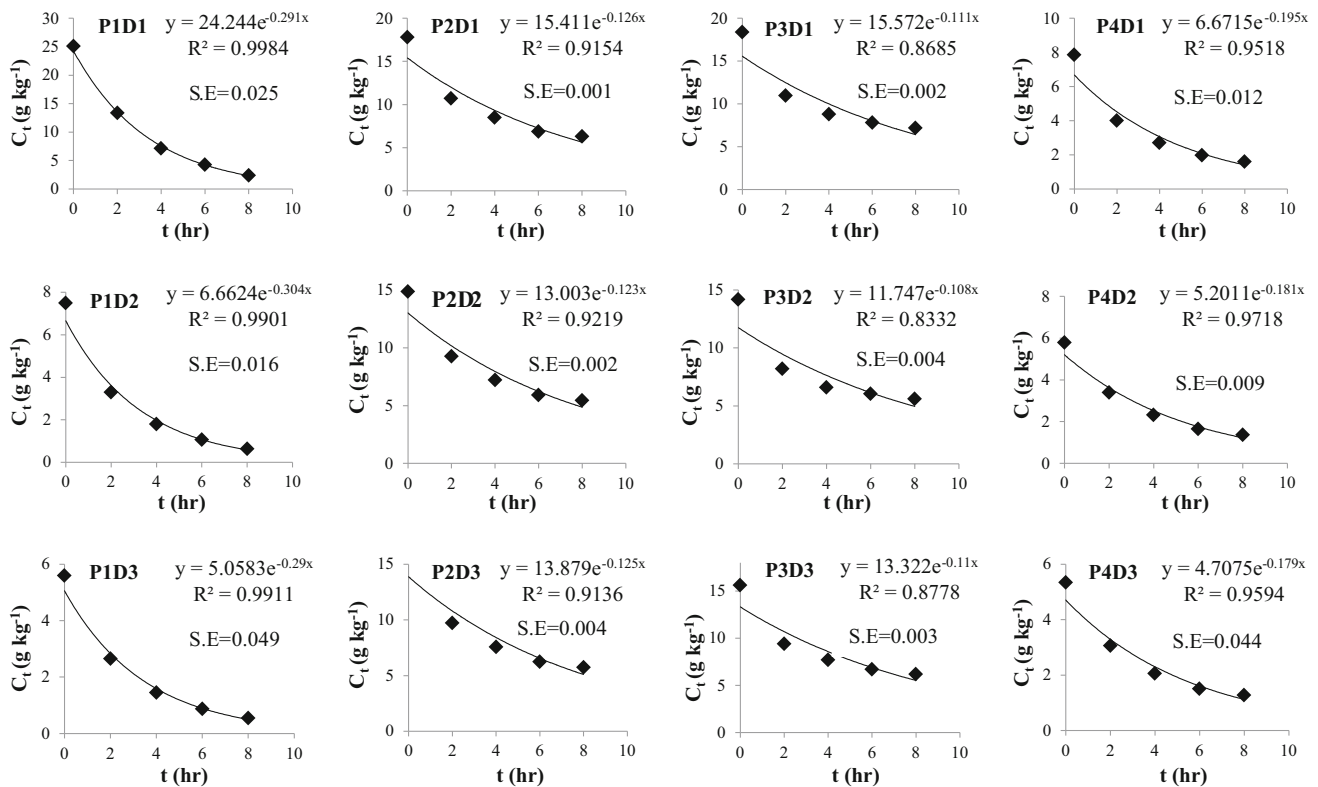
Hill top soils were sandy clay loam in texture on surface to clay loam in sub-surface Removal of finer soil fractions

**Table 1** Soil texture and total organic carbon (TOC) in soil depths of different land positions

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture	TOC (g kg <sup>-1</sup> )
Airideo (P1, hill top)					
0–9 (A1)	52	22	26	Sandy clay loam	25.1
9–20 (Bw1)	46	22	32	Sandy clay loam	7.5
20–45 (Bw2)	34	32	34	Clay loam	5.6
Basauli (P2, side slope)					
0–8 (A)	38	36	26	Clay loam	17.8
8–24 (AC)	36	40	24	Loam	14.8
24–40 (C)	30	40	30	Clay loam	16.0
Someswar (P3, broad valley)					
0–18 (Ap)	32	32	36	Clay loam	18.4
18–32 (Bw1)	20	44	36	Silty clay loam	14.2
32–48 (Bw2)	18	44	38	Silty clay loam	15.6
Kosi (P4, narrow valley)					
0–11 (A)	66	16	18	Sandy loam	7.9
11–25 (AC)	62	18	20	Sandy clay loam	5.8
25–50 (C)	64	18	18	Sandy loam	5.3

**Table 2** Result of two-way ANOVA for exploring significance of rate constant and TOC

	TOC		Rate constant	
	<i>F</i>	<i>P</i> value	<i>F</i>	<i>P</i> value
Profile (P)	7917.91	0.0001	59.81	0.0001
Depth (D)	7376.32	0.0001	0.02	Ns
P × D	2671.65	0.0001	0.16	Ns

**Fig. 1** Carbon desorption with time in soil depths of different land positions

from surface soil through high rainfall in this region (Table 1). In side slope and broad valley, soil texture were found to be of finer fractions (clay loam and silty clay loam) due to the fluvial action and/or eluviation of fine silt and clay during puddling in rice–wheat cropping system in the broad valley. Narrow valley soils were found to have sandy loam texture, which may be due to dominance of physical weathering and washing out of finer soil fractions by the run-off water. Two way ANOVA results indicated that TOC decreased significantly with depth and was also significantly affected by the land position and interaction between soil depth and land position (Table 2). P2 soils had highest TOC content followed by P3, P1 and P4 soils. Many authors [10, 11] have also reported such variations in TOC content in soils due to the physiographical settings.

The decrease in the OC content with depth was due to the addition of OM in the form of leaf litters in the surface layers and has been well documented [3, 12]. The highest TOC content in the side slope may be attributed to the forest land use system. Cultivation decreased the C content of soil [13] as evident from the lower C content in broad and narrow valley.

The C desorption data fitted well to the first order exponential equation with high values of  $R^2$  indicating desorption of humus C exponentially with time (Fig. 1), signifying that the simple first order exponential equation can be used for assessing soil C stability through humus desorption. Irrespective of land position and depth, the rate constant varied from  $0.108 \text{ day}^{-1}$  to  $0.304 \text{ day}^{-1}$  which was much higher than  $0.03 \text{ day}^{-1}$  obtained by Vennila and



Datta [7]. The rate constant was significantly ( $p < 0.0001$ ) affected by the land position of which P1 soils were observed to have highest values ( $0.305 \text{ day}^{-1}$ ) followed by P4 soils ( $0.184 \text{ day}^{-1}$ ), P2 soils ( $0.125 \text{ day}^{-1}$ ) and P3 soils ( $0.11 \text{ day}^{-1}$ ) (Table 2). Lower rate constant implies higher stability; therefore, P2 and P3 soils indicated to have higher stable soil C followed by P4 and P1 soils. Soil depth while exerting a significant effect on soil C content does not affect the rate constant suggesting that extracted humus C and its stability was not affected by the total SOC because TOC consists of varying degrees of labile and non-labile fraction of soil C. The higher desorption rate constant or lower stability in hill top followed by narrow valley indicated that the coarse texture (sandy) these soils decreased the stabilization of the humus C against clay loam dominated soils profiles of side slope and broad valley region. Humus is often bound to clay minerals and fine textured soils have more active minerals and composition for binding it [14]. The higher stability of C on the side slope was due to removal of labile C (plant debris) by rain water with consequent enrichment of non-labile C, and deposition, mineralization of the labile C in the broad valley due to the intensive cropping. It is therefore pertinent that if soils are exposed to erosion factors, the stabilized layer may be eroded reducing the sequestration potential of soil. This implies that conservation measures to decrease soil and water erosion may play an important role in stabilization of soil C to increase C sequestration in the hilly tracts of Western Himalayan region of India. The assessment of OC stability was simple by this method and may be extended for routine assessment of soil C stability and sequestration studies.

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#### Compliance with Ethical Standards

**Conflict of interest** There is no conflict of interest.

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