



Influence of Human, Livestock Population and Land Use Systems on Soil Characteristics and Soil Organic Carbon Stock in Western Rajasthan

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Abstract: A study has been conducted during 2016-17 to estimate soil organic carbon stock in 0-30 cm soil depth as influenced by land use, spatial variations and human and livestock population for developing strategies to reduce land degradation and enhance carbon sequestration and land productivity. Forests, oran, pasture lands, agriculture, roadside and fallow land are different land uses covered in six Panchayat Samitis-called blocks viz. Abu Road, Baap, Baitu, Bali, Sanchor and Sankara situated in Sirohi, Jodhpur, Barmer, Pali, Jalore and Jaisalmer district, respectively in western Rajasthan. Land holding (2444-37444 m²), family size and livestock population in terms of head counts per household (HH⁻¹; 5.3-5.9 and 4.4-11.0, respectively) varied ($P < 0.05$) widely between blocks. Variations in soil gravel content, bulk density (BD), organic carbon (SOC) and carbon stock without (CSW) and with (CSG) gravel correction like 1.49-32.51%, 1.45-1.56 g cm⁻³, 0.114-0.584%, 5.31-25.37 t ha⁻¹ and 5.04-16.63 t ha⁻¹ between blocks, and 4.41-18.88%, 1.48-1.53 g cm⁻³, 0.133-0.324%, 6.08-14.20 and 5.73-9.72 t ha⁻¹ respectively between land uses indicated strong spatial rather than land use effects. Spatial variation in annual rainfall and soil characteristics lead carbon stock in order: Baitu < Baap < Sankara < Sanchor < Bali < Abu Road among blocks, whereas overgrazing, organic manuring and vegetation status controlled land use order like roadside < fallow land < pastureland < agriculture < oran < forest land. Though varied between blocks and land uses, non-significant decrease in gravel and increase in BD during 2013 to 2017 indicated increased soil compactness. Thus increased rainfall/soil water and vegetation status favored soil carbon storage. Enhanced vegetation in forest, oran and pastureland, organic manuring of agriculture and avoiding overgrazing of pasture/rangelands can promote soil carbon sequestration and reverse the process of land degradation and improve land productivity.

Key words: Carbon stock, land use, soil properties, spatial variations.

High climatic variability has its impact on all ecosystems, regions and sectors, but the nature and extent of vulnerability to the climate change differs with adaptive capacity of the individual, society and region (Singh and Kumar, 2015). The regions with scarce resources are among the most vulnerable systems and such regions exist in extreme climatic conditions like deserts and snow covered areas. The vulnerability of arid regions is accentuated by low levels of socio-economic development leading to fast depletion of available natural resources including soil and water (Mittal and Gupta, 2015). Along with high population density climate variations is enhancing the risk of degradation of soil, water and other natural resources affecting their effective usage for livelihoods support (Kundu *et al.*, 2016; Olofsson, 2017).

The increasing variability in weather pattern in western part of India could impose both

positive and negative impacts on agricultural and rangelands (Rao and Purohit, 2013). Some land use practices can degrade the quality of soil, waterway, air and other natural resources (Jamal *et al.*, 2016). More than 70% of the world's poor are living in rural areas, with land use as a major source of subsistence. Improving the productivity of these lands is essential for increasing the incomes and food security among the rural population (Chitonge, 2013). Forests, agriculture, pastureland, human habitations and various economic activities are different land use types and all are under varying degree of degradation affecting people livelihoods (Kundu *et al.*, 2016). While gross cropped area, cropping intensity and area under non-agricultural uses increased significantly in Rajasthan in recent years, the area under pasture, barren and uncultivable land and culturable wasteland has declined and are becoming overcrowded due to increasing livestock population (GoR, 2012). Farmers

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are now opting for crop diversification and commercial crops like oil producing crop (i.e., mustard) and condiments and spices, medicinal and narcotic etc., whereas there is a decrease in area under cereals. These land use practices are influencing plant cover (biological diversity) and carbon storage-important indicators of land productivity and degradation (Rajan *et al.*, 2010; Kosmas *et al.*, 2014; Gaur *et al.*, 2018).

Soil organic carbon (SOC) is an important factor controlling other soil attributes and a decline in SOC stock may indicate degradation or even loss of land and soil (Hazarika *et al.*, 2014; Kosmas *et al.*, 2014). However, the magnitude of the change in carbon storage depends on how physical, chemical or biological processes are altered over time under different land uses as reflected in changing soil carbon storage, net primary productivity

and soil respiration (Dintwe and Okin, 2018; Chuluun and Ojima, 2002). Because of intrinsic relationship with vegetation productivity, SOC is therefore very sensitive to natural and human disturbances. While reducing SOC losses become an important strategy in climate change mitigation and enhancing food security (Shrestha *et al.*, 2017; Bruun *et al.*, 2015; Keesstra *et al.*, 2016), the impact of shifts in land use on soil carbon storage further influences to global warming. Thus human-land relationship over the long period of developmental activities and alterations of earth's surface through anthropogenic shifts in land use has become an important topic of research.

Therefore, this study was carried out to: (i) monitor soil carbon stock under different land uses and (ii) its relationships with human and livestock population in western Rajasthan.

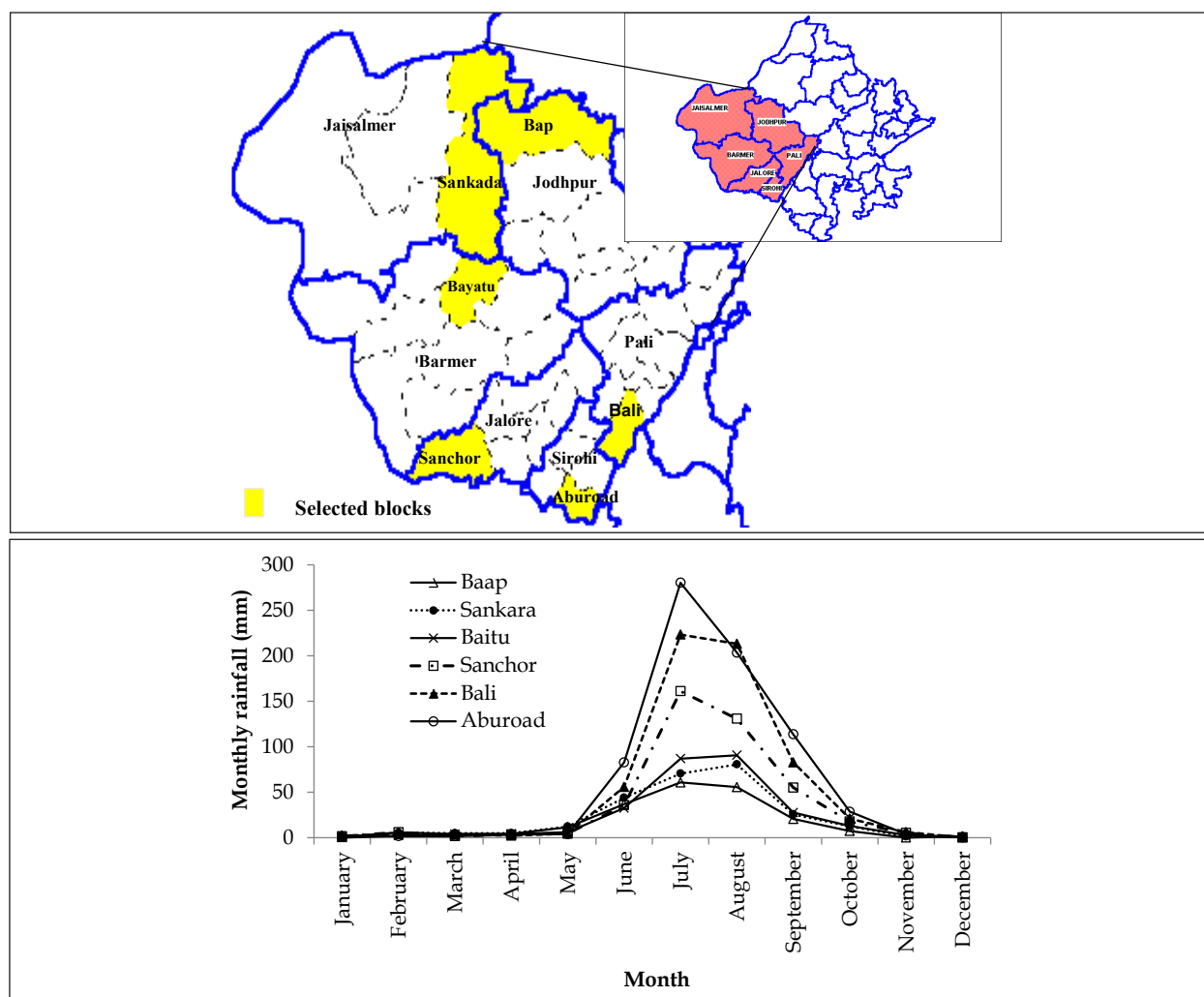


Fig. 1. Studied blocks and average monthly rainfall (1995-2016) in the blocks situated in Jodhpur, Jaisalmer, Barmer, Jalore, Pali and Sirohi districts of Rajasthan.

Materials and Methods

Site description

The study was conducted covering different land uses in selected villages of six Panchayat Samitis (called blocks), one each in six districts in western Rajasthan. These blocks were Abu Road, Baap, Baitu, Bali, Sanchore and Sankara situated in Sirohi (24°20' to 25°17' N and 72°16' to 73°10' E), Jodhpur (26°0' to 27°37' N and 72°55' to 73°52' E), Barmer (24°58' to 26°32' N and 70°05' to 72°52' E), Pali (24°45' and 26°29' N and 72°47' to 74°18' E), Jalor (24.48°5' to 25.48°37' N and 71°07' to 75.5°53' E) and Jaisalmer (26°04' to 28°23' N and 69°20' to 72°42' E) districts, respectively in Western Rajasthan, India (Fig. 1). The climate of the region is characterized by extreme of temperature, uncertain rainfall, high potential of evapotranspiration and strong winds. Landscape of the region is variable. The area in Abu Road block is mainly comprised of pediments, hills, intervening basins and plains, whereas Sankara block has undulating dunes, sandy plains with shallow soils and saline depressions. Maximum temperature rises up to 51°C during summer, whereas minimum temperature drops down to freezing point during winter season. Rainfall of 1994 to 2017 period in the studied areas showed high temporal and spatial variations. There was more rainfall in August than in July at Jodhpur, Jaisalmer and Barmer, whereas it was vice-versa at Jalore, Pali and Sirohi districts. Further, area under the former districts received less rainfall as compared to the area under the latter districts. The soils are sandy to sandy loam in texture, whereas soil depth varies with physiographic conditions of the area. The vegetation of the

area is xerophytic in nature and most of the plant species are spiny and smaller in leaf size (Champion and Seth, 1968).

Selection of Villages and Households Survey

Out of 1024 villages in the above-mentioned six blocks, 102 villages (about 10% of the total villages) were randomly selected for the study purpose. Number of villages ranged from 9 in Bali block to 32 in Baitu block, whereas the number of households surveyed varied from 170 in Baap block to 406 in Baitu blocks covering 1792 household across the study areas during 2016-17 (Table 1). To know the family size and the number of livestock per household one person from a family was interacted through focus group discussions based on sample size of about 10% of all households of a village (Lema and Majule, 2009). Four levels of stratification (number of villages in block, size of village, economy and caste, gender and age) were done to ensure proper representation of the block (Table 1).

Land Use and Soil Sampling

Out of 9-fold classification of land uses, five major land uses in the region are agriculture, forests, oran/sacred groves (community lands), pasture and roadside. However, these five land uses are not available in all the villages. Therefore, depending upon the availability of land use types in the selected villages (102), soil sampling was done for carbon content analysis. Besides these land uses, fallow lands other than the current fallows were also available and soil samples were also collected from this land use. Soil samples were collected from 0-30 cm soil layer from the centre of the central plot of the

Table 1. Number of households and people interacted under different gender and age categories in the selected 102 village in different blocks of western Rajasthan

Block	Total village (nos.)	Household (nos.)	People interacted (nos.)	Male respondents (nos.)			Female respondents (nos.)		
				<25	25-45	>45	<25	25-45	>45
Baitu	32	4823	406	1	323	77	0	4	1
Sankara	20	4884	371	7	308	54	0	1	1
Baap	14	2840	170	6	17	10	7	97	33
Sanchore	17	7381	308	1	53	4	8	197	45
Abu Road	10	3213	215	0	75	0	24	111	5
Bali	9	5550	322	0	72	6	9	208	27
Total	102	28691	1792	15	848	151	48	618	112
Per cent			100	0.84	47.32	8.43	2.68	34.49	6.25

cluster plots mentioned above for soil organic carbon (SOC) estimation. For soil bulk density, soil samples were collected from each plot using an iron core of fixed volume at 15 cm depth after excavating a pit. These soil samples were transported to laboratory, oven dried at 110°C and weighed (McIntyre and Loveday, 1974). Thereafter, they were passed through a 2 mm sieve for separation of gravel and fine earth fraction. Soil organic carbon was determined from fine earth fraction following standard procedures (Walkley and Black, 1934; IPCC, 2007). Soil organic carbon stock was calculated and was corrected for gravel content using the following equation (Batjes, 1996):

$$Q_i = C_i D_i E_i (1 - G_i) \times 1000 \quad \dots \dots (1)$$

where; Q_i (tons or Mg C ha⁻¹) is soil organic carbon content in a soil layer i , E_i is soil depth in meters, C_i is carbon content in g C g⁻¹ soil, D_i is bulk density in Mg m⁻³ and G_i is volume fraction of coarse (gravel or stones of >2 mm size) elements.

Statistical Analysis

All data were analyzed statistically using SPSS version 17.0 statistical package. Gravel content, soil bulk density, SOC and soil carbon stock were analyzed using two ways ANOVA. Spatially distributed blocks (one in each district) and land use types were considered the main factors. Number of defined land uses sampled in each blocks (based on the selected villages) were considered replications. To find out relations between rainfall, soil bulk density, SOC, soil carbon storage, human and livestock population, Pearson correlation coefficient were also estimated. Duncan Multiple Range Tests (DMRT) was applied to observe homogeneous sub-setting of different block for different observed variables at the $P < 0.05$ levels.

Regression relations were observed to relate SOC stock with average rainfall, soil bulk density and impacts of human and livestock population.

Result

Land holdings and human population

Average land holding in the studied region was 14244.6 m² per household (HHs) in 2016-17. Per house hold land holding ranged from 37203.1 m² in Baap to 2428.1 m² in Sanchore block in 2016-17 as compared to the respective value of 50989.1 m² and 2428.1 m² in 2006-07. Highest percentage (23.7%) households were in the category of 1600 to <8100 m². It was followed by land holding of <1600 m² (22.0%), >32400 m² (17.4%) and landless (12.8%) in 2016-17 (Table 2). Among the blocks, percentage of HHs was in <1600 m² category in Sanchore and Bali blocks, 1600 to <8100 m² in Abu Road, 8100 to <16200 m² in Baitu, 16200 to <32400 m² in Sankara and >32400 m² in Baap block. Almost 12% households were in the category of landless as well as 16200 to <32400 m² in the region.

Average family size (persons per households) varied from 5.3 in Baitu to 5.9 in Sankara block with an average size of 5.6 in the studied areas (Table 2). It was relatively high as compared to the average family size normally taken to be four to five. Average male and female individuals per households were 1.25 (1.1 in Baitu/Sanchore to 1.6 in Sankara block) and 1.32 (1.1 in Baap to 1.6 in Sankara block) across the blocks. Number of children per household ranged from 2.7 in Sankara to 3.5 in Baap areas. Contribution of male, female and children to the total population was 22.3%, 23.6% and 54.1% in 2016-17 than 20.6%, 20.4% and 59.0% in 2013-14, respectively.

Table 2. Landholding (m²) and human population per households in different blocks of western Rajasthan

Block	Land holding (m ² /HH)						Human population (nos./HH)			
	Landless	<1600	1600- <8100	8100- <16200	16200- <32400	>32400	Male	Female	Children	Total
Baitu	6.2	3.4	20.7	25.1	23.6	20.9	1.1	1.2	3.0	5.3
Sankara	22.6	0.3	7.5	14.0	26.4	29.1	1.6	1.6	2.7	5.9
Baap	5.9	0.0	4.7	12.4	22.9	54.1	1.0	1.1	3.5	5.7
Sanchore	23.1	23.7	40.9	11.7	0.3	0.3	1.1	1.2	3.2	5.6
Abu Road	16.3	43.7	34.0	6.0	0.0	0.0	1.4	1.4	3.0	5.7
Bali	2.5	60.6	34.2	2.2	0.6	0.0	1.3	1.4	2.8	5.5
Average	12.8	22.0	23.7	11.9	12.3	17.4	1.3	1.3	3.0	5.6

Table 3. Livestock population in the surveyed villages of different blocks of western Rajasthan

Block	HHs (nos)	Animals							Total	Per HHs
		Cow	Buffalo	Ox	Goat/sheep	Horse	Camel	Poultry		
Baitu	406	500	8	0	2933	0	1	0	3442	8.5
Sankara	371	552	4	8	2038	1	0	0	2603	7.0
Baap	170	612	2	7	1227	0	10	0	1858	11.0
Sanchor	308	275	220	11	818	1	0	30	1355	4.4
Abu Road	215	223	51	11	828	0	0	259	1372	6.4
Bali	322	357	134	190	1467	0	0	13	2161	7.0
Total	1792	2519	419	227	9311	2	11	302	12791	7.1
Per cent	-	19.7	3.27	1.77	72.8	0.02	0.08	2.36	100	-

Livestock Population

Number of livestock per household varied from 4.4 in Sanchor to 11.0 in Baap with an average value of 7.1 in the region (Table 3). In this, contribution of cow was 19.7% and that of goat and Sheep combined was 72.8%. Other animals like Buffalo, Ox, horse, Camel and Poultry were below <8%, in which population of Buffalo was highest. Poultry was observed only in tribal areas of Abu Road and Bali blocks. While goats and sheep population were high in Baitu and Sankara, buffaloes was more in Sanchor, Bali and Abu Road blocks as compared to the other blocks.

Soil properties

Gravel content: Gravel content (G) ranged from <10% to >50% in the soil of different blocks and varied ($P<0.05$) both due to blocks and land uses (Table 4). Soils of Sanchor and Baitu were lowest in G followed by those of Baap and Sankara blocks. Soils of Bali and Abu Road block differed significantly ($P<0.05$) from

other blocks and were highest in G. Among the land uses, lowest G was in fallow land, whereas it was highest ($P<0.05$) in forest lands. It was followed by Oran (the sacred grove). Soils of agriculture land, roadside and gochar lands did not differ in G. Both blocks and land uses significantly influenced each other as indicated by significant ($P<0.01$) block $\times$ land use interaction term. It was highest in forests of Abu Road and lowest in forest land of Sanchor block.

Soil bulk density: Soil bulk density varied from 1.2 g cm⁻³ to 1.8 g cm⁻³ with an average value of 1.51 g cm⁻³ across the blocks and land uses. The variation was significant due to blocks but not due to land uses in 2016-17 (Table 5). Among the blocks, soil bulk density was 1.45 g cm⁻³ in the soils of Abu Road block and 1.56 g cm⁻³ in Baitu block. Soils of these blocks can be categorized into four groups in increasing order of soil bulk density as Abu Road-Bali<Sankara-Sanchor<Baap<Baitu. Among the land uses, soil bulk density was 1.53 g cm⁻³ ($P<0.05$) in fallow land and lowest

Table 4. Effects of spatial variations and land uses on soil gravel content in 2016-17 (values are mean $\pm$ SE of multiple replications)

Land use	Blocks					
	Bali	Baitu	Abu Road	Sanchor	Baap	Sankara
Forest	33.04 $\pm$ 4.05	3.50 $\pm$ 2.50	46.48 $\pm$ 7.40	0.06 $\pm$ 0.07	1.75 $\pm$ 1.00	6.74 $\pm$ 3.51
Oran	31.09 $\pm$ 7.12	1.86 $\pm$ 0.97	37.63 $\pm$ 5.81	0.39 $\pm$ 0.32	5.97 $\pm$ 4.73	20.63 $\pm$ 5.82
Pasture land	36.39 $\pm$ 4.48	3.11 $\pm$ 1.14	33.67 $\pm$ 6.02	2.68 $\pm$ 1.84	7.66 $\pm$ 2.85	5.88 $\pm$ 1.52
Agriculture	19.72 $\pm$ 3.71	3.17 $\pm$ 0.90	22.54 $\pm$ 3.54	0.64 $\pm$ 0.33	9.52 $\pm$ 2.67	8.18 $\pm$ 2.39
Roadside	25.63 $\pm$ 3.77	6.70 $\pm$ 1.66	27.90 $\pm$ 4.42	2.99 $\pm$ 1.07	7.03 $\pm$ 2.84	6.52 $\pm$ 1.92
Fallow land	20.49 $\pm$ 0.00	3.28 $\pm$ 1.65	20.13 $\pm$ 0.00	0.13 $\pm$ 0.07	5.51 $\pm$ 1.73	8.35 $\pm$ 3.03
Two-way ANOVA	F value					
Block	48.37					
Land use	2.99					
Block $\times$ land use	2.40					

Table 5. Effects of spatial variations and land uses on soil bulk density (g cm^{-3}) in 2016-17 (values are mean $\pm$ SE of multiple replications)

Land use	Blocks					
	Bali	Baitu	Abu Road	Sanchor	Baap	Sankara
Forest	1.45 $\pm$ 0.02	1.53 $\pm$ 0.04	1.46 $\pm$ 0.02	1.51 $\pm$ 0.02	1.54 $\pm$ 0.01	1.48 $\pm$ 0.01
Oran	1.48 $\pm$ 0.02	1.54 $\pm$ 0.01	1.45 $\pm$ 0.02	1.50 $\pm$ 0.01	1.56 $\pm$ 0.01	1.47 $\pm$ 0.01
Pasture land	1.42 $\pm$ 0.02	1.54 $\pm$ 0.02	1.45 $\pm$ 0.02	1.50 $\pm$ 0.02	1.54 $\pm$ 0.01	1.50 $\pm$ 0.01
Agriculture	1.43 $\pm$ 0.03	1.54 $\pm$ 0.01	1.45 $\pm$ 0.01	1.50 $\pm$ 0.01	1.53 $\pm$ 0.01	1.49 $\pm$ 0.01
Roadside	1.47 $\pm$ 0.02	1.56 $\pm$ 0.01	1.43 $\pm$ 0.01	1.49 $\pm$ 0.02	1.49 $\pm$ 0.02	1.47 $\pm$ 0.01
Fallow land	1.55 $\pm$ 0.01	1.58 $\pm$ 0.01	1.49 $\pm$ 0.02	1.50 $\pm$ 0.01	1.51 $\pm$ 0.01	1.49 $\pm$ 0.02
Two-way ANOVA		F value	P value			
Block		10.32	0.000			
Land use		1.333	0.249			
Block $\times$ land use		1.387	0.104			

(1.48 g cm^{-3}) in the soils of forest land. Soil bulk density was almost similar in Oran and the soils of roadside, agriculture land, pasture lands. Block $\times$ land use interactions is not significant ($P>0.05$), though its highest value was in fallow lands of Baitu and lowest value in pasture lands of Bali block.

Soil organic carbon: Per cent soil organic carbon (SOC) in top 0-30 cm soil layer was 0.21% in 2016-2017 across the blocks. Among different blocks, per cent SOC was highest in Abu Road and lowest in Baitu block. Soils of Bali block had less SOC content than in the soils of Abu Road, but greater ($P<0.05$) than the soils of other blocks. Soils of Baap block did not differ ($P>0.05$) in SOC content with the soils of both Sankara and Baitu block, whereas the soils of Sankara block were almost similar with soils of Baap and Sanchor blocks in SOC (Table 6). Soils of Sanchor were higher ($P<0.05$) in SOC

content compared to the soils of Sankara, Baap and Baitu blocks. Among the land uses, soils of fallow land showed significantly ($P<0.05$) less SOC, even though its values were higher in the soils of Bali and Abu Road blocks. Highest amount of SOC was in forest land. It was followed by the soils of Oran. Soils of pasture land does not differ ($P>0.05$) from soils of agriculture land. Block $\times$ land use interaction was significant ($P<0.01$) indicating mutual influence of these two factors on each other e.g. SOC content was highest in Oran area of Abu Road and lowest in pasture land of Baitu block.

Soil organic carbon stock

Average soil carbon stock in 0-30 cm soil layer was 7.60 $\pm$ 0.23 (mean $\pm$ SE) tons ha^{-1} after correcting it for gravel (CSG) and 9.18 $\pm$ 0.35 t ha^{-1} without gravel correction (CSW) across the blocks and land uses. Both types of carbon

Table 6. Effects of spatial variations and land uses on per cent soil organic carbon content in 2016-17 (values are mean $\pm$ SE of multiple replications)

Land use	Block					
	Bali	Baitu	Abu Road	Sanchor	Baap	Sankara
Forest	0.48 $\pm$ 0.06	0.15 $\pm$ 0.05	0.70 $\pm$ 0.07	0.19 $\pm$ 0.02	0.14 $\pm$ 0.02	0.13 $\pm$ 0.01
Oran	0.34 $\pm$ 0.06	0.12 $\pm$ 0.02	0.72 $\pm$ 0.04	0.17 $\pm$ 0.02	0.13 $\pm$ 0.03	0.17 $\pm$ 0.01
Pasture land	0.27 $\pm$ 0.02	0.10 $\pm$ 0.01	0.63 $\pm$ 0.06	0.18 $\pm$ 0.02	0.13 $\pm$ 0.01	0.16 $\pm$ 0.01
Agriculture	0.47 $\pm$ 0.04	0.15 $\pm$ 0.01	0.49 $\pm$ 0.05	0.22 $\pm$ 0.02	0.15 $\pm$ 0.01	0.16 $\pm$ 0.01
Roadside	0.27 $\pm$ 0.04	0.09 $\pm$ 0.01	0.46 $\pm$ 0.07	0.15 $\pm$ 0.02	0.15 $\pm$ 0.01	0.14 $\pm$ 0.01
Fallow land	0.48 $\pm$ 0.02	0.11 $\pm$ 0.01	0.49 $\pm$ 0.03	0.14 $\pm$ 0.02	0.14 $\pm$ 0.01	0.14 $\pm$ 0.01
Two-way ANOVA		F value	P value			
Block		144.96	0.000			
Land use		8.683	0.000			
Block $\times$ land use		4.480	0.000			

stock varied ($P<0.01$) significantly between the blocks as well as land uses (Table 7). Across the land uses, soil carbon stock was lowest ($P<0.05$) in Baitu block (5.04 and 5.31 t ha^{-1}) and highest in Abu Road block (16.63 and 25.37 t ha^{-1} for CSG and CSW respectively) with 4.8-fold spatial variations between these two blocks. Carbon stock in Baitu, Baap and Sankara were almost similar ($P>0.05$) for CSG. Soils of other blocks varied significantly ($P<0.05$) with each other and were in order as Baitu-Sankara-Baap<Sanchor<Bali<Abu Road. Among the land uses (across the blocks), the lowest CSG (5.72 t ha^{-1}) was in the soils of fallow lands, but it did not differ with the carbon stock in the soils along the roadside. The highest (9.72 t ha^{-1}) carbon stock was in forest land, which did not differ ($P>0.05$) with that in agriculture land and oran. Thus, the order of land uses for soil carbon storage was: Fallow land<roadside<pasture land<agriculture land<Oran<Forest. Block $\times$ land use was highly significant ($P<0.01$), where the value was highest (19.43 t ha^{-1}) in oran of Abu Road and lowest (3.74 t ha^{-1}) in the soils along roadside of Baitu block. This interaction was significant ($P<0.01$) for CSW also indicating mutual effects of block and land use.

Change in soil status

When the present data were compared with literature data (Singh, 2014), there was a decrease in gravel content in 2017 (10.12%) as compared to 13.96% in 2013 across the blocks and land uses. Extent of decrease was greater in Bali and Abu Road among the blocks and fallow land among the land uses. The least difference in gravel content of the soils of 2013 and 2017 was for the soil along roadside (Fig. 2a). However, soil bulk density was greater in 2017 than in 2013. The increase in bulk density was relatively greater in Baitu and Bali blocks as compared to the soils of other blocks. Among the land uses, the difference in soil bulk density was low ($P>0.05$) for the soil collected during 2013-14 and 2016-17 from fallow land (Fig. 2b). There was almost negligible change in per cent SOC during this period. However, within blocks there was a slight increase in SOC in Baitu and Sankara blocks, and a minor decrease in Bali and Abu Road blocks. Among the land uses, soils of oran and agriculture lands showed an increase, whereas the soils of fallow land indicated a decrease in SOC. The soils of pasture land and roadside showed negligible variations in SOC

Table 7. Effects of spatial variations and land uses on soil organic carbon stock (t ha^{-1}) (values are mean $\pm$ SE of multiple replications)

Land use	Block					
	Bali	Baitu	Abu Road	Sanchor	Baap	Sankara
Soil organic carbon without gravel correction (CSW)						
Forest	20.65 $\pm$ 2.64	6.93 $\pm$ 2.45	30.42 $\pm$ 3.08	8.70 $\pm$ 0.79	6.65 $\pm$ 0.79	5.78 $\pm$ 0.59
Oran	14.90 $\pm$ 2.69	5.76 $\pm$ 0.87	31.38 $\pm$ 2.02	7.49 $\pm$ 1.00	5.98 $\pm$ 1.16	7.48 $\pm$ 0.24
Pasture land	11.50 $\pm$ 0.76	4.83 $\pm$ 0.41	27.25 $\pm$ 2.40	8.02 $\pm$ 0.76	5.89 $\pm$ 0.47	7.23 $\pm$ 0.28
Agriculture	20.23 $\pm$ 1.93	7.19 $\pm$ 0.27	21.45 $\pm$ 2.37	9.91 $\pm$ 1.06	6.97 $\pm$ 0.52	6.93 $\pm$ 0.31
Roadside	11.85 $\pm$ 1.81	4.07 $\pm$ 0.28	19.70 $\pm$ 2.99	6.89 $\pm$ 0.74	6.60 $\pm$ 0.53	6.05 $\pm$ 0.56
Fallow land	22.29 $\pm$ 2.68	4.69 $\pm$ 0.22	21.81 $\pm$ 3.11	6.34 $\pm$ 0.73	6.29 $\pm$ 0.51	6.24 $\pm$ 0.42
Soil organic carbon with gravel correction (CSG)						
Forest	13.35 $\pm$ 1.20	6.62 $\pm$ 2.20	15.80 $\pm$ 2.12	8.70 $\pm$ 0.79	6.51 $\pm$ 0.75	5.46 $\pm$ 0.64
Oran	9.92 $\pm$ 1.69	5.68 $\pm$ 0.88	19.43 $\pm$ 2.02	7.47 $\pm$ 0.99	5.42 $\pm$ 0.70	5.88 $\pm$ 0.43
Pastureland	7.28 $\pm$ 0.66	4.68 $\pm$ 0.40	18.57 $\pm$ 2.69	7.73 $\pm$ 0.70	5.43 $\pm$ 0.49	6.80 $\pm$ 0.28
Agriculture	16.56 $\pm$ 1.91	6.94 $\pm$ 0.25	16.35 $\pm$ 1.72	9.84 $\pm$ 1.05	6.26 $\pm$ 0.49	6.33 $\pm$ 0.29
Roadside	8.94 $\pm$ 1.53	3.74 $\pm$ 0.24	13.79 $\pm$ 1.97	6.64 $\pm$ 0.68	6.09 $\pm$ 0.51	5.58 $\pm$ 0.48
Fallowland	17.72 $\pm$ 2.16	4.51 $\pm$ 0.22	17.42 $\pm$ 2.56	6.33 $\pm$ 0.73	5.98 $\pm$ 0.53	5.64 $\pm$ 0.36
Two-way ANOVA		CSW		CSG		
		F value		F value		
Block		139.836		68.598		
Land use		9.302		9.138		
Block $\times$ land use		4.485		2.905		

content during this period (Fig. 2c). For soil organic carbon stock, there was an increase in CSW from 9.07 t ha⁻¹ in 2013-14 to 9.18 t ha⁻¹ in 2016-17 and in CSG from 6.81 t ha⁻¹ during

2013-14 to 7.60 t ha⁻¹ during 2016-17 across the blocks and land uses. CSW increased in the soils of Baitu, Sanchor and Sankara blocks and decreased in Bali, Abu Road and Baap blocks

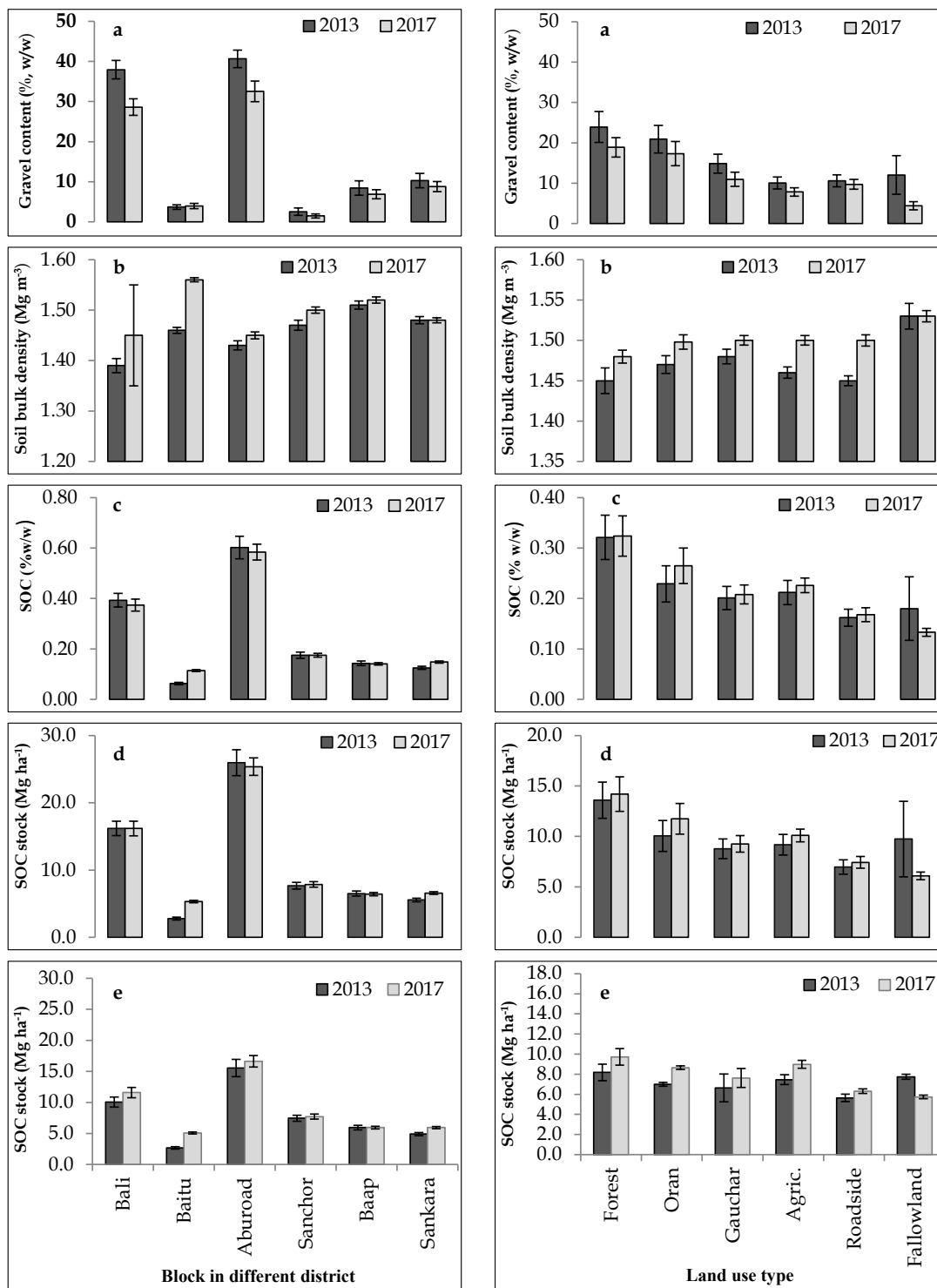


Fig. 2. Soil gravel (a), bulk density (b), SOC content (c), SOC stock without (d) and with gravel correction (e) under the influence of blocks (left panels) and land uses (right panels) in western Rajasthan during 2013-14 and 2016-17. Error bars are $\pm$ SE of multiple replications.

during 2017 than in 2013, whereas an increase in CSG was evident in all blocks during the same period (Fig. 2). Among the land uses, both carbon stock increased in all land uses (except fallow lands) during this period.

Correlation and regressions

There were positive correlations between annual average rainfall and gravel content, per cent SOC and soil carbon stock and human and buffalo and ox population. However, rainfall showed negative correlations with soil bulk density, number of animals per households (cow, goat and sheep) and land holdings (Table 8). Per cent soil organic carbon and carbon stock were negatively correlated to soil bulk density, livestock per households and goat/sheep population due to overgrazing and trampling, but indicated positive correlations to human, buffalo and ox populations. Number of households was greater in the villages situated in the blocks receiving high rainfall and had greater SOC, CSW and CSG and total human and livestock population (buffalo and ox) than the villages in low rainfall zone (i.e., positive correlation-ships). Family size was relatively small and land holding and cow and sheep/goat population were high in relatively low rainfall areas of Baap and Sankara as compared to those in high rainfall zone of Bali and Aburaod. This was shown by negative correlations between family size and cow and goat/sheep population and land holdings. Likewise, land holding was negatively correlated to annual rainfall, but was positively correlated to animals per households ($r=0.547$, $P<0.01$) and population of

cow ($r=0.460$, $P<0.01$) and goat/sheep ($r=0.547$, $P<0.01$).

Though depending upon parent material and weathering pattern gravel content was related to annual rainfall by a quadratic relationship ($F_{2/442}=175.9$, $R^2=0.443$, $P<0.001$), where it was lowest in the area with about 400 annual rainfall and increased with increase in annual rainfall because of erosion of fine soil fractions (Fig. 3a). High soil water availability and increased biological activities and roots and litter turnover in high rainfall areas was shown by a linear increase in soil organic carbon stock with increase in annual rainfall in case of CSW ($F_{1/447}=653.2$, $R^2=0.494$, $SE=4.70$, $P<0.001$) and by a quadratic relationship in case of CSG ($F_{2/445}=253.3$, $R^2=0.532$, $SE=3.29$, $P<0.001$) (Fig. 3b). Soil bulk density decreased linearly with increase in annual rainfall ($F_{1/446}=103.7$, $R^2=0.189$, $P<0.001$) and by a logarithmic relationship ($F_{1/446}=108.2$, $R^2=0.195$, $SE=5.09$, $P<0.001$) with per cent SOC (Fig. 3c). Carbon stock (CSW and CSG) decreased significantly ($F_{1/446}=174.7$ and 222.6 , $P<0.001$) by power of 0.24 and .31 respectively with increase in land holding probably due to organic manuring (in Fig. 3d). Soil carbon increased with increase in village level population by a power ($F_{1/446}=31.27$, $R^2=0.067$, $SE=0.604$, $P<0.001$ and $F_{1/446}=23.58$, $R^2=0.050$, $SE=0.524$, $P<0.001$) relationships (Fig. 3e). However soil carbon stock either without gravel correction ($F_{1/360}=8.11$, $R^2=0.022$, $SE=9.95$, $P<0.01$) and after gravel correction ($F_{1/360}=15.08$, $R^2=0.04$, $SE=6.22$, $P<0.001$) decreased with increase in number of livestock per household (Fig. 3f).

Table 8. Correlations in different variables of soils and socio-economic profile of a village in different blocks in western Rajasthan

Variable	Gravel	% SOC	BD	CSW	CSG	Rainfall	HHs individuals
Gravel	-	0.620**	-0.307**	0.616**	0.334**	0.576**	-
% SOC	0.620**	-	-0.404**	0.998**	0.914**	0.778**	-
Soil bulk density	-0.307**	-0.404**	-	-0.364**	-0.335**	-0.434**	-
Rainfall	0.576**	0.778**	-0.434**	0.771**	0.695**	-	-
Population		0.171*	-0.249*	0.162*	0.146*	0.366**	0.984**
-							
LS/HHs	-	-0.222**	0.230**	-0.217**	-0.219**	-0.331**	0.874**
Cow	-	-0.136**	0.115*	-0.132*	-0.135*	-0.295**	-0.186**
Buffalo	-	0.197**	-0.195**	0.193**	0.264**	0.400**	0.217**
Ox	-	0.283**	-0.243**	0.279**	0.255**	0.417**	0.458**
Goat/sheep	-0.128**	-0.209**	0.223**	-0.204**	-0.211**	-0.285**	-0.262**
Land holding	-	-0.410**	0.285**	-0.405**	-0.398**	-0.653**	-0.313**

Discussion

Land holding and household population

Variations in land holding in the studied region depended upon population density (which was highest in Abu Road), family size ($r=-0.313$, $P<0.01$) and fragmentation of the family into smaller ones. Land holding

increased from Abu Road and Baap blocks and was related to population density and land productivity influenced by rainfall, which decreased from Abu Road to Baap block thus land holding and rainfall followed a reverse trend ($r=-0.331$, $P<0.01$). A positive correlation of family size with livestock per households and population of buffalo and ox, and negative correlation with population of cow and goat/

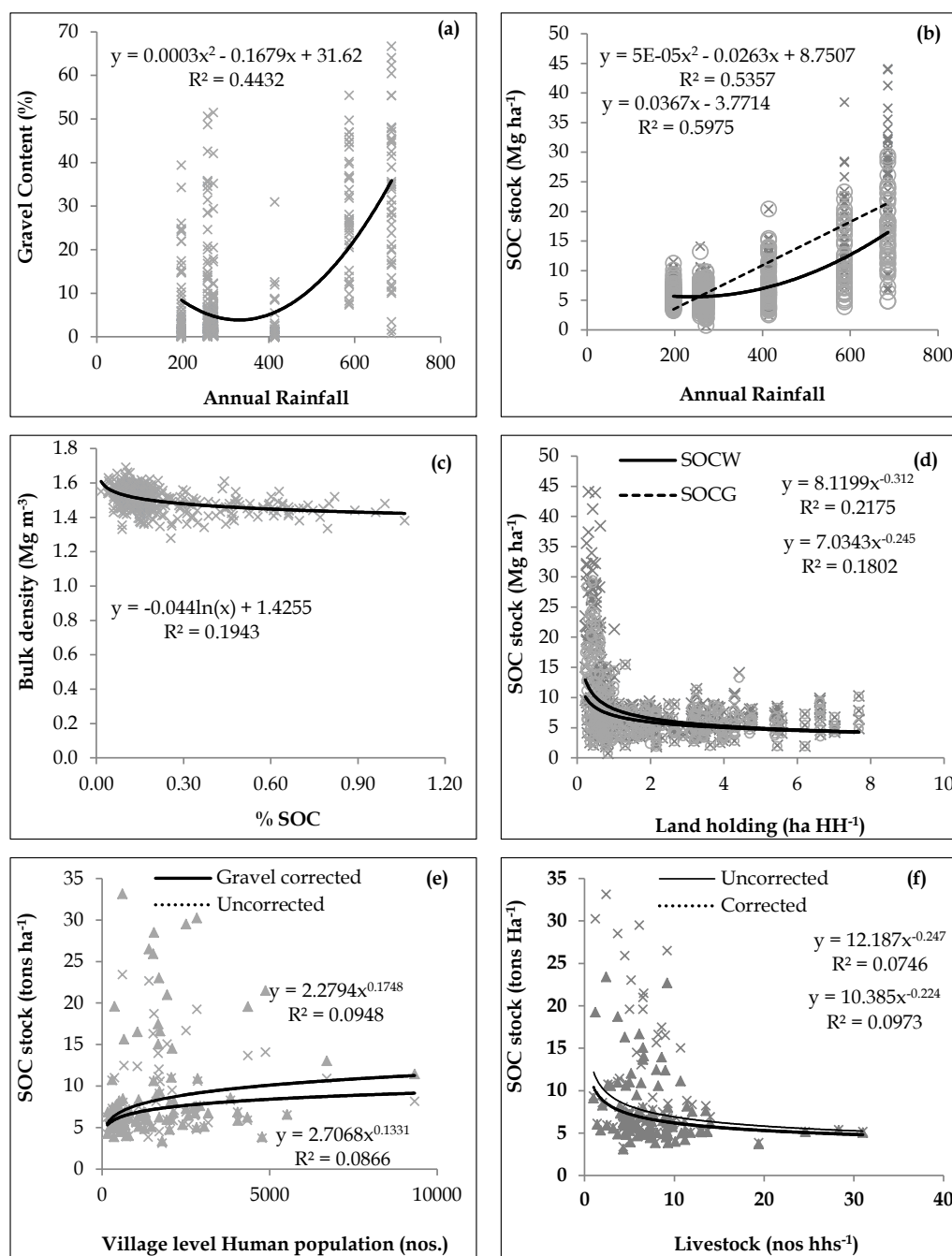


Fig. 3. Relationships of annual rainfall with gravel content (a) and soil carbon stock (b), per cent SOC with soil bulk density (c) and land holding and soil carbon stock with village level human population (e) and livestock per household (f) in the studied region of western Rajasthan.

sheep and land holdings indicates that livestock dominated by small ruminants and cow play an important role in livelihoods of relatively poor households. These animals moderate the risk in dry areas by providing more resilience as they help in diversifying livelihood and income because they can be easily migrated or liquidated during drought and famines (Louhaichi *et al.*, 2014). However, high population of goat and sheep in Baitu and Sankara blocks was also due to more resilience in these domestic animals towards climatic variability. This was also reflected by negative correlations between rainfall and the population of cow ($r=-0.295$, $P<0.01$) and goat/sheep ($r=-0.285$, $P<0.01$). Increasing population of buffalo in Sanchor, Bali and Abu Road blocks areas as compared to the other areas was due to increased water availability (and also rainfall, $r=0.400$, $P<0.01$) and increasing stall feeding practices in these blocks. Soju and Meena (2017) have also reported an increase in buffalo population by more than four times during 1956 to 2012. Large variations in number of domestic animals per households among different blocks have also been related to socioeconomic status as number of animals per household was observed greater with BPL (below poverty line) as compared to APL (above poverty line) families.

Soil characteristics and carbon storage

High value of significance level for variations in gravel content, soil bulk density, soil organic carbon and soil carbon stock among the blocks as compared to the value for variations due to land uses indicates that spatial distribution of the blocks had greater impact as compared to the land uses. Relatively high organic matter content reduces soil bulk density and increases porosity in the soils and thus soil fertility. It was shown by a negative logarithmic relationship ($F_{1/446}=108.2$, $R^2=0.195$, $SE=5.09$, $P<0.001$) between soil bulk density and per cent soil organic carbon (Fig 3c). SOC content, carbon stock and soil bulk density are very much related to rainfall and soil conditions (Venkanna *et al.*, 2014). Per cent SOC content showed an increasing trend as the average annual rainfall increased. This indicates the beneficial effects of soil water availability through rainfall on soil organic carbon as observed in the other studies, where soil carbon content and stock were favored by rainfall at regional level (Chaplot *et al.*, 2010;

Singh, 2014). It was also indicated by highest SOC content and SOC stock in Bali and Abu Road with relatively high annual rainfall as compared to the other blocks. However, soil types also played role on these variables as observed in Baitu block dominated by dune soil that is sandy in nature. Soil bulk density showed a decreasing trend with increase in rainfall indicating the effects of increased soil organic matter. Beneficial effects of rainfall are through increased soil water availability favoring vegetation growth and biomass production and subsequently soil organic carbon enrichment and improvement of soil structure. Thus climate and land management practices have the largest relative influence on variation in total SOC.

Distribution of rainfall and soil characteristics among the blocks played important roles in influencing the above-mentioned soil variables. Lowest gravel, SOC contents and carbon stock, and highest soil bulk density in Baitu block may be due to dune dominated soil (sandy) with increased coarse sand content under wind action or movement of silt and clay content in deeper soil layer (below 30 cm soil layer). Highest amount of gravel and SOC and lowest soil bulk density in Abu Road areas was due to high rainfall leading to vegetation growth and development of soil organic matter. Relatively high value of standard error on the mean value of soil bulk density in Bali block is indicative of high variations in soil bulk density collected from different land uses also. However, significantly high carbon storage in soils of Abu Road and Bali areas was also associated with small land holding coupled with relatively high vegetation status, organic manuring and rainfall as shown by a significant ($F_{1/446}=174.7$ and 222.6 , $P<0.001$) decrease in both gravel corrected and uncorrected soil carbon stock by power of 0.24 and .31 respectively with increase in land holding (Fig. 3d).

Highest gravel, SOC and carbon storage and lowest soil bulk density in forest land or oran indicated that presence of gravel helped in increasing soil porosity. Relatively greater vegetation availability in forests and the oran probably favored SOC accumulation by turnover of roots and litters added through vegetation. Non-significant difference in soil carbon storage in the soils of forest lands, agriculture land and oran indicates that this

region is very low in SOC stock and variation in carbon stock is influenced by organic manuring particularly in agriculture land and intensive grazing by the increasing livestock population on the pasture land or sacred groves and in some cases forest land also. This indicates the impacts of land use change on the soil carbon budget as observed by variations in carbon storage in grassland, woodland, cropland and unused land studied by Yang *et al.* (2018). Grazing and trampling impacts of livestock appeared more dominant factor as compared to the chemical and biological impact of the faeces and urine that the animal adds to the soils affecting the soil carbon status along roadside or those in pasturelands or fallow lands (Whitmore, 2001). Positive and negative impacts of human population per village and number of livestock per household respectively indicate a link between poverty dynamics and soil degradation in small land holder. Large households are able to invest in soil fertility management while the poorer households are mining nutrients in the soils. The decrease in SOC stock was more significant with increase in population of goat ($F_{1/446} = 20.74$, $P < 0.001$) as compared to that of cow population ($F_{1/446} = 8.25$, $P < 0.01$), but SOC stock showed quadratic relation by first increasing and then decreasing with increase in buffalo population ($F_{2/445} = 23.9$, $R^2 = 0.97$, $P < 0.001$) defining an optimum number per households, i.e. 1 buffalo per household. The probable cause indicating positive effect of buffalo population on increased SOC stock was their stall feeding particularly in area with increase water availability and its manure applied to the farm for increasing farm productivity (Ngo *et al.*, 2014).

A decrease in gravel content and increase in bulk density and soil carbon stock during 2013-2017 was due to increase in content of fine earth fraction (soil) under the influence of wind and water (rainfall) as well as biological actions. Relatively higher average soil bulk density (1.51 g cm^{-3}) in 2017 as compared to 1.46 g cm^{-3} in 2012-13 indicated increased compactness. Changes in SOC content depends upon the climatic and edaphic factors along with anthropogenic activities going on in the region due to increased human and livestock population. Variations in soil carbon stock from $7.60 \pm 0.23 \text{ t ha}^{-1}$ after correcting it for gravel and $9.18 \pm 0.35 \text{ t ha}^{-1}$ without gravel correction across

the blocks and land uses indicates the effects of gravel in reducing the SOC estimate and an overestimation if it is not corrected for gravel content.

Highest soil bulk density and lowest SOC and SOC stock in fallow land, roadside and pasture lands were due to grazing and trampling effects that facilitates SOC loss along with soils and soil compaction (due to land abandonment). However, higher SOC and SOC stock in the soils of fallow lands of Bali and Abu Road blocks and agriculture lands of Bali, Baitu and Sanchor blocks appeared to be due to organic manure added to the agriculture land and dependence of soil compaction and SOC content on rainfall, vegetation status and anthropogenic activities as latter blocks situated in arid regions as compared to the former blocks i.e., Bali and Abu Road blocks, which are situated in relatively high rainfall region. Significant ($P < 0.01$) block $\times$ land use interaction indicated that these two factors influenced each other. Highest SOC in Oran area of Abu Road and lowest SOC in pasture land of Baitu block indicated the importance of soil moisture influenced by rainfall (irrigation) and soil conditions/types that varied spatially between these two blocks (Fig. 3b). Soil carbon stocks are reported to be significantly affected by land uses (largest under forest, less under shifting cultivation and the smallest under continuous cultivation) and correlated to various factors like total annual rainfall and latitude at regional level and soil type, hill-slope, distance to the water sources and the slope angle at the local level (Chaplot *et al.*, 2010; Singh *et al.*, 2013).

Conclusion

Density of human and livestock, their dynamics and land use variations influenced soil characteristics and soil carbon stock in western Rajasthan. Further, spatial variations in rainfall and soil texture in different blocks also played dominant role on soil gravel content, bulk density, SOC content and soil carbon storage by influencing vegetation status and land productivity. Though relatively high in soil carbon storage, the forest and woodlands (oran) need effective managements for further improvement. Pasture lands are under degradation due to overgrazing, careless management and drought leading to accelerated

soil erosion and reduced soil carbon storage but have great potential to sequester soil organic carbon when managed effectively.

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