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Carbon stock and its distribution in soils of Ajmer district and management strategies for carbon sequestration

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Abstract:The soils of the Ajmer district have been studied for their organic and inorganic carbon distribution and the stock has been calculated in different soil series. The variation has been observed in the organic and inorganic carbon stock of the soils over Aravalli landscape (37.92 and 11.99 Tg), and the Eastern Rajasthan Upland (77.32 and 39.08 Tg) respectively. The stock of organic and inorganic carbon in Semi-Arid Transitional Plain is significantly lower (0.91 and 0.79 Tg) for the upper 25 cm soil depth. The management strategies towards sequestering organic carbon have been discussed.

Additional key words: *Arid and semi-arid regions, organic and inorganic carbon stock, sequestration of organic carbon*

Introduction

Management of soil organic carbon to maintain the soil in good health is a matter of major concern and a challenging task in the arid and semi-arid regions. The extent of organic matter content in the soil is a measure of soil quality. The contribution of soil organic carbon on the physical, chemical and biological properties of soils in sustaining their productivity has already been reported by several workers. Factors that have a bearing on the maintenance of organic carbon stock of soils are related mainly to climate, hydrology, parent material, soil fertility, biological activity, type and extent of vegetation and land use intensity and type (Jenny 1941). Anthropological interventions like deforestation, biomass burning, unplanned land use and unwarranted land use modifications and environmental pollution either directly or indirectly affect the soil organic carbon stock. It is, therefore, essential to have a prior knowledge of quantity and quality of soil organic carbon, to sustain productivity and quality of soils.

Jenny and Raychaudhari (1960), while studying the organic carbon content of over 500 soil samples drawn from different cultivated fields and forests under variable rainfall and temperatures in India, were the first to confirm the impact of climate on organic carbon status. However, the first attempt to present organic carbon status of soils in terms of soil organic carbon stock was made by Gupta and Rao (1994) in 48 benchmark soil series of India and reported the organic carbon stock to be around 24.3 Pg (1 Pg=10^{15} g).

Concerns of global warming have led several workers to investigate the quality, kind, distribution and behaviour of soil organic carbon (Eswaran *et. al.* 1993; Sombroek *et al.* 1993; Bajtes 1996; Velayutham *et al.* 2000). These concerns have led to several quantitative estimates of soil organic carbon in addition to those reported above (Bohn 1982; Buringh 1984; Kimble *et al.* 1990). The reporting the organic carbon status of soils in terms of per cent distribution is one way of knowing yet, it does not throw light on the

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reservoir of organic carbon, spread over a particular area. For this, it would be meaningful to report soil organic carbon on unit area basis for a specified depth interval. Such a representation requires information on spatial distribution of soil types, soil organic carbon content and bulk density of soils. Recently Bhattacharyya *et al.* (2000 a and b) reported the organic carbon stock of soils of India for different physiographic regions. The present study attempts to report the effect of different soil types associated with different landforms on the soil organic and inorganic carbon stock of soils of Ajmer district and suggest management strategies for carbon sequestration in soils.

Materials and Methods

Ajmer district lies between 25°38′ N to 26°58′ N latitudes and 73°54′ E to 75°22′ E longitudes and covers an area of 8423.88 sq. kms. The district has a semi-arid climate with rainfall varying from 400 to 1000 mm. The distribution of rainfall is presented in figure 1 and table 1. The district has been delineated into three physiographic divisions namely Aravalli landscape, the Eastern Rajasthan Upland and the Semi-Arid Transitional Plain with their subdivisions. During the survey, 37 soil series (Table 1) have been identified and delineated into 111 soil mapping units (association of soil series). Each soil series association consists of a dominant and a sub-dominant soil series. Standard laboratory techniques were used to estimate the physical and chemical attributes of the soils (Page 1986; Klute 1986). Soil organic carbon was estimated using the Walkley and Black method, while bulk density, in absence of measured values, is being inferred based on the texture of the soil as well as from reference to available data. The size of total soil organic carbon stock is calculated following the method described by Bajtes (1996). This consists of calculating the stock as a product of soil organic carbon (g g^{-1}), bulk density (Mgm^{-3}) and depth (m) as a first step followed by multiplying the product by the area of the particular soil type (soil series). The soil organic carbon (SOC) stock has been estimated for depth ranging from 0-25, 0-50, 0-100 and 0-150 cm. For soil inorganic carbon (SIC), the calculation was made using 12 per cent C values in $CaCO_3$ using the other steps as detailed for organic carbon. The $CaCO_3$ was estimated from the acid-base titration method (Page 1986).

Results and Discussion

The salient physical and chemical characteristics of the soil series are presented in table 2. The soils of the district are extremely shallow to deep, sandy to clay in texture, alkaline in reaction with moderate cation exchange capacity. In the eastern Rajasthan Upland, some soils had more than 15 exchangeable sodium percent (ESP). The majority of the soils of the eastern Rajasthan upland and the semi-arid transitional plains are low in organic carbon content and soils of few series have OC content more than 0.5 per cent. However, soils of the Aravalli landscape are the exception. The SOC and SIC stock of different soil series in Aravalli landscape, Eastern Rajasthan Upland and Semi-Arid Transitional Plains is depicted through figure 2 and tables 3 to 5, respectively.

The eastern Rajasthan Upland had 67 per cent of the SOC stock in the surface 25 cm of the soil and 75 per cent of the SIC stock constituting 69 per cent of stock (Table 4 and Fig. 2). The SOC reserves in this physiographic region is based on 22 series and ranges from 0.17 to 12.73 Tg (1Tg = 10^{12}g) and 0.59 to 65.60 Tg in the first 0- 25 cm and 0-150 cm soil depth respectively. The SIC stock ranged from nil to 19.55 Tg and nil to 28.85 Tg in the 0-25 cm soil and 0-150 cm soil depth, respectively.

The Aravalli landscape (27 per cent of the TGA), contributes relatively less to the total SOC stock in the surface 25 cm soil depth (33 %) whereas SIC stock contributed 23 per cent towards total inorganic carbon stock in this physiographic unit (Table 3 and Fig. 2). The lower SOC and SIC stocks as compared to the eastern Rajasthan upland is due to less aerial extent. The SOC store in this physiographic region is based on 13 series and ranged from 0.25 to 6.26 Tg in the first 0- 25 cm and from 5.99 Tg in 0-150 cm soil depth respectively. In case of SIC, it ranged from nil to 7.18 Tg in the 0-25 cm and from nil to 47.74 Tg in 0-150 cm layer, respectively. Here more number of soil series had higher SOC than other physiographic regions. This could be attributed to more vegetative cover in this region as well lower average annual temperature (23.58 ^{0}C) as compared to the other regions (Table 1). Bhattacharyya *et al.* (2000b) while studying the organic carbon stock of Indian soils attributed lower rainfall and higher temperatures to adversely affect the organic carbon status of soils. Though the rainfall in the Eastern Rajasthan Upland is relatively higher (769 mm) as compared to Aravalli landscape (736 mm), yet lower organic carbon content could be attributed to lower vegetative cover and a higher average annual temperature (24.58 ^{0}C).

The Semi-Arid Transitional plain covers 1.15 per cent of the TGA. The surface 25 cm soil contributed 0.78 per cent to the total organic carbon stock. Similarly the SIC stock was just 1.52 per cent of the total inorganic carbon stock of the region. The SOC stock of the region, based on the 2 series, ranged from 0.45 to 0.46 Tg in the first 25 cm and 1.68 to 2.37 Tg in 0-150 cm soil depth, respectively (Table 3 and Fig. 2). The Semi-Arid Transitional Plain had lowest organic carbon owing to low rainfall (712 mm) and higher mean temperature (>26.6^{0}C) throughout the year as compared to the Eastern Rajasthan Upland (769mm; 24.6^{0}C) and the Aravalli landscape (736 mm; 23.6^{0}C). The lower carbon stock in Aravalli landscape as compared to Eastern Rajasthan Upland is due to less coverage. The calcium carbonate has been reported to increase with depth in a majority of soil series across the physiography and the increase was relatively more in coarse-textured soils (Giri *et al. 2003*). Similar observations have also been made by Wieder and Yaalon (1974) who found texture to have also a definite role in depth-related accumulation of carbonates.

In general, soils with clay texture (Table 2) contained more organic carbon (mean 0.58 %) than soils having textures of loamy sand (mean 0.36 %) and sand (mean 0.2 %) (Table 6; Fig. 3). The relatively higher content of organic carbon in fine-textured soils may be due to greater surface area for binding the organic colloids (Bhattacharyya *et al.* 2000b). The relatively higher content of organic carbon in Kanas soil series (loamy sand texture) may be attributed to vegetative cover. Besides texture, soil organic is also controlled by management practices, cropping pattern, rainfall and temperature. In the present study, management practice (quantity and frequency of organic matter addition) appears to have more influence.

Although in Makarwali soils, enough FYM is added, the soils showed a lower content of organic carbon owing to high cropping intensity. Scott *et al.* (1996), however, found that soil texture had no effect on litter decomposition but along with moisture, finer textured soils had more decomposed matter as compared to coarser textured soils. But texture has been reported to affect inorganic carbon (pedogenic calcium carbonate) distribution. According to Murthy *et al.* (1982) soils with lower content of silt and clay had lower content of $CaCO_3$, as nodule formation has been observed to be a function of textural characteristics (Wieder and Yaalon 1974). It is observed that, in general, coarse textured soils (loamy sand or sandy loam) were virtually free of $CaCO_3$ content as compared to finer textured (sandy clay loam to clay) soils (Table 2). However, the presence of $CaCO_3$ in coarse textured soils in some soil series namely Au, Bhadun, Bherukhera, Jharwasa, Kalanada and Rupangarh could be attributed to the depletion of Ca^{2+} ions and the consequent increase in exchangeable sodium content (Balpande *et al.* 1996). The presence of $CaCO_3$ in other coarse textured soils *i.e.* Jawaja and Kuchil with low ESP suggests that the $CaCO_3$ could be carried from elsewhere and deposited here either due to wind or water (Brewer 1976).

Management of carbon sequestration

There exists a large potential for organic carbon sequestration in soil through appropriate land use and scientific soil management. Appropriate management strategies and timely policy consideration are two approaches to exploit this potential. Management strategies include following of proper land use and farming systems, effective soil management practices and proper utilization of plant and animal wastes. Policy considerations include economic factors, environmental and health concerns and ethical issues (Lal *et al.* 1997).

It is observed that in soils where the higher quantity of organic matter (15 to 20 tons ha^{-1} of FYM every second year) was added, the content of organic carbon was higher (soil series of Aravalli landscape) as compared to soils which received less quantity or frequency of added FYM (in soil series of eastern Rajasthan upland and semi-arid transitional plain). Thus FYM appears to be a good source of rapid car-

Table 1. Soil series, area, physiography and climatic characteristics in Ajmer district

Soil series name	Physiographic region	Climate*		Area (ha)**
		MAR	Avg. temp	
Beawar	*A. Aravalli landscape*	725-750	23.58⁰ C	32630
Dabla		675-700		6796
Devmali		725-750		21334
Gangwana		750-775		4333
Jawaja		1000-1025		29284
Kanas		750-775		22873
Kalesara		675-700		31308
Kuchil		625-650		8357
Makarwali		750-775		19217
Mewaria		675-700		2234
Nituti		625-650		22873
Rupra		925-950		7586
Samla		675-700		15084
	B. Eastern Rajasthan Upland			
Au		625-650	24.58⁰ C	2050
Bhadun		625-650		1251
Bherukhera		825-850		12797
Champaneri		800-825		38981
Chavandiya		750-775		6179
Dathali		625-650		19145
Goyala		825-850		11289
Jalkhera		925-950		48791
Jharwasa		1000-1025		35867
Kabania		925-950		43770
Kalanada		750-775		16152
Kalera		925-950		70518
Khirana		825-850		8933
Kurari		625-650		16174
Kushalpura		925-950		17650
Mandawaria		750-775		1901
Pari		625-650		41462
Rupangarh		625-650		9906
Sanawata		725-750		2199
Sarana		750-775		31105
Sonkaliya		750-775		35596
Taswaria		725-750		4471
Gowaliya	*C. Semi arid Transitional Plain*	750-775	26.58⁰ C	6210
Immatpura		675-700		3445

Source *Anonymous (1997); ** Giri *et al.* (2003)

Table 2. Selected soil properties of soil series in Ajmer district

Physiography/ Soil series	Total depth (cm)	Surface texture	Org C (%)*	$CaCO_3$ (%)*	pH (1:2.5)*	C E C c mol/kg^{-1})*	ESP (%)*
			A. Aravalli Landscape				
Beawar	98	sl	0.57	-	8.7	11.5	2
Dabla	140	sl	0.60	-	7.8	8.8	4
Devmali	48	sl	0.3	-	7.5	6.9	9
Gangwana	88	cl	0.8	4.5	8.0	21.7	3
Jawaja	144	sl	0.4	8.5	7.9	9.6	5
Kanas	10	ls (gr)	0.63	-	7.6	6.6	4
Kalesara	36	scl (gr)	0.3	-	7.8	15.3	1
Kuchil	74	sl	0.7	10.3	8.0	13.9	4
Makarwali	140	scl	0.4	-	8.3	16.5	4
Mewaria	102	sl	0.3	-	8.3	10.5	8
Nituti	130	ls	0.39	-	8.0	7.6	5
Rupra	73	sl	0.36	-	7.6	9.8	8
Samla	82	scl	0.6	-	7.5	19.3	2
			B. Eastern Rajasthan Upland				
Au	140	sl	0.2	7.7	9.0	10.7	77
Bhadun	150	sl	0.2	4.5	8.8	11.6	18
Bherukhera	120	sl	0.5	9.6	8.0	11.1	24
Champaneri	70	sl	0.4	-	7.0	13.9	3
Chavandiya	95	scl	0.6	-	8.5	15.2	3
Dathali	45	cl	0.39	-	8.4	26.6	2
Goyala	140	c	0.5	2.1	8.5	27.8	11
Jalkhera	16	sl	0.5	-	8.1	8.8	7
Jharwasa	77	sl	0.5	21.0	8.9	11.1	47
Kabania	38	sl	0.4	-	8.4	10.8	10
Kalanada	85	sl	0.4	3.2	8.1	11.9	8
Kalera	140	c	0.4	2.05	8.5	37.2	5
Khirana	120	sl	0.3	-	7.8	11.5	3
Kurari	41	sl	0.3	-	8.5	10.4	5
Kushalpura	101	l	0.6	-	8.3	18.1	2
Mandawaria	30	ls	0.2	-	8.7	6.6	4
Pari	72	cl	0.4	-	8.1	19.7	3
Rupangarh	150	ls	0.2	4.0	8.9	3.7	19
Sanawata	135	c	0.8	0.92	7.8	39.6	1
Sarana	68	scl	0.5	-	7.7	15.7	4
Sonkaliya	71	l	0.3	-	8.4	14.2	2
Taswaria	100	c	0.6	-	7.7	32.6	1
			C. Semi arid Transitional Plain				
Gowaliya	150	s	0.2	1.2	7.8	6.2	8
Immatpura	120	sl	0.4	-	8.1	8.8	9

*values are for the surface layers

Table 3. Organic and Inorganic Carbon Stock (Tg) in Soils of Aravalli landscape of Ajmer district

Soil series (Soil Taxonomy)		Carbon stock (Tg) Depth range (cm)			
		Hills and Hilly Terrain			
		0-25	0-50	0-100	0-150
Beawar (Typic Haplustepts)	SOC	5.48	9.99	19.47	-
	SIC	0	0	0-	0
	TC	5.48	9.99	19.47	0
Kalesara (Lithic Ustrorthents)	SOC	4.76	7.76	0	0
	SIC	0	0	0	0
	TC	4.76	7.76	0	0
Kanas (Lithic Ustorthents)	SOC	2.13	0	0	0
	SIC	0	0	0	0
	TC	2.13	0	0	0
Makarwali (Typic Haplustepts)	SOC	6.26	7.27	14.01	17.43
	SIC	0	0	0	0
	TC	6.26	7.27	14.01	17.43
		Pediments			
Dabla (Typic Haplustepts)	SOC	1.26	2.14	3.98	5.99
	SIC	0	0	0	0
	TC	1.26	2.14	3.98	5.99
Devmali (Lithic Haplustepts)	SOC	2.81	5.04	0	0
	SIC	0	0	0	0
	TC	2.81	5.04	0	0
Gangwana (Typic Haplustepts)	SOC	1.37	2.58	4.36	0
	SIC	0.92	1.76	3.33	0
	TC	2.29	4.34	7.69	0
Jawaja (Typic Haplustepts)	SOC	3.32	4.90	8.51	11.61
	SIC	7.18	10.90	25.99	47.74
	TC	10.50	15.80	34.50	59.35
Kuchil (Typic Haplustepts)	SOC	2.19	4.44	6.43	0
	SIC	3.89	7.11	10.31	0
	TC	6.08	11.55	16.74	0
Mewaria (Typic Ustorthents)	SOC	0.25	0.42	0.69	0
	SIC	0	0.20	0.73	0
	TC	0.25	0.62	1.42	0
Nituti (Typic Torripsamments)	SOC	3.30	5.75	10.22	13.88
	SIC	0	0	0	0
	TC	3.30	5.75	10.22	13.88
		Arvalli Plains			
Rupra (Typic Haplustepts)	SOC	1.04	2.36	3.18	0
	SIC	0	2.42	3.43	0
	TC	1.04	4.78	6.61	0
Samala (Typic Haplustepts)	SOC	3.75	8.18	14.47	0
	SIC	0	0	0	0
	TC	3.75	8.18	14.47	0
Total	SOC	37.92	60.83	85.32	48.91
	SIC	11.99	23.41	43.79	47.74
	TC	49.91	84.24	129.11	96.65

Table 4. Organic and Inorganic Carbon Stock (Tg) in Soils of Eastern Rajasthan Uplands of Ajmer district.

Soil series / Soil Taxonomy		Carbon stock (Tg) Depth range (cm)			
		0-25	0-50	0-100	0-150
		Residual Hills and Disintegrated hills			
Jalkhera (Lithic Ustorthents)	SOC	5.78	0	0	0
	SIC	0	0	0	0
	TC	5.78	0	0	0
Mandawaria (Lithic Ustorthents)	SOC	0.17	0	0	0
	SIC	0	0	0	0
	TC	0.17	0	0	0
		Gently sloping uplands			
Chawandiya (Typic Haplustepts)	SOC	1.30	2.38	4.00	0
	SIC	0	0	0	0
	TC	1.30	2.38	4.00	0
Sarana (Typic Haplustepts)	SOC	6.50	12.21	15.22	0
	SIC	0	0	0	0
	TC	6.50	12.21	15.22	0
		Very gently to gently sloping			
Champaneri (Typic Haplustepts)	SOC	7.41	16.40	22.13	0
	SIC	19.55	76.04	149.46	0
	TC	26.96	92.44	171.59	0
Jharwasa (Typic Haplustepts)	SOC	6.37	10.48	13.96	0
	SIC	33.01	77.07	124.36	0
	TC	39.38	87.55	138.32	0
Kabania (Lithic Haplustepts)	SOC	7.48	11.96	0	0
	SIC	0	0	0	0
	TC	7.48	11.96	0	0
Kalanada (Typic Calciustepts)	SOC	2.16	3.98	6.34	0
	SIC	3.83	9.58	21.99	0
	TC	5.99	13.56	28.33	0
Kurari (Lithic Haplustepts)	SOC	2.15	3.75	0	0
	SIC	0	0	0	0
	TC	2.15	3.75	0	0
Kushalpura (Typic Haplustepts)	SOC	3.40	6.15	10.29	0
	SIC	0	0	0	0
	TC	3.40	6.15	10.29	0
Pari (Typic Haplustepts)	SOC	6.39	11.32	14.06	0
	SIC	0	0	0	0
	TC	6.39	11.32	14.06	0

Contd..

Sonkaliya (Typic Haplustepts)	SOC	4.86	9.66	14.49	0
	SIC	0	0	0	0
	TC	4.86	9.66	14.49	0
Nearly level Micro basin					
Dathali (Lithic Haplustepts)	SOC	2.45	3.87	0	0
	SIC	0	0	0	0
	TC	2.45	3.87	0	0
Goyala (Typic Haplustepts)	SOC	1.79	2.89	4.91	5.85
	SIC	1.12	2.35	5.09	15.01
	TC	2.91	5.24	10.00	20.86
Kalera (Vertic Haplustepts)	SOC	12.73	24.88	53.95	64.68
	SIC	5.33	8.88	23.98	286.93
	TC	18.06	33.76	77.93	351.61
Sanawata (Typic Haplusterts)	SOC	0.57	1.01	1.70	2.14
	SIC	0.17	0.41	0.85	1.19
	TC	0.74	1.42	2.55	3.33
Taswaria (Vertic Haplusterts)	SOC	0.93	1.58	2.84	0
	SIC	0	0	0.82	0
	TC	0.93	1.58	3.66	0
Gently to moderately sloping land along lake margins					
Au (Typic Ustifluvents)	SOC	0.16	0.35	0.63	0.83
	SIC	0.77	1.47	2.98	4.29
	TC	0.93	1.82	3.61	5.12
Bhadun (Typic Ustipsamments)	SOC	0.001	0.25	0.45	0.59
	SIC	0.26	0.59	1.37	2.30
	TC	0.261	0.84	1.82	2.89
Rupangarh (Typic Ustipsamments)	SOC	0.72	1.23	2.15	2.99
	SIC	1.74	3.47	5.17	7.27
	TC	2.46	4.70	7.32	10.26
Nearly level young leeve					
Bherukhera (Typic Ustifluvents)	SOC	2.45	4.66	8.93	10.40
	SIC	6.31	12.50	24.20	28.85
	TC	8.76	17.16	33.13	39.25
Khirana (Typic Ustifluvents)	SOC	1.55	3.09	5.77	6.76
	SIC	0	0	0	0
	TC	1.55	3.09	5.77	6.76
Total	SOC	77.321	132.10	181.82	94.24
	SIC	72.09	192.36	359.45	345.84
	TC	149.411	324.46	541.27	440.08

Table 5. Organic and Inorganic Carbon Stock (Tg) in Soils of Semi-Arid Transitional plains of Ajmer district.

Soil series (Soil Taxonomy)		Carbon Stock (Tg) Depth range (cm)			
Gently to Moderately sloping land dotted with hummocks					
		0-25	0-50	0-100	0-150
Gowaliya (UsticTorripsamments)	SOC	0.46	0.93	1.77	2.37
	SIC	0.33	0.84	2.05	3.49
	TC	0.79	1.77	3.82	5.86
Immatpura (Aridic Haplustepts)	SOC	0.45	0.83	1.56	1.68
	SIC	0	0	0	0
	TC	0.45	0.83	1.56	1.68
Total	SOC	0.91	1.76	3.33	4.05
	SIC	0.79	0.84	2.05	3.49
	TC	1.70	2.60	5.38	7.54

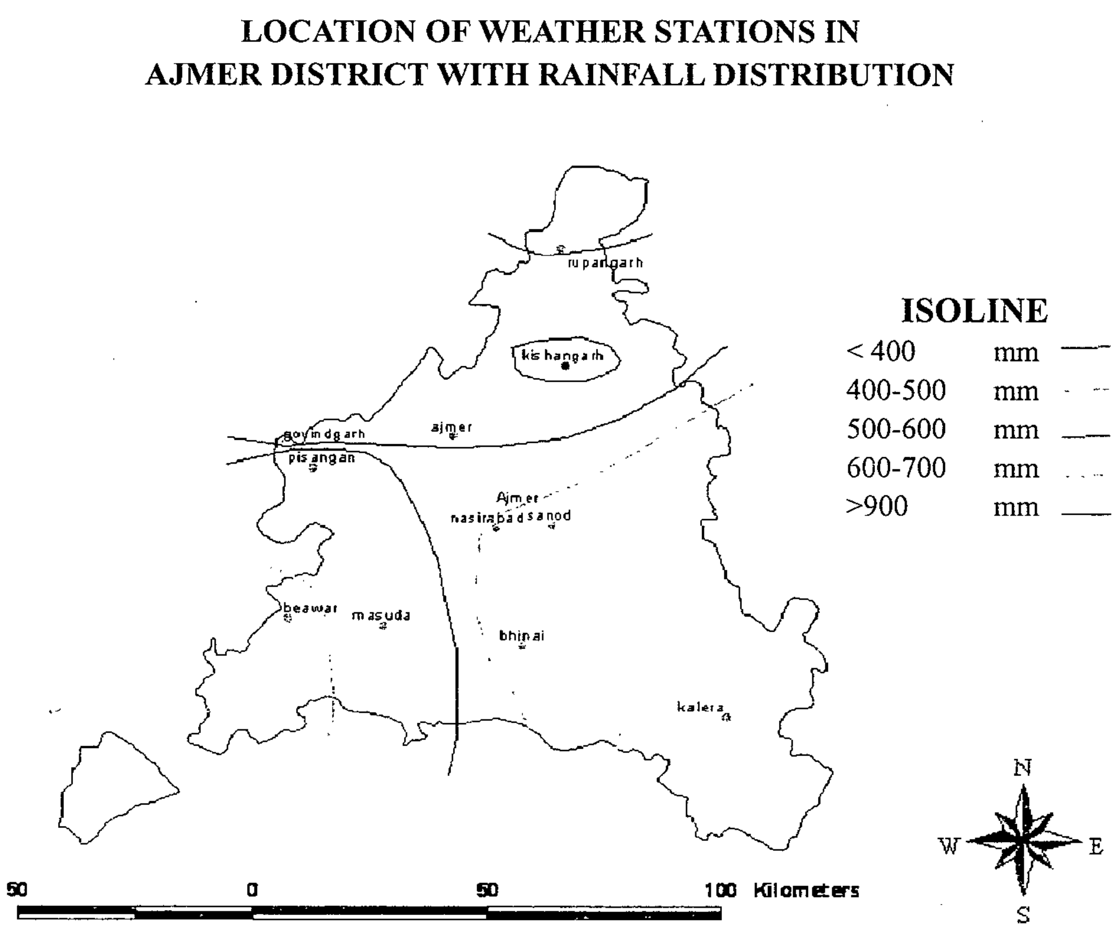

Fig. 1

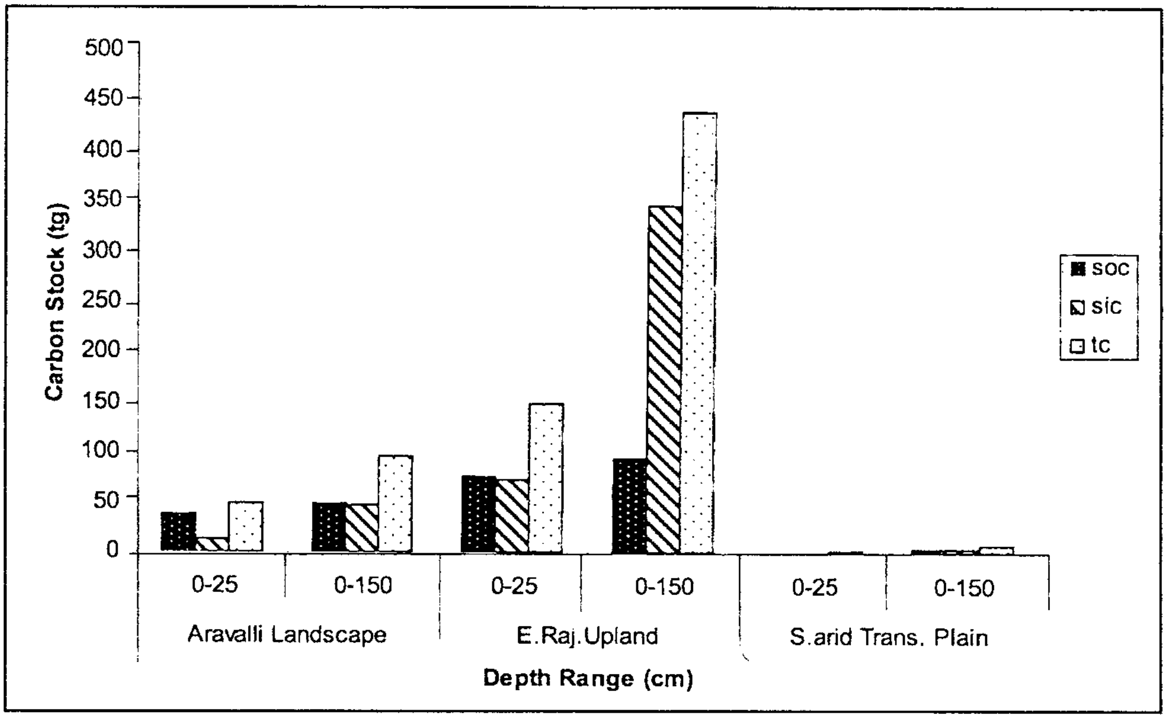

Fig. 2 Carbon stock of different physiographic Regions in Ajmer district

bon sequestration (Parton *et al.*, 1987; Gupta and Rao 1994, Swarup *et al.* 1999; Bhattacharyya *et al.* 2000b). In soils with carbonate accumulation (both non-pedogenic or pedogenic) as well as high exchangeable sodium accumulation, Ca^{2+} ions in the immobile $CaCO_3$ is released in the soil as a result of application of gypsum followed by selection of appropriate crops (Gupta and Abrol 1994; Pal *et. al.* 1999 and 2000) and the subsequent reduction of $CaCO_3$. The soils of the eastern Rajasthan upland especially Au, Bhadun, Bherukhera, Goyala, Jharwasa and Rupangarh had higher quantity of calcium carbonate and exchangeable sodium. To improve their productivity, application of gypsum would

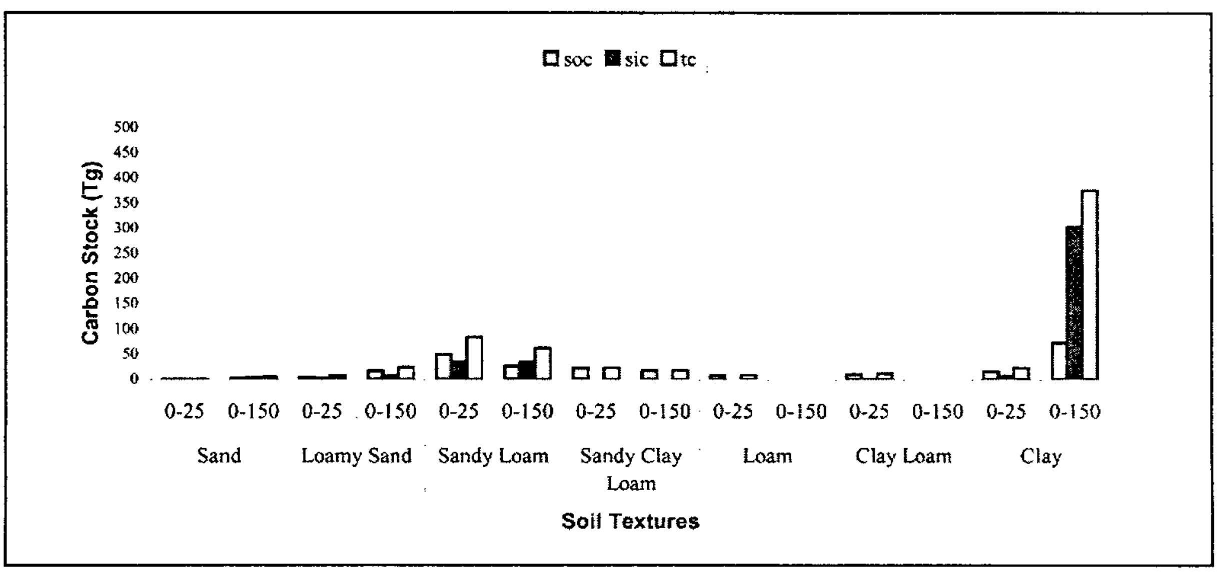

Fig. 3 Carbon stock in different soil textures in Ajmer district

be the appropriate management practice.

Among the physiographic regions, immediate attention needs to be given to augment the organic carbon status of the Semi-Arid Transitional Plains and the Eastern Rajasthan Upland and in particular Aravali landscape. Effective management of the organic carbon will not only help in building up the soil organic carbon stock to desirable levels, but also to dissolve the inorganic carbon in the soil for restoring the soil health and ultimately its productivity. Afforestation of the hills and hilly terrain should be taken up in the Aravalli landscape as well as the Eastern Rajasthan Uplands. In cultivated areas of the Aravalli landscape, the Eastern Rajathan Upland and the Semi-Arid Transitional Plains, addition of FYM, green manuring and gypsum application may be followed. In the wastelands, appropriate land use combinations like agri-pastoral, agri-horticultural, agri-silviculture, horti-pastoral, horti-silvicultural and silvi-pastoral systems would help in sequestering the desired quantity of soil organic carbon (Bhattacharyya *et al.* 2000b).

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