Vol. 13, No. 1, pp. 13-21 (2013)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Loss of Soil Carbon and Nitrogen through Wind Erosion in the Indian Thar Desert

PRIYABRATA SANTRA*[1], R.S. MERTIA[2], R.N. KUMAWAT[3], N.K. SINHA[2] AND H.R. MAHLA[2]

[1]*Central Arid Zone Research Institute, Jodhpur-342003, Rajasthan*

[2]*Central Arid Zone Research Institute, RRS, Jaisalmer-345001, Rajasthan*

[3]*Zonal Project Directorate (Zone-VI), CAZRI campus, Jodhpur-342005, Rajasthan*

ABSTRACT

Wind erosion is the most noticeable land degradation process in the hot arid region of India that covers about 16% of the geographical area of India. It results into loss of considerable amount of nutrient-rich particles from the region. Field investigations were carried out in a rangeland site located at Jaisalmer centre of Central Arid Zone Research Institute in the province of western Rajasthan to quantify the nutrient loss through wind erosion. The aeolian mass fluxes ($M\ L^{-2}\ T^{-1}$) were collected at four different heights: 0.25 m, 0.50 m, 0.75 m, and 2 m above land surface. Analysis of eroded soil was performed using Foss Heraeus CHN-O-rapid elemental analyzer. The results have revealed an average loss of 4 g C kg^{-1} and 0.37 g N kg^{-1}. Present study shows that the C and N content in eroded soils were highest during the month of July and the accumulated annual loss was approximated as 45.9 kg C ha^{-1} and 4.3 kg N ha^{-1}. To mitigate such appreciable soil nutrient losses through wind erosion, suitable rangeland utilization practices, which can help to retain the soil health and would also support the crop/grassland productivity in arid ecosystem, need to be evolved on priority.

Key words: Dust storm, Carbon and nitrogen loss, Desert rangelands, Wind erosion

Introduction

Desertification is affecting the livelihoods of more than 2 billion people across the world living in dryland areas that occupy nearly 41% of the Earth's land area. In India, about 22.96 m ha land is affected by desertification, out of which 15.2 m ha land is affected by wind erosion (Kar *et al.*, 2009). During wind erosion events, considerable amount of nutrient rich soil particles are eroded from top soil surface in the Indian Thar desert (Santra *et al.*, 2006, Mertia *et al.*, 2010). Loss of topsoil from arable desert soils consequently leads to the loss of soil productivity (Larney *et al.*, 1998; Zhao *et al.*, 2006a). These nutrient-rich aeolian masses may also travel long distances along with supra-regional dust storms influencing ecosystems that are far away from the origin of these dust particles (Zhao *et al.*, 2006b, Hoffman *et al.*, 2008). Deposition of such aeolian sediments is also considered to have important fertilizing effect on grasslands in the arid and semi-arid regions, field boundaries, surface water bodies, etc. (Offer *et al.*, 1996).

*Corresponding author,
Email: priyabrata.iitkgp@gmail.com

Abbreviations: CHN-O: Carbon Hydrogen Nitrogen-Oxygen; SOC: Soil Organic Carbon; DSE: Dust Storm Event; POWE: Periodical Observations on Wind Erosion

Loss of topsoil influences soil organic carbon (SOC) and nitrogen dynamics (Mendez *et al.*, 2006) that eventually affect the soil carbon sequestration potentials (Stallard, 1998; Lal, 2003). Conservation and maintenance of SOC contents is a key step in maintaining soil quality and productivity. Progressive trends of landuse changes from natural rangeland ecosystem to arable farming in dryland areas have also resulted in faster decline of the meager SOC pool of desert soils and even more under the scenario of global climate change related desertification processes (Lal, 2001; Dawson and Smith, 2007). Investigation on quantification of carbon (C) and nitrogen (N) losses through wind erosion may help to assess the adverse environmental impacts in desert regions. Several studies on Indian deserts (Dhir, 1985; Narain *et al.*, 2000) revealed the richness of eroded soils in terms of nutrient contents. However, these studies were confined to surface deposited sediments only. However, reports are sparse on the quantification of C and N losses through field investigations and their periodical variations. Therefore, the present field investigation was carried out to assess the C and N losses through suspended soil sediments due to continuous wind erosion and dust storm events in the Indian Thar desert.

Material and methods

Study site

Field investigation on wind erosion / dust storm events was carried out in a rangeland site, which was located at 6 km eastward from Jaisalmer city in the Indian Thar desert (Fig. 1). The site was dominated with *Lasuirus sindicus* (sewan) grass, an abundantly available perennial plant species in the Indian Thar desert. Tussock density of sewan grass at the site was 8000-9000 tussocks ha^{-1}. Grazing of animals in the field site was regulated through fencing and by allowing

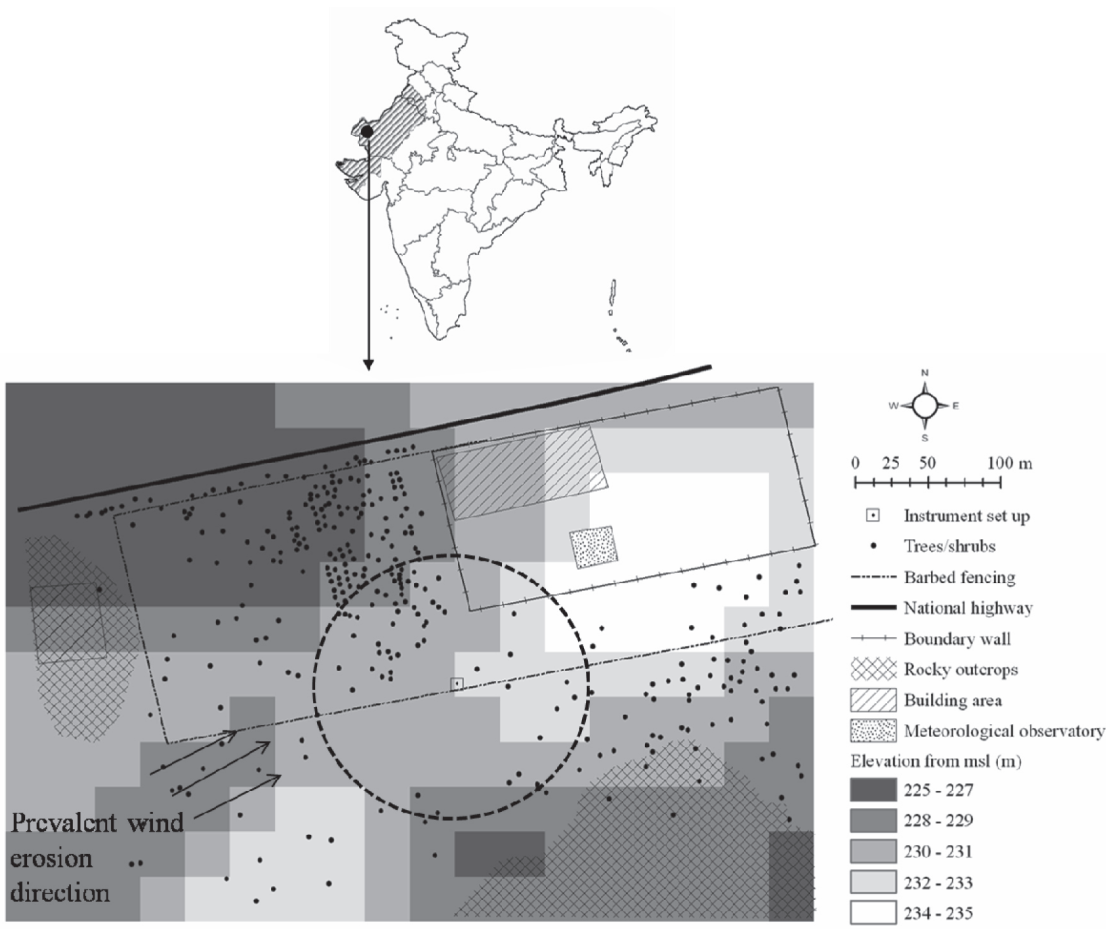

Fig. 1. Location of field experimental site at Jaisalmer region of the Indian Thar desert

cattle to browse up to 70% of available biomass leaving behind a grass height of 10-15 cm from surface. Bushes of *Ziziphus mauritiana*, *Propospis juliflora*, *Calotropis procera*, *Aerva persica* etc., with maximum canopy height of 3 m were sparsely available at the site with an average density of 15 bushes ha^{-1}. Soils were shallow in depth (60-70 cm) with occurrence of calcite concretion below the soil profile in most cases. Soils of the region were predominantly classified as Typic Torripsamments (Shyampura *et al.*, 2002).

Meteorological data

Daily data on meteorological parameters during field investigation period from June to September of the year 2009 are presented in Fig. 2. Annual rainfall during the study year was 73.6 mm, which was far less than the long term average of the region (196 mm). Maximum and minimum air temperatures during field investigation were 33-46°C and 20-30°C, respectively. Daily average relative humidity was 58.6%. Daily average wind speed ranged between

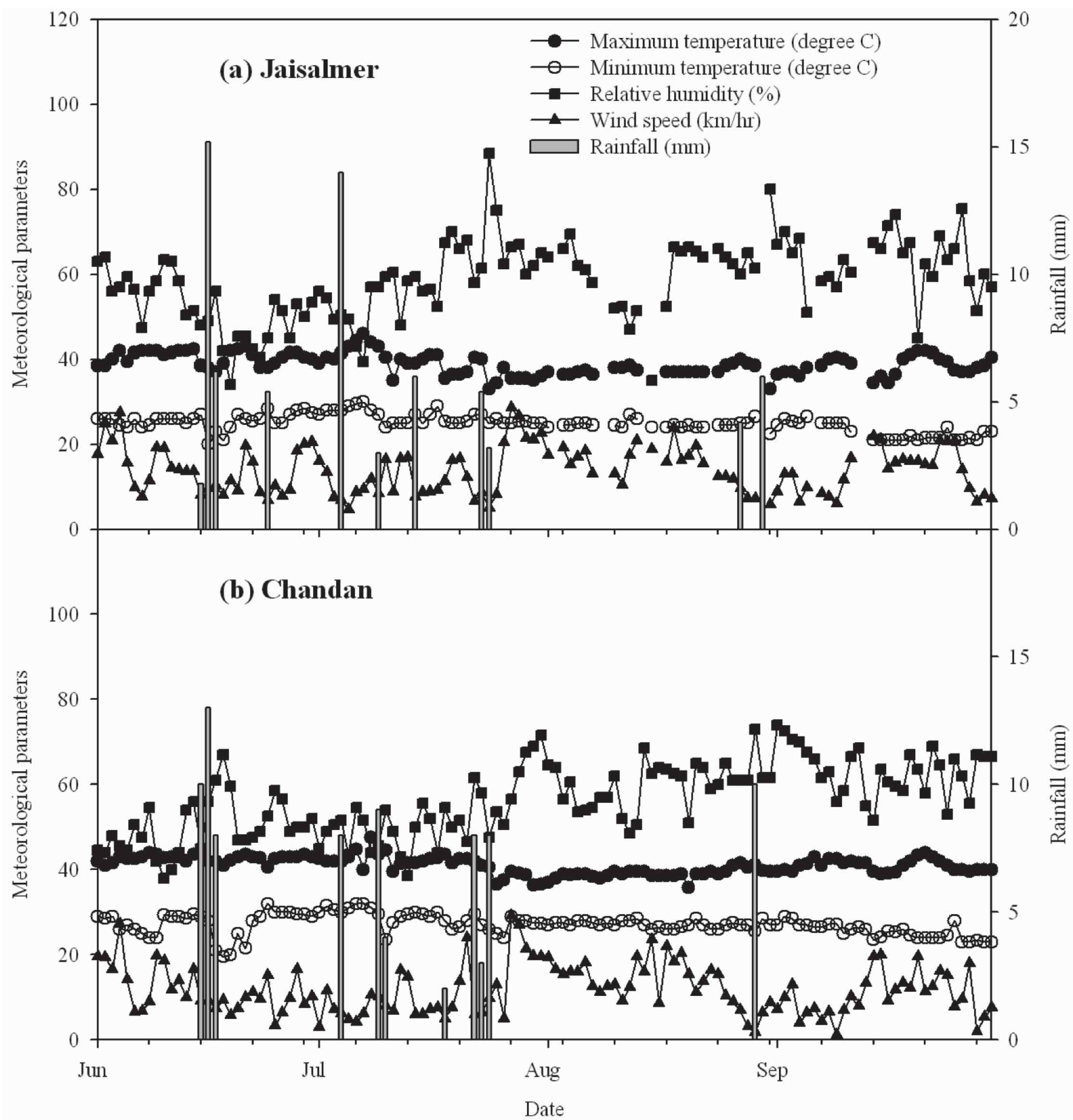

Fig. 2. Mean daily meteorological parameters during the observation periods (June-September, 2009) at the experimental site located at Jaisalmer, Rajasthan, India

4.58 and 28.62 km hr^{-1} with an average of 13.84 km hr^{-1}.

Measurements on loss of soil carbon and nitrogen through wind erosion

For the present field investigation, wind erosion sampler designed and fabricated by Santra *et al.* (2010) was used to collect wind eroded aeolian masses during wind erosion / dust storm events. The collection efficiency of the sampler was 85-90%. The sampler with four collectors at different heights from surface was installed at the center of the field site. The approximate distance between the sampler and surrounding non-eroding boundaries at the periphery of the field site ranged from 100 to 200 m. Rocky outcrops on western side, barbed wire fences inhabiting scattered trees of about 2-3 m height on northern and north western side, concrete boundary wall of about 1.5 m height on north eastern side and again rocky outcrops on south eastern side represented the non-eroding periphery of the field site (Fig. 1a). Apart from these, a long fetch of land with scattered grasses and shrubs on south western side and a small hillock at 500-600 m distance from the sampler on the south western side were present.

Four collectors of the sampler were fixed at 0.25, 0.75, 1.25, and 2 m height from land surface. Polyethylene bags were fixed at the end of the collector to store the entrapped soil mass inside the collector. Wind eroded soil masses were emptied from polyethylene bags and carried to the laboratory either at fortnight interval or after the occurrence of dust storm event. Eroded amount of soil mass for each sampling height was then converted into mass flux ($M\ L^{-2}\ T^{-1}$). Calculated mass fluxes were multiplied with a correction factor of 1.176 considering the average efficiency of the sampler as 85%. Mass-fluxes of eroded aeolian masses were fitted in power decay mass-height profile model, which was considered as the best model for the Indian Thar desert (Mertia *et al.*, 2010) and is shown in Eq (1):

$$q(z) = a\,z^{b} \qquad \ldots(1)$$

where, q is the mass flux ($M\ L^{-2}\ T^{-1}$) of wind eroded soil at height z (L) from surface; 'a' and 'b' are empirical constant of the equation. Total aeolian mass transport rate ($M\ L^{-1}\ T^{-1}$) was computed through integration of Eq (1) with lower limit of z = 0.25 m to upper limit of z = 2 m representing the suspension mode of wind erosion. However, to calculate the approximate estimate of total soil loss, lower limit of z was extrapolated up to 0.01 m height from land surface. The calculated mass transport rate was converted into soil loss ($M\ L^{-2}$) for each observation period by approximating the average width of experimental field site as 150 m.

C and N content of each collected sample were analyzed using Foss Heraeus CHN-O-rapid elemental analyzer. The variation in C and N content of eroded soil with height from surface and time of the season were analysed using Tukey's multiple comparison tests. Total loss of C and N due to wind erosion were computed as follows:

$$\text{Total C/N loss (kg ha}^{-1}\text{)} = \text{C/N content of eroded soil (g kg}^{-1}\text{)} \times \text{soil loss (kg ha}^{-1}\text{)} \qquad \ldots(2)$$

Results and Discussion

Soil loss due to wind erosion

A total of five dust storm events (DSE) and five periodical observations on wind erosion events (POWE) were recorded during the investigation period from June to September, 2009 (Table 1). The wind erosion sampler collected significant amount of eroded masses during both DSE and POWE. After the month of September, although few scattered POWE were observed but they were very weak to cause any significant soil loss and hence are not included in Table 1. Computed soil loss through suspension mode during DSE revealed a maximum soil loss of 389 kg ha^{-1} during a single dust storm event on June 15, 2009 (DSE-1), which prevailed for about 30 minutes duration (Table 1). Cumulative soil loss through suspension mode during the middle of June till the end of September of the year 2009 was 1.36 t ha^{-1} whereas extrapolating the Eq (1) very near to surface (lower limit of z = 0.01 m) resulted into a total soil loss of 12.02 t ha^{-1}. It was also noticed that almost half of the total soil

Table 1. Wind erosion / dust storm events during June to September, 2009 at Jaisalmer and the approximate soil loss during each event

Name of the observations	Time of occurrence	Duration	§Soil loss in suspension mode (kg ha^{-1})	§§Total soil loss (kg ha^{-1})
Dust storm events (DSE)				
DSE-1	June 15, 2009	30 min	389	1166
DSE-2	June 17, 2009	20 min	246	466
DSE-3	June 24, 2009	15 min	19	58
DSE-4	July 09, 2009	25 min	128	1485
DSE-5	July 14, 2009	15 min	16	30
Periodical observations on wind erosion (POWE)				
POWE-1	June 25 – July 2, 2009	7 days	23	30
POWE-2	July 15 – July 30, 2009	16 days	203	3244
POWE-3	July 31 – Aug 18, 2009	19 days	255	5287
POWE-4	Aug 19 – Sept 3, 2009	15 days	49	68
POWE-5	Sept 4 – Sept 23, 2009	20 days	39	188

§Soil loss was computed within the observation heights (0.25 to 2 m above surface), which generally indicates the soil loss in suspension mode

§§Total soil loss was calculated through extrapolation of mass-height profile up to very near to soil surface (0.01 m)

loss was occurred through dust storm events and rest half during local wind erosion events. Average rate of soil loss was observed as 17 kg ha^{-1} min^{-1} during DSE and 25 kg ha^{-1} day^{-1} during POWE.

Carbon and nitrogen loss through wind erosion

Average C and N content of eroded soils from the experimental site were 4 g kg^{-1} and 0.37 g kg^{-1}, respectively with a range of 3.01-5.44 g kg^{-1} C and 0.30-0.51 g kg^{-1} N. In general, both C and N contents were higher during DSE as compared to POWE. It was also observed that average C and N contents of surrounding top soils at the field site were 5.01 g kg^{-1} C and 0.44 g kg^{-1} N, respectively, in spite of the loss of almost similar amount through wind erosion processes. It indicates the gain of C and N at experimental site through simultaneously occurring deposition processes, which was not directly measured in the present study. However, nutrient enrichment through dust deposition in the field site can be approximated indirectly from several measured data on C content in the region. For example, average soil organic carbon (SOC) content of 78 soil samples covering eight land use systems at Jaisalmer region was observed < 2 g kg^{-1}. Similarly, SOC content of 117 soil samples in a cultivated farm of 76 ha at Jaisalmer region was observed to range from 1.06 to 2.13 g kg^{-1} (Santra *et al.*, 2012). From these two databases, overall SOC content from Jaisalmer region may be considered < 2 g kg^{-1}. With the application of suitable conversion factor (Krishnan *et al.*, 2009), the average C content of Jaisalmer as per CHN-O analyser may be approximated as < 3 g kg^{-1}. Carbon content of the top soil at the field site was found slightly higher (5.01g kg^{-1}) than the average C content of soils in Jaisalmer region (~ 3 g kg^{-1}). Therefore, we consider overall enrichment of soils in the rangeland site based on the above measurements and approximations. Moreover, average C content of eroded soil (4 g kg^{-1}) was found to be lower than parent soil (5.01 g kg^{-1}). It indicates that apart from dust emission, deposition of eroded soil mass in rangeland is common, which finally leads to enrichment of top soils. However, continuous overgrazing associated with severe drought situations in the desert may lead to rapid loss of these top fertile soils.

Table 2. Carbon (C) and Nitrogen (N) contents of eroded soils at different sampling heights during wind erosion events at Jaisalmer

Sampling heights	§C (g kg^{-1})		§N (g kg^{-1})	
	DSE	POWE	DSE	POWE
0.25 m	4.25±0.30	3.97±0.52	0.40±0.03	0.34±0.02
0.75 m	4.51±0.33	3.50±0.20	0.42±0.04	0.34±0.02
1.25 m	4.38±0.40	3.47±0.13	0.42±0.05	0.33±0.02
2.00 m	4.40±0.53	3.44±0.41	0.40±0.04	0.34±0.03
Topsoil	5.01±0.18	0.44±0.03		

§Values of C and N content are not significantly different between heights of observations ($P<0.05$, Tukey test).

Height wise variation in C and N contents

Average C and N content of the eroded soils at different sampling heights above land surface is presented in Table 2. It was observed that the C and N content of eroded soil did not significantly vary with height both during DSE and POWE ($p<0.05$). Initially, we hypothesized that C content in eroded soils would increase with height as C particles were lighter than mineral soils but no such significant trend was observed in the present study. However, slight increase in C and N content of eroded soil with sampling height was observed during severe wind erosion events. For example, during DSE-4 occurred on July 9, 2009, C content increased with height from 4.73 g kg^{-1} at the sampling height of 0.25 m from surface to 5.44 g kg^{-1} at the sampling height of 2 m from surface. Similarly, N content of eroded soils during DSE-1 occurred on June 15, 2009 increased from 0.34 g kg^{-1} at 0.25 m height to 0.48 g kg^{-1} at 2 m from surface. Similar to these observations, Hoffman *et al.* (2008) also reported non significant variation in C and N content in eroded soil with height from land surface except in case of severe wind erosion events, for which about 10% and 24% increase in C and N content, respectively, was reported with an increase in height from near land surface to 1 m above land surface. Observed C and N contents in eroded soil masses as reported by Hoffman *et al.* (2008) varied from 29-47 g kg^{-1} of C and 2.7-4.2 g kg^{-1} of N, which was quite higher than C and N loss in the present study (3.01 to 5.44 g kg^{-1} C and 0.30 to 0.51 g kg^{-1} N). However, Bielders *et al.* (2002) reported the loss of 0.2-0.3 g N kg^{-1} through wind erosion in Sahel region, which was slightly lower than the observed values from the present investigation.

Periodical variation

Variation of C and N contents of eroded soils with time for the season is presented in Fig. 3. Carbon content of eroded soils was observed maximum (5.13 g kg^{-1}) during DSE-4 at the second week of July and reduced to the minimum of 3.35 g kg^{-1} at the end of September. Similarly, N content of eroded soils was also observed maximum (0.50 g kg^{-1}) during DSE-4 at the second week of July and reduced to the minimum of 0.33 g kg^{-1} at the end of September. Month-wise comparison has revealed that during July, both C and N contents were significantly higher than other periods of the year. Higher C and N content in eroded soil during July was probably due to exposure of soils underneath top thin layer of relatively coarse sand particles, which was eventually removed during few initial wind erosion events at the beginning of summer season.

Total loss of C and N

Cumulative loss of soil nutrients along with the eroded mass during three and half month's period from the middle of June to the end of September was calculated as 45.93 kg C ha^{-1} and 4.37 kg N ha^{-1}. Among dust storm events, the highest loss of C was recorded during DSE-1 and the associated loss was 4.39 kg C ha^{-1}. Among periodical observations, the loss of C was highest during POWE-3 and the corresponding loss was 17.73 kg C ha^{-1}. The average nutrient loss was

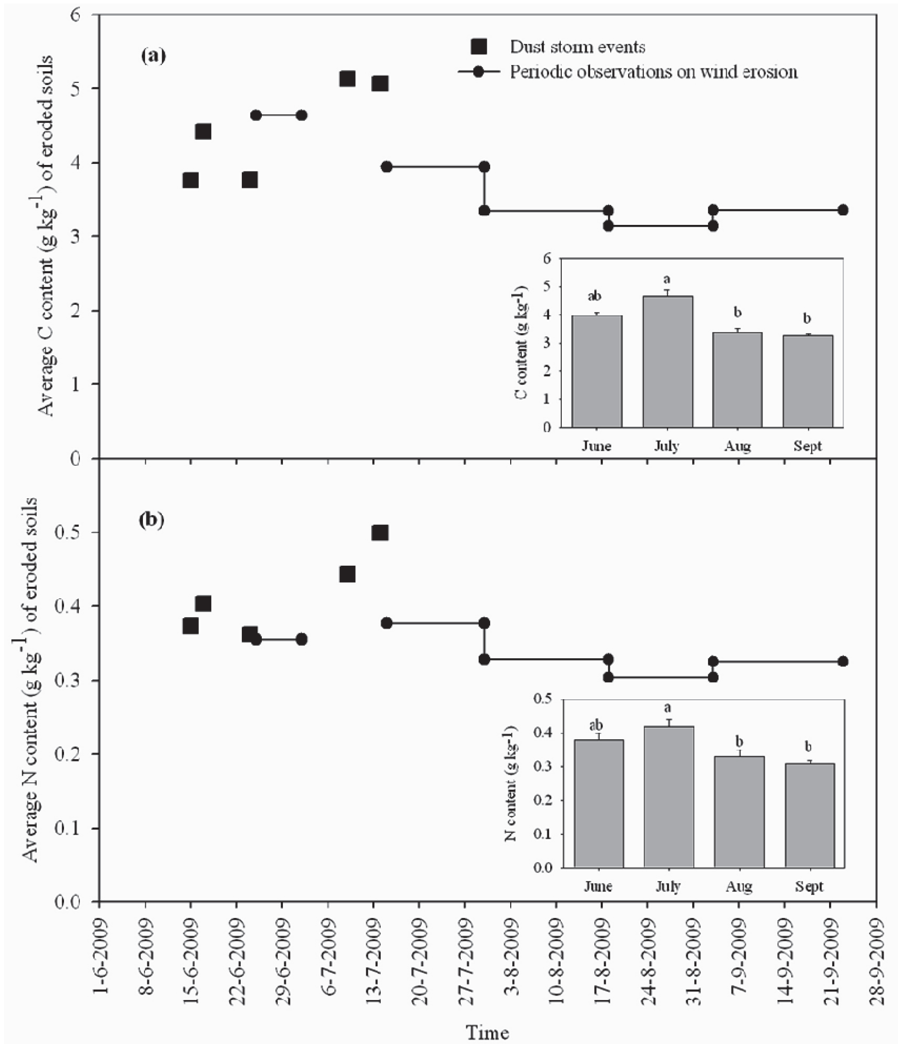

Fig. 3. Periodic variation of carbon (C) and nitrogen (N) content of eroded soils; (a) C content and (b) N content Values with the same letters above the bars are not significantly different (P<0.05, Tukey test).

0.12 kg C ha^{-1} min^{-1} during DSE and 0.36 kg C ha^{-1} day^{-1} during POWE. Similarly, the loss of N was highest during DSE-1 and the associated loss was 0.44 kg N ha^{-1}. Among periodical observations, the loss of N was highest during POWE-3 and the associated loss was 1.73 kg N ha 1. It is notable here that the reported loss of C and N in this study was measured at a controlled grazing rangeland site. Therefore, the observed losses of C and N may be considered as the loss from semi-protected rangelands in the Indian Thar desert. Such loss of C and N from cultivated lands, open grazing rangelands and denuded soil surface are expected to be 3-5 times higher than these observed losses (Mertia *et al.*, 2010).

Conclusions

Measurements of wind eroded soil loss from a rangeland site at Jaisalmer region of the Indian Thar desert revealed significant loss of C and N through wind erosion processes. Average C and N contents in eroded soils was observed as 4 g C kg^{-1} and 0.77 g N kg^{-1}, respectively. Cumulative loss of C and N for a period of three and half months from the middle of June to the end of September was 46 kg C ha^{-1} and 4 kg N ha^{-1}. The present investigation was carried out at a controlled grazing rangeland site at Jaisalmer with a single measurement system and for a period of three and half months during summer season with an attempt to analyze the impact of wind erosion on loss of C and N from rangeland ecosystem in the Indian Thar desert. A large part of the Indian Thar desert lies under similar type of rangelands, however with excessive grazing pressure. Therefore, the amount of soil loss and associated C and N loss from overgrazed rangeland is expected to be higher and has been reported by Mertia *et al.* (2010). Recently, several studies revealed a rapid conversion of rangelands into cultivable lands, which might have aggravated the problem of C and N loss through wind erosion. Therefore, temporal varation with intensive experimental set up may be initiated in different land use system of the Indian Thar desert focusing agricultural lands, overgrazed rangelands, rocky terrains, open sand dunes etc for overall assessment of C and N loss from the Indian Thar desert.

Acknowledgement

We sincerely thank the Director, Central Arid Zone Research Institute, Jodhpur for providing necessary supports and facilities to carry out the field investigations. We also sincerely thank the Director, Vivekananda Parvitya Krishi Anusandhan Shala (VPKAS), Almora, India for providing the CHN-O-rapid analyser facilities to determine carbon and nitrogen content of wind eroded aeolian samples.

References

Bielders, C.L., Rajot, J.L. and Amadou, M. 2002. Transport of soil and nutrients by wind in bush fallow land and traditionally managed cultivated fields in the Sahel. *Geoderma* **109**: 19-39.

Dawson, J.C. and Smith, P. 2007. Carbon losses from soil and its consequences for land use management. *Science of the Total Environment* **382**: 165-190.

Dhir, R.P. 1985. Characterization and properties of dune and associated soils. p. 41-49. In *Sand dune stabilization, shelterbelts and afforestation in dry zones*. Food and Agricultural Organization of the United Nations, Rome.

Hoffmann, C., Funk, R., Li, Y. and Sommer, M. 2008. Effect of grazing on wind driven carbon and nitrogen ratios in the grasslands of Inner Mongolia. *Catena* **75**: 182-190.

Kar, A., Moharana, P.C., Raina, P., Kumar, M., Soni, M.L., Santra, P., Ajai, Arya, A.S. and Dhinwa, P.S. 2009. Desertificatiion and its control measures. p. 1-47. In Kar, A., Garg, B.K., Singh, M.P. and Kathju, S. (Eds.), *Trends in Arid Zone Research in India*. Central Arid Zone Research Institute, Jodhpur, India.

Krishnan, G., Srivastava, S.K., Kumar, S., Saha, S.K. and Dadhwal, V.K. 2009. Quantifying the underestimation of soil organic carbon by the Walkley and Black technique-examples from Himalayan and Central Indian soils. *Current Science* **96**(8): 1133-1136.

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. *Climate Change* **51**: 35-72.

Lal, R., 2003. Soil erosion and the global carbon budget. *Environment International* **29**: 437-450.

Larney, F.J., Bullock, M.S., Janzen, H.H., Ellert, B.H. and Olson, E.C.S. 1998. Wind erosion effects on nutrient redistribution and soil productivity. *Journal of Soil and Water Conservation* **53**: 133-140.

Mendez, M.J., Oro, L.D., Panebianco, J.E., Colazo, J.C. and Buschiazzo, D.E. 2006. Organic carbon and nitrogen in soils of semiarid Argentina. *Journal of Soil and Water Conservation* **61**: 230-235.

Mertia, R.S., Santra, P., Kandpal, B.K. and Prasad, R. 2010. Mass-height profile and total mass transport of wind eroded aeolian sediments from rangelands of Indian Thar desert. *Aeolian Research* **2**: 135-142.

Narain, P., Kar, A., Ram, B., Joshi, D.C. and Singh, R.S. 2000. *Wind erosion in Western Rajasthan*. CAZRI, Jodhpur, India.

Offer, Z.Y., Sarig, S. and Steinberger, Y. 1996. Dynamics of nitrogen and carbon content of aeolian dry deposition in an arid region. *Arid Soil Research and Rehabilitation* **10**: 193-199.

Santra, P., Mertia, R.S. and Narain, P. 2006. Land degradation through wind erosion in Thar Desert - Issues and Research priorities. Indian Journal of Soil Conservation **34**(3): 214-220.

Santra, P., Mertia, R.S. and Kushawa, H.L. 2010. A new wind erosion sampler for monitoring dust storm events in the Indian Thar desert. *Current Science* **99**(8): 1061-1067.

Santra, P., Kumawat, R.N., Mertia, R.S., Mahla, H.R. and Sinha, N.K. 2012. Spatial varation of soil organic carbon stock in a typical agricultural farm of hot arid ecosystem of India. *Current Science* **102**(9): 1303-1309.

Shyampura, R. L., Singh, S.K., Singh, R.S., Jain, B.L. and Gajbhiye, K.S. 2002. *Soil series of Rajasthan*. NBSS & LUP Publication No. 95, NBSS&LUP, Nagpur.

Stallard, R.F. 1998. Terrestrial sedimentation and the carbon cycle: coupling weathering and erosion to carbon burial. *Global Biogeochemical Cycles* **12**: 231-257.

Zhao, H.L., Yi, X.Y., Zhou, R.L., Zhao, X.Y., Zhang, T.H. and Drake, S. 2006a. Wind erosion and sand accumulation effects on soil properties in Horqin Sandy Farmland, Inner Mongolia. *Catena* **65**: 71-79.

Zhao, T.L., Gong, S.L., Zhang, X.Y., Blanchet, J.P., McKendry, I.G. and Zhou, Z.J. 2006b. A simulated climatology of Asian dust aerosol and its trans-Pacific transport. Part I: mean climate and validation. *Journal of Climate* **19**: 88-103.

Received: 2 December 2012; Accepted: 8 March 2013