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Soil Carbon Sequestration Mediated by Herbaceous Species Diversity Along the Gradient of Nitrogen Amendment in a Dry Tropical Environment of India

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ABSTRACT

Increased concentrations of CO_2 and reactive nitrogen (N) in the atmosphere are recognised as serious threats to the lives on the planet 'Earth'. The ecologists and environmental scientists are exploring the possible ways to combat this global problem. In this context, the impact of urea amendment as a measure of N deposition on the herbaceous species diversity and soil organic carbon (SOC) stock (a measure of CO_2 sequestration), as well as relationship between species diversity and SOC stock were studied from 135, 1×1 m permanent plots distributed over 15 locations on the campus of Banaras Hindu University. These plots were continuously receiving urea amendment since January 2007. In year 2011, herbaceous diversity and SOC stock were estimated and analysed statistically. The study showed that moderate (60 kg N $ha^{-1}yr^{-1}$) levels of N treatment supported high herbaceous diversity and SOC stock. The species diversity indices were positively and significantly related with SOC stock in control and 60 kg N treated plots, while such relationships were negative in 120 kg N treated plots. The study suggested that the herbaceous species diversity mediates the C accumulation in soil against the N deposition in dry tropical environment of India. Therefore, N and species diversity need to be managed for long-term C storage in the soils of dry tropical grasslands.

Keywords: C-Ssequestration; Dry Tropics; Herbaceous Vegetation; N-Amendment; SOC Stock; Species Diversity

INTRODUCTION

Since the time of industrial revolution to the present day, the CO_2 concentration in atmosphere has increased from 280 ppm to more than 395 ppm (Falkowski et al. 2000, Tans and Keeling 2014) and it would be around 550 ppm by 2050 (Norby et al. 2005). Currently, it is increasing at a rate of 3.5 billion Mg yr^{-1} (Jina et al. 2008). Similar to CO_2 concentration, the reactive N (NOx and NHy) deposition in global terrestrial environment was 63.5 Tg yr^{-1} in the early 1990s, which was four-folds higher than that in 1860 (Galloway et al. 2004). The global estimate suggested that the N deposition would be more than double (125.2 Tg yr^{-1}) in year 2050 compared to that in early 1990s (Asner et al. 1997). Also, the N_2O responsible for greenhouse effect (which is only five percent of the total deposited N_2O in the atmosphere) is increasing in the atmosphere at a rate of 5.55×10^{11}g yr^{-1} (Ricklefs and Miller 2000). It is more harmful than the CO_2 because one molecule of N_2O adds 200-times greater to the earth's greenhouse than a molecule of CO_2 (Schlesinger 1991). The increased concentration of atmospheric CO_2, N_2O and rise in temperature are the reasons behind the global climate change which has raised the global mean temperature by 0.5°C in previous hundred years (Kellomaki 2000) and 0.4°C in the preceding 70 years for the Indian region (Negi et al. 2003). Among the green house gases, CO_2 (60%) coupled with N_2O (6%) contributes around two-third of the total worming potential (Singh et al. 2014). The consequences of increased CO_2 on flora and fauna as well as on human civilization have been well addressed in Kyoto Protocol (Chavan and Rasal 2011). The ecological and environmental scientists realised it as a serious problem under the umbrella of global climate change (Asner et al. 1997, Falkowski et al. 2000, Ricklefs and Miller 2000, Magnani et al. 2007, Singh et al. 2014). The increased N deposition causes soil acidification, eutrophication of water bodies, reduction in species diversity, changes in community composition, increased greenhouse effects (Wang et al. 2009). Thus, reduction in atmospheric C and N depositions is a big challenge, globally.

As a positive point of N deposition with reference to C storage, majority of studies from Europe and North America viewed that N deposition increases the forest growth by accumulating the C in wood, over long-term (Magnani et al. 2007, Hogberg 2007, Xia et al. 2009). With the help of a grassland study, Isbell et al. (2013) showed increase in primary productivity (a measure of atmospheric C storage in plants) in early-stage of N deposition and decline over long-term. Moreover, studies indicated that ecosystems with high species diversity sequester more C in soil than those with low species diversity (Lal and Akinremi 1983, Huston et al. 2003). Tilman et al. (2006) showed that high-diversity mixtures of perennial grassland plant species store 500% more soil C than the monoculture plots. In relation to such global problem, the carbon sequestration potential of different forests (Chaturvedi et al. 2011, Kale et al. 2009, Jantz et al. 2014) and soils (Watson et al. 2000, Lal 2008, Singh et al. 2011, Farage et al. 2013) have been well studied all around the globe, including India, while, the studies on plant responses to N depositions and C sequestration were mostly highlighted from the Europe and North American studies (Galloway et al. 2004, Bobbink et al. 2010, Jensen et al. 2011) but lack from tropical regions.

Globally, large volume of literature is available on various aspects of species diversity against N deposition (Ricklefs and Miller 2000, Sagar and Singh 2005, Sahu et al. 2008, Bobbink et al. 2010, Verma et al. 2014) except on linking plant diversity and soil carbon storage against the N deposition, which is genuine to study under the global change perspectives. Therefore, the objective of present study was to understand the relationship between herbaceous species diversity and soil organic carbon (SOC) stock against the N-input (a measure of N deposition) in a dry tropical environment of India which could be fruitful in opening the window looking for atmospheric C and N mitigation, sustainable ecosystem services and functioning (Isbell et al. 2011, Verma et al. 2014). Nevertheless, the present study helps understand the interaction of species diversity and C sequestration against the nitrogen deposition from a dry tropical environment.

STUDY AREA

The study was conducted at 15 local sites situated on plain, alluvial grounds within the campus of Banaras Hindu University (24°18' N and 83°03' E and 76 m altitude), Varanasi, India, in January 2007. The study sites fall in a seasonally dry tropical monsoon climate with three discrete seasons viz: a hot dry season (April-June), a warm monsoon season (July-September), and a cold winter (November-February). The months of March and October are transition periods, between winter and dry seasons, and between monsoon and winter seasons, respectively. The mean monthly minimum and maximum temperatures ranged from 7.3 to 25.4 °C, and from 25.6 to 35.6 °C, respectively. The mean annual rainfall was 932 mm. The soils are moderately fertile being low in soil-C (0.84 ± 0.07%) and –N (0.08 ± 0.01%) and the soil pH is neutral to alkaline.

METHODS

The study was based on the three doses of N amendment (control, 60 kg N ha^{-1} yr^{-1} and 120 kg N ha^{-1} yr^{-1}) experienced by herbaceous grassland since January 2007. In this study, total 135, 1×1 m plots distributed over 15 locations were used (15 locations × 3 treatments × 3 replicates).

The top storey vegetation is locally dominated by the *Azadiracta indica, Dalbergia sissoo, Madhuca longifolia, Mangifera indica, Sterculia alata, Tamarindus indica, Tectona grandis, Zizyphys glaberrima,* etc. These species were planted some 80 years ago and being managed by the Horticulture Unit of the university. The ground vegetation is locally dominated by A*lysicarpus monilifer, Cynodon dactylon, Cyperus compressus, Desmodium gangeticum, Dichanthium annulatum, Evolvulus nummularius, Imperata cylindrica, Malvastrum coromandelianum, Oplismenus burmannii, Sida acuta,* etc. (Sagar and Verma 2010, Sagar et al. 2008).

After four years of N treatment, soil and vegetation data were collected in year 2011. Each 1×1 m plot was gridded into four 50 cm × 50 cm quadrats as workable units for vegetation sampling. For each quadrat, number of individuals and their herbage cover were recorded by species in mid October. Cover was measured by gridding the quadrats into 5 cm × 5 cm cells and charting the cover outlines on a graph paper (Verma et al. 2013). The relative importance value [= (relative frequency + relative density + relative basal area)/3] of each herbaceous species for each 1×1 m plot was calculated on each location. Shannon index (Shannon and Weaver 1949) for each 1×1 m plot was calculated as:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

where, H = Shannon-Wiener index, S = number of species, pi = proportion of importance value belonging to species 'i' and ln = natural log.

Number of species m^{-2} was used for computing the species richness. Species evenness (e^{H}/S) was determined based on the Sheldon equation (Sheldon 1969).

Within each 1×1 m plot, three soil samples (0–10 cm depth) were collected using a corer of 100 cm^3 volume. The three soil samples were combined to form a composite soil sample for each plot. These composite samples were gently homogenized. Large roots, woods, litters and all fine roots were removed from the composite soil samples carefully. One part of soil sample was air dried, sieved through 2 mm mesh screen, and was used for the analysis of soil bulk density and soil organic carbon. Soil bulk density was determined by the corer method. Soil organic carbon (SOC) was analyzed by using dichromate oxidation and titration with ferrous ammonium sulfate (Walkley 1947). The SOC-stock in 0–10 cm soil depth was calculated by multiplying the soil thickness (10 cm) and soil bulk density with that of SOC (Singh et al. 2011).

Multivariate analysis of variance (MANOVA) procedure, selecting General Linear Model (GLM) option in SPSS package (SPSS 1997) was used to notice the effects of N treatments on the SOC stock and diversity parameters. Further, analysis of covariance (ANCOVA) was used to observe real effects between N level and diversity parameters on SOC stock. Tukey's HSD test was used to determine the significance of differences in mean values of SOC stock and diversity parameters among different N-treatment levels. Species richness, evenness and Shannon index of each N level were linearly regressed with SOC stock opting linear regression option in SPSS software (SPSS 1997).

RESULTS

The number of species and their respective families present in each N treated plots are shown in Appendix 1.

The summary of MANOVA on species richness, evenness, Shannon index and SOC stock are presented in Table 1. Results show substantial variations in diversity indices and SOC stock due to differences in N-inputs (Table 1). The diversity indices and SOC-stock were higher in 60 kg N treated plots compared to control and 120 kg N treated plots (Figure 1A). Tukey's test showed that variations in species richness, evenness, Shannon index and SOC stock between control and 60 kg N treatments, and between 60 kg and 120 kg N treatments were significant but those between control and 120 kg N treatments were insignificant (Figure 1A).

Table 1. Summary of analysis of variance (MANOVA in the upper panel and ANCOA in the lower panel) indicating the effects of independent variable on various response variables. **$p \leq 0.001$, *** $p \leq 0.0001$

Source of Variation	Dependent variables	*Df*		*F*
		Numerator	Denominator	
N-levels	Species richness	2	42	124***
	Species evenness	2	42	114***
	Shannon index	2	42	66***
	SOC	2	42	10**
ANCOVA on SOC (N-levels were used as fixed factor and diversity parameters as covariates)				
Species richness	SOC	1	39	29***
Species evenness		1	39	38***
Shannon index		1	39	14**

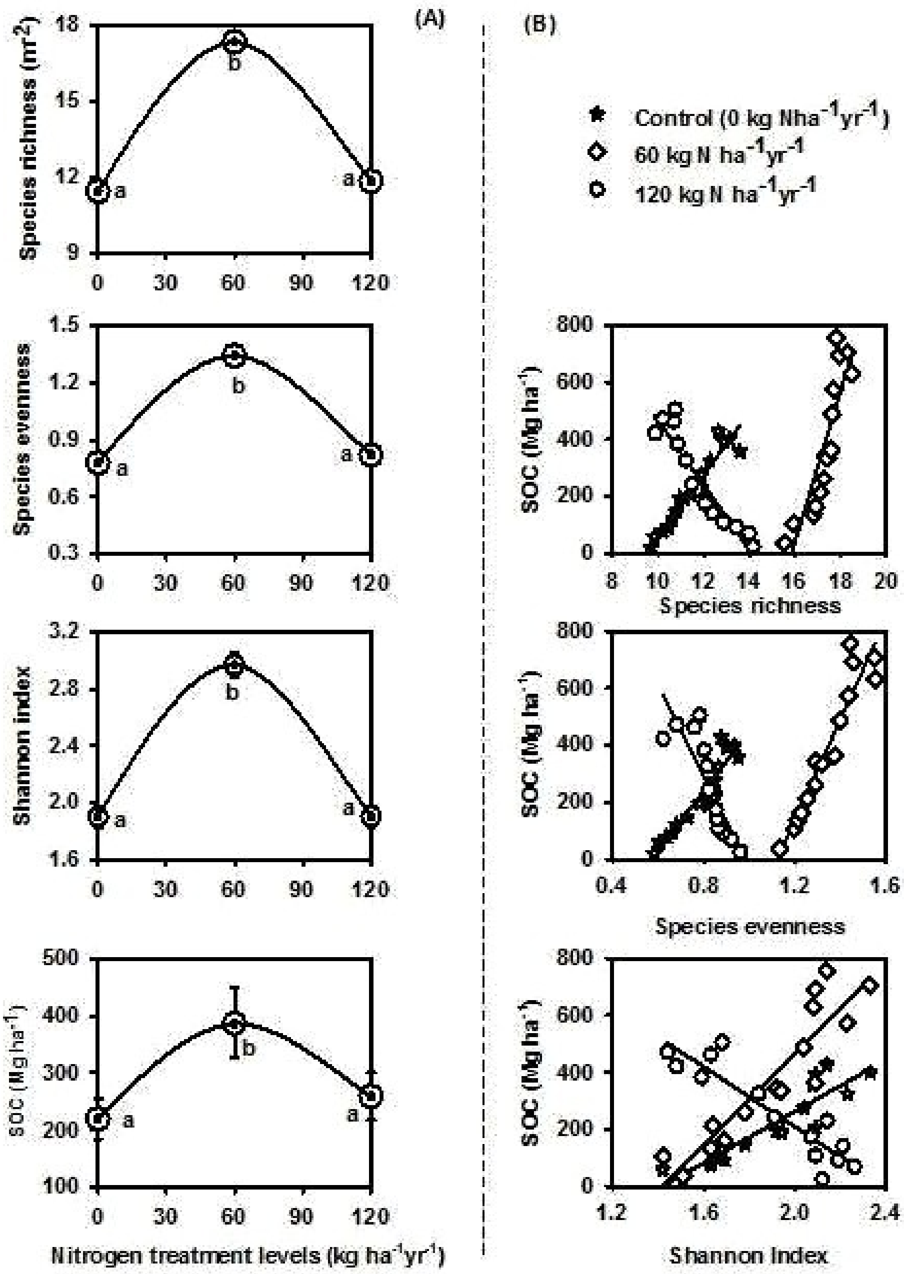

Figure 1. A (left): Patterns of herbaceous species diversity (species richness, species evenness and Shannon index) due to N inputs in a dry tropical environment. The error bars within a diagram affixed with different letters significantly differ from each other at $p < 0.001$. B (Right): Linear relationships of SOC with herbaceous species richness, evenness and Shannon index at three N treatment levels in a dry tropical environment. The determination coefficient of each linear relationship falls between 0.72 and 0.93 and each relationship was statistically significant at $p < 0.001$.

Since N levels and diversity parameters caused variations in the SOC stock as revealed by ANCOVA results (Table 1), therefore, relationships of SOC stock with diversity indices within each N level were essential to explore. The analysis expressed that the SOC stock for each N level was linearly and significantly related with diversity indices. The relations were positive for control and 60 kg N treatments, and negative for 120 kg N treatment (Figure 1B). The results further implied that moderate level of N mediated high herbaceous diversity and consequently enhanced the SOC stock.

DISCUSSION

Presence of *Ammannia baccifera, Cyperus fuscus, Desmodium triflorum, Oldenlandia ambellata, Oxalis corniculata* and *Ruellia tuberosa* only in 60 kg N treated plots and the dominance of high aggressive species (*Amaranthus spinosus, Argemone mexicana, Euphorbia pulcherrima, Hyptis suveolens, Parthenium hysterophorus, Portulaca oleracea, Sonchus oleraceus* and *Urena. lobata*) in 120 kg N treated plots suggested the elimination of rare (*A. baccifera, Anisomeles ovata, Cissampelos pareira, Commelina nudiflora, Oldenlandia ambellata, O. corniculta*) and nodule forming (*Atylosia marmorata, Desmodium. triflorum*) species. Thus, the traits of species determined the species to survive and adopt under different levels of N, and finally changed the species composition of different N levels of N treated plots as also suggested in other studies (Tilman 1982, Verma et al. 2013).

In present study, the use of moderate quantity of N fertilizer could have positive impacts on herbaceous species diversity as well as on storage of C in the soil system. Further, the study indicated that comparatively higher dose of N reduced the species diversity as suggested in our previous study. Such patterns were argued because of greater availability of soil nutrients and survival of large number of species in 60 kg N treated plots and dominance of aggressive and nitrophilic species in 120 kg N treated plots which eliminated the rare, nodule forming and N sensitive species at comparatively higher level of N input (Verma et al. 2013, Verma et al. 2014).

Similar to present study, other studies have also suggested that ecosystems with low plant diversity absorb and sequester less C in soil than those with high plant diversity (Lal and Akinremi 1983, Huston et al. 2003, Srivastava et al. 2012) in N limited grasslands (Tilman et al. 2006). Lower plant diversity could potentially decrease the ability of herbaceous vegetation in capturing the atmospheric C and storing it in the grassland soil (Tilman et al. 2006, Fornara and Tilman 2008) because plant assemblages with a low species diversity use N from soil less efficiently and reduce net primary production (Conant et al. 2001) and, consequently, store the C in the soil with lower rate (Kirby and Potvin 2007) compared to the sites with a higher species diversity. It can be further advocated that the mostly herbaceous vegetations are therophytic in habit (Sharma and Upadhyaya 2002) and most of them are short-lived, complete their life cycle within a year, hence add substantial amounts of litters (leaves, stem/culm and roots) in the soil which are quickly decomposed (Janzen 2004), as a result, partial C returns into the atmosphere and remaining goes in the soil. Such events happen in ground cover rapidly within short duration (Dinakaran et al. 2011), therefore, they rapidly add C in the soils, in this way, grassland soil could be considered as a major potential sink for carbon (Dinakaran et al. 2011).

The positive relationships between species diversity and SOC stock in control and 60 kg N treated plots and the negative relationship between these variables in 120 kg N treated plots provide an early warning for management of herbaceous species diversity which is a vital source for capturing the atmospheric CO_2 (Watson et al. 2000, Lal 2008, Singh et al. 2011). Therefore, it could be argued that storage of atmospheric C in the soil mediated by plant photosynthesis could be a viable solution for mitigating the global warming (Schlesinger and Andrews 2000, Singh et al. 2011). Further, the SOC stock was higher in 60 kg N treatment than the control and 120 ka N treatment, suggested that the atmospheric C can be stored in soil over long-term by improving the fertilizer management (Conant et al. 2001).

A part from the above discussion, it can be presumed that the average nitrogen use efficiency of the studied vegetation was maximum in 60 kg N treated plot than the 120 kg N treated plot, and the extra N applied to the plots was lost in the atmosphere in form of N_2O, nitrogen oxides, ammonia and nitrates emissions (Skiba et al. 2012). Evidently, the 120 kg N treated plots supported less SOC stock than the 60 kg N treated plots. The value SOC stock was a little bit higher than the control plot, however, difference in values of SOC stock between control and 120 kg N treated plots were statistically insignificant (Figure 1A). Hence, the fertilizer management seems to be helpful in CO_2 sequestration, reduction in N emission (Reay et al. 2012, Sutton et al. 2013) and bearing the comparatively greater species diversity. It has been reported that fertilizer management and improving nitrogen use efficiency by 20% would bring saving of N by value of $23 billion USD, as well as health and environmental benefits equivalent to $160 billion USD at global scale (Sutton et al. 2014). For this reason, N management in grasslands is likely to have, a positive effect on biodiversity, carbon sequestration and ecosystem services derived from the biodiversity (Srivastava et al. 2012).

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Appendix 1

Table 1. Number of herbaceous species with their families and biomass at experimental plots of Banaras Hindu University, Varanasi having different doses of nitrogen input.

Species	Family	Presence	Trait initials
Achyranthes aspera L.	Amaranthaceae	1, 2, 3	H, K, O
Ageratum conyzoides L.	Asteraceae	1, 2, 3	I, K, P
Alternanthera sessilis L.	Amaranthaceae	2, 3	H, K, P
Amaranthus spinosus L.	Amarantahceae	2, 3	I, K, Q
Ammannia baccifera L.	Lythraceae	2	I, K, P
Anagallisarvensis L.	Primulaceae	2, 3	I, K, Q
Anisomeles ovata R. Br.	Lamiaceae	1, 2	I, K, O
Argemone mexicana L.	Papaveraceae	2.3	I, K, P
Atylosia marmorata Benth.	Fabaceae	1, 2	H, M, O
Blepharis repens Vahl.	Acanthaceae	1, 2, 3	H, K, O
Cayratia trifolia L.	Vitaceae	1, 2, 3	J, K, O
Cissampelos pareira L.	Menispermaceae	1, 2	H, K, O
Clerodendrum indicum L.	Verbenacaea	1, 2, 3	H, K, O
Coccinia cordifolia L.	Cucurbitaceae	1, 2	H, K, O
Commelina benghalensis L.	Commelinaceae	1, 2, 3	I, K, Q
Commelina nudiflora L.	Commelinaceae	1, 2	I, K, Q
Convolvulus pluricaulis Chois.	Convolvulaceae	1, 2	H, K, Q
Corchorus olitorius L.	Malvaceae	1, 2, 3	I, K, O
Corchorus tridens L.	Malvaceae	1, 2, 3	H, K, O
Croton bonplandianum Bail.	Euphorbiaceae	1, 2, 3	H, K, P
Cynodon dactylon Pers.	Poaceae	1, 2	H, L, P
Cyperus kyllingia Endl.	Cyperaceae	1, 2, 3	I, N, Q
Cyperus rotundus L.	Cyperaceae	1, 2	I, N, P
Cyperus fuscus L.	Cyperaceae	2	I, N, Q
Desmodium gangeticum L.	Fabaceae	1, 2, 3	H, M, O
Desmodium triflorum L.	Fabaceae	2	H, M, Q
Dichanthium annulatum Forsk.	Poaceae	1, 2, 3	H, L, O
Digitaria sanguinalis L.	Poaceae	1, 2, 3	I, L, O
Eleusine indica Gaertn.	Poaceae	1, 2	I, L, O
Eragrostis tenella L.	Poaceae	1, 3	I, L, P
Eulaliopsis binata Retz.	Poaceae	1, 2, 3	H, L, O
Euphorbia hirta L.	Euphorbiaceae	1, 2, 3	H, K, Q
Euphorbia pulcherrima Willd,	Euphorbiaceae	2, 3	H, K, O
Euphorbia thamifolia L.	Euphorbiaceae	2, 3	I, K, Q
Herpestis monniera Kunth.	Scrophulariaceae	1, 2, 3	H, K, Q
Hyptis suaveolens Poir.	Lamiaceae	2, 3	H, K, O
Malvastrum tricuspidatum L.	Malvaceae	1, 2, 3	H, K, O
Nicotiana plumbagimifolia Viv.	Solanaceae	2, 3	I, K, P
Oldenlendia ambellata L.	Rubiaceae	1	H, K, Q
Oplismenus burmannii Retz.	Poaceae	1, 2, 3	I, L, Q
Oxalix corniculata L.	Oxalidaceae	2	H, K, P
Panicum psilopodium Trin.	Poaceae	1, 2, 3	I, L, O
Parthenium hysterophorus L.	Asteraceae	2, 3	I, K, O
Portulaca oleracea L.	Portulacaceae	2, 3	I, K, Q
Ruellia tuberosa L.	Acanthaceae	2	H, K, P
Scoparia dulcis L.	Scrophulariaceae	1, 2	H, K, Q
Sonchus oleraceus L.	Asteraceae	2, 3	I, K, O
Tridax procumbens L.	Asteraceae	1, 2	H, K, Q
Urena lobata L.	Malvaceae	1, 2	H, K, P

The numbers 1, 2 and 3 in the presence column indicate the presence of the species in control, 60 and 120 Kg N treated plots, respectively. Letters as trait initials are: H = Perennial, I = Annual, J = Biennial, K = Forb, L = Grass, M = Legume, N = Sedge, O = Large, P = Medium and Q = Small.