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The role of soil nutrient availability on the invasion establishment and carbon sequestration potential of an invasive shrub from Doon Valley, India

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ABSTRACT

Invasive plants are capable of modifying the soil properties to enable the further invasion of other plant species. In the present study we assessed the relation between soil properties and different growth patterns of *Lantana* (a noxious weedy shrub) and further its role in the atmospheric carbon sequestration process from Doon Valley, India. We found that in all the invaded sites the pH was increased but the increase in pH value did not show any positive relation with the measured and calculated attributes of *Lantana* like plant height, crown diameter, crown length, Phytovolume and biomass. However, this showed that less acidic conditions of soil is favouring the invasion of *Lantana* in all the land use systems. On the other side total Nitrogen (%) and Carbon (%) was greatly significant in deciding most of the measured and calculated attributes of *Lantana*. Nitrogen (%) was increased in all the invaded sites. The highest Nitrogen (%) content was recorded from Sahastradhara, which was from 0.14 (± .01) to 1.12 (±0.44) followed by Mothronwala swamp which was from 0.17 (± 0.01) to 0.1.06 (±0.41). Nitrogen % from all the sites showed a strong and significant correlation with other calculated attributes of *Lantana*. Nitrogen % with canopy coverage % (R^2 = 0.82), Nitrogen % with average crown diameter (R^2 = 0.98), Nitrogen % with shrub canopy area (R^2 = 0.96), Nitrogen % with Phytovolume (R^2 = 0.81) and Nitrogen % with biomass of *Lantana*/m^2 (R^2 = 0.92) but Nitrogen % with average height of shrub (R^2 = 0.57) was not very significant. The SOC (Soil Organic Carbon) also showed a strong correlation in determining the different measured attributes of *Lantana*. Carbon % with canopy coverage % (R^2 = 0.85), carbon % with average crown diameter (R^2 = 0.94), carbon % with shrub canopy area (R^2 = 0.93), carbon % with phytovolume (R^2 = 0.75) and with biomass of *Lantana*/m^2 (R^2 = 0.91) but like nitrogen this time carbon also did not show a significant correlation with average shrub height (R^2 = 0.47). The PCA shows that soil parameters like pH, available P and K, represent negative correlation with other soil parameters (r = - 0.042 with P, 0.109 with K – 0.009 with N and 0.0624 with C). Both available P and K along with the C:N ratio were showing negative correlation with other calculated attributes.

Keywords: invasive plants, soil properties, biomass of shrub, carbon sequestration, Principal Component Analysis

INTRODUCTION

Biological invasions are often thought to be one of the leading threats to global biodiversity. However, recent studies and popular literature have begun to question this view, especially in the context of invasive plants, asking 'Are invasive species really that bad?' For example, invasive plants have never been implicated as the sole cause in driving a native plant extinct. It is important to understand the local-scale processes that contribute to the loss of biodiversity from plant invasions and that future research should examine the impacts of invasives across local and regional spatial scales. The local-scale reduction of diversity by invasives is also the scale at which ecosystem services can be altered by invasive species. With the influx of invasive plant species; ecosystems may endure reductions in biodiversity, alterations in forage production and changes in ecosystem processes [1]. Many theories on exotic plant invasion have been proposed and used as frameworks for land management practices, but these theories are often too general to be applied to the variety of diverse ecosystem in which invasions are occurring and produce desired results.

Along with ecological diversity, invasive plant species also display a wide array of physiological traits that aid in their competitive ability. This exotic species diversity may also contribute to the inadequacy of generalized models for restorative land management efforts. India is a large developing country known for its diverse forest ecosystems and mega biodiversity. It ranks 10th amongst the most forested nations of the world [2] with 23.4 percent (76.87 million ha) of its geographical area under forest and tree cover [3]. These forests are under immense anthropogenic pressure in the form of rapid industrialization and related land-use change in the past few decades. With increase in human population forests are also exposed to illegal sporadic tree felling, widespread lopping of trees for timber resources and shrubs for fuel wood or leaf fodder. All these have lead to forest fragmentation, which is prone to subsequent invasion by exotic species [4]. Invasion of species may lead to local declines [5], and even extinction of native species [6], thus altering species richness in the forest fragment [7].

India is suffering from the impacts of invasive alien species in many ways. Recently it was reported that the alien flora of India accounts for 1599 species, belonging to 842 genera in 161 families and constituting 8.5% of the total vascular flora found in the country [8]. The negative impacts have been felt through losses of grazing, agricultural production and for some species, human health [9]. Due to high forest cover, the central Himalayan forests are rich in biodiversity with 10,000 species of vascular plants, 13,000 species of fungi and 1,100 species of lichens and a large reservoirs of carbon as well. Biomass values of forest stands in the central Himalayan parts tend to cluster around two very important levels from a low approximately 200 t ha^{-1} for early successional communities such as pine to a high of about 400 t ha^{-1} for the late successional communities such as the oaks and Sal [10]. *Lantana* is one of the most obnoxious weeds that has encroached most of the areas under community and reserve forestlands of central Himalaya. The outer fragile Himalayas are almost completely enraptured by this rapidly spreading weed. This weed, not only ruins common agricultural and forestlands but also makes shade as well as alellopathy impacts on the regeneration of important forestry species. Due to spread of *Lantana*, the yields of crops and pastures get reduced. The harvesting costs have increased manifolds. Heavy expenditure is incurred for afforestation of lands infested with this weed which requires frequent weedings so as to avoid suppression of young seedlings of planted species.

Afforestation cost is also increased due to loss of stand and slower growth rate due to weed competition. *Lantana* (*Lantana camara* L.) has spread in almost all the fragmented areas in the subtropical forests of central Himalaya and has been ranked as the highest impacting invasive species [11], and is among the 100 worlds worst invasive alien species [12], because it is a very effective competitor with native colonizers and is capable of interrupting the regeneration process of other indigenous species by reducing germination, reducing early growth rates and increasing mortality [13]. In India it was introduced in early nineteenth century as an ornamental plant but now it is growing densely throughout India.

Recent evidence suggests that positive feedbacks between invasive plants and soils could contribute significantly to plant invasions [14 – 19], perhaps exemplifying ‘ecological engineering’ by biological invaders [20]. In the envisioned process, invasive species modify soils that they occupy in ways that increase their own fitness relative to that of native species. Positive feedbacks ensue if increased invasive fitness furthers the degree or extent of soil modification, in turn further favouring these invasives over natives. There is much evidence that invasive plant species can modify physical or chemical attributes of soil, including inputs and cycling of nitrogen and other elements [21 – 23], pH [24], and soil organic matter and aggregation [25]. There is also evidence of direct modification of various components of the biotic composition of invaded soil, e.g., affecting a soil food web [26], total soil microbial communities [27] and mutualistic fungi [28]. As noted, these effects will enable plant invasion by positive feedback with soil attributes only if invasive species are benefited, and indeed there are clear indications of such benefits. In temperate old-field communities, modification of soil micro biota by common invasive species typically had beneficial or neutral effects on growth of these species [29] and micro biota associated with roots of several invasive woody species have increased growth of these species [30].

Most changes in species composition reflect changes in soil water nutrient availability and changes in availability of essential plant resources such as light, nutrients and water may result in a change in vegetation community composition [31]. Nutrient dynamics may become altered as a result of changes in the physical properties of the soil caused by the introduction of an alien species such as *Lantana* but it is not always the case that soil properties will be altered following alien species invasion. *Lantana* population persistence also occurs through processes unrelated to allelopathy such as edaphic effects and changes in ecosystem functioning [32]. These processes may facilitate ongoing suppression of indigenous species by altering nutrient cycles and modifying micro environments and disturbance regimes [33].

Lantana also has negative effect on soil water supply [34]. The dense stands of this shrub vegetation and the capacity of the soil beneath to absorb rain which could potentially increase the amount of runoff and the subsequent risk of soil erosion in areas infested with this shrub [35]. Increase in the soil nitrate following *Lantana* invasion to the benefit of thisshrub and to the detriment of some native species and decline in other nutrients. In Australia, the moisture content and pH were not significantly affected by *Lantana*. The allelochemicals produced by this woody shrub could alter the populations of soil microbial symbionts necessary for the early establishment of certain seedlings [36]. Some other invasive species like *Bromus tectorum* L. (cheat grass) was also found highly invasive in bunchgrass and shrub communities across the western U.S. This winter annual grass is a strong competitor due to its high degree of plasticity, ability to alter N cycles within ecosystems, and aptitude to rapidly uptake N during its short life cycle.

Nutrient dynamics are altered as a result of changes in physical properties of the soil caused by the introduction of new species [37]. Other introduced species release compounds that inhibit their own growth, as well as that of competitors [38].The soils of the Doon valley were developed on the deep alluvial deposits with parent material derived from the Doon alluvium. It consists of accumulated beds of clays, boulders, pebbles and sand with the admixture of water borne small to big size stones in the subsoil in varying proportions [39]. This alluvium was deposited by multilateral, multibraided channel system. Few study sites investigated in the present study were heavily forested with northern subtropical moist deciduous forest having an admixture of a variety of species in four tier structures (Top canopy, middle strata, and understory shrub and herb strata) with *Shorea robusta* as predominant species and understory heavily covered by *Lantana* and *Eupatorium*. Shrub biomass is an important component of the total forest biomass, especially in natural stands. While keeping in view the above mentioned facts, the objectives of the present study aim to calculate the relation between different soils attributes with measured and calculated shrub attributes like plant height, canopy coverage, shrub canopy area, phytovolume and biomass of shrub. To investigate the invasion of this exotic species, two specific sites were identified from all the chosen sites, a logged site (invaded) and a comparatively less invaded site where per hectare density of *Lantana* was less. Attempts were also made to analyse the soil nutrient change from all the invaded areas thereby, associating this property with the carbon sequestration potential of *Lantana* by calculating the biomass to assess their relevance in local and global carbon cycle. Since, Shrub level carbon sequestration has never been calculated in Doon Valley, which can give more accurate estimation of forest biomass; therefore this attribute has been taken as one of the major aspect of the current study. We chose non destructive biomass calculation of *Lantana*, by using an allometric equation approved and recommended in FAO statistical manual for Asia pacific. One way ANOVA, pearson correlation matrix and PCA ordination was calculated to see the level of correlation between different soil parameters and their direct and indirect role in measuring different shrub attributes which finally decide the biomass of this invasive shrub.

MATERIALS AND METHODS

Study sites: The present study was carried out in the Doon Valley, a part of western Himalaya, India. The Doon Valley is surrounded by hills on all the sides and has a varied range of subtropical deciduous forests mainly dominated by *Shorea robusta*, *Syzygium spp.*, *Terminalia spp.*, *Ehertia spp.*, *Litsea spp.* and others (Fig. 1). It is lying between latitudes $29^{0}55'$ and $30^{0}30'$ N and longitudes $77^{0}35'$ and $78^{0}24'$ E. It is a saucer shaped valley about 20km wide and 80km long with a geographical area of about 2100km^{2}. The Doon Valley falls under the sub-tropical to temperate climate due to its variable elevation. The average maximum temperature for the Doon Valley was 27.65^{0}C and the average minimum temperature was 13.8^{0}C with average maxima in June (40^{0}C) and average minima in January (1.80^{0}C).

The area received an average annual rainfall of 2025.43 mm. The region receives most of the annual rainfall during June to September; the maximum rainfall was recorded in July and August. We selected eight sampling sites (Table 1) covering all parts of the Valley named Golatappar (open canopy area), Railway tracks (abandoned land), Asarori forest (dense forest area dominated by Sal and *Syzygium* spp.), Sahastradhara (tourist place), Rajpur forest periphery (Sal dominated forest), Selaqui/Jhajra (abandoned residential plots and riverside forests dominated by Sal), Jolly Grant airport (protected urban area) and Mothronwala (swampy area). The criteria for selecting these sampling sites were to create maximum variation in physical factors like different ranges of altitude, topography, habitat and biotic interference level. We divided each site into two categories, 1. Invaded (where, *Lantana* invasion is very high and 2. A comparatively less invaded area where *Lantana* invasion is very less. Six plots each were laid in all the study sites.

Table 1: Site characteristics of Doon Valley with dominant invasive species

Name of the Sites	Dominant species	Mean % cover	Freq.	Point Coordinates	Elevation	Land Use
Golatappar	*Parthenium hysterophorus* L.	41	100	30^{0} 02′ 31.72″ N, 78^{0} 13′ 10.77″ E	1101 ft	open canopy forest
	Lantana camara L.	17	100			
	Ageratum conyzoides L	22.5	100			
Railway Track	*Parthenium hysterophorus* L.	38.4	100	30^{0} 17′ 10.40″ N, 78^{0} 03′ 22.27″E	2061 ft	open disturbed area
	Lantana camara L.	29	100			
	Ageratum conyzoides L	26	100			
Asarori Forest Periphery	*Lantana camara* L.	21.2	100	30^{0} 15′ 26.03″ N, 78^{0} 00′ 29.45″ E	2031 ft	dense forest
	Opuntia dillenii Ker Gawl.	17.8	100			
	Adhatoda zeylanica L.	16	100			
Sahastradhara (Tourist Place)	*Lantana camara* L.	27.9	100	30^{0} 23′ 08.17″ N, 78^{0} 07′ 53.81″ E	2916 ft	forest but disturbed
	Adhatoda zeylanica L.	20.8	100			
	Parthenium hysterophorus L.	15.5	100			
Rajpur Forest Periphery	*Lantana camara* L.	23.5	100	30^{0} 23′ 02.83″N, 78^{0} 05′ 09.93″ E	3122 ft	forest
	Murraya koenigii L. (Spreng)	10.6	100			
	Parthenium hysterophorus L.	10.3	100			

	Reinwardtia indica Dum.	9.1	100			
Selaqui/Jhajra Forest	*Lantana camara* L.	26.9	100	30^0 20′ 19.65″ N, 77^0 55′ 40.44″ E	1735 ft	forest
	Parthenium hysterophorus L.	16.6	100			
	Cassia occidentalis L.	14.8	100			
	Adhatoda zeylanica L.	12	100			
Jolly Grant Airport	*Lantana camara* L.	26.8	100	30^0 11′ 17.16″ N, 78^0 11′ 17.91″ E	1840 ft	open area
	Arundinella spicata Dalzell.	15.7	100			
	Ageratum conyzoides L	11.2	100			
	Parthenium hysterophorus L.	9	100			
Mothronwala (Swamp)	*Parthenium hysterophorus* L.	25.2	100	30^0 15′ 22.81″ N, 78^0 01′ 42.46″ E	1744 ft	swamp
	Lantana camara L.	25.1	100			
	Ageratum conyzoides L	20.2	100			
	Eupatorium odoratum L.	14.5	100			

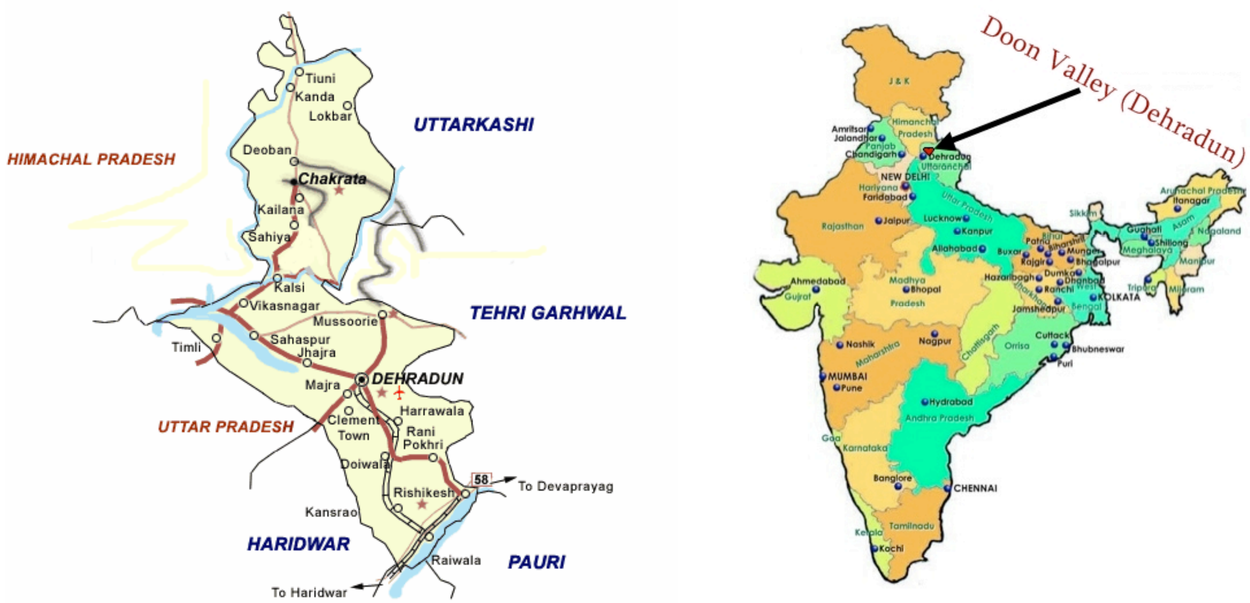

Figure 1: Map of study sites from Doon Valley, western Himalaya (Source: Google maps)

Lantana invaded areas are represented as *I* and non invaded (control) areas as *C*, which is also the control in this study) Soil was randomly sampled from the centre of the four small (1 m^2) subplots near the centre and at the centre of the middle plot measuring 100 m^2 after litter was removed.

A hand held push probe measuring 2.5 cm diameter was used to collect soil from a depth of 15 cm below the ground surface to ensure sufficient quantity of soil was collected for subsequent analysis. Ten samples were collected at invaded and ten at less invaded sites per habitat totalling to 120 which were obtained and analysed. The soil samples from invaded sites were collected within the *Lantana* thickets for consistency in data capture. Each soil sample was packed in a separate labelled plastic bag and transported to the laboratory for analysis. The soil samples were oven dried at 55°C for 24 h to reduce the moisture content and increase the concentration of the nutrients prior to chemical analysis. Then, they were passed through a 2 mm pore sieve for homogenization before they were analyzed for various contents. The detailed soil analysis method is as follows:

Soil texture: Bouyoucos hydrometer method [40] was used for calculating the particle size since it is less time consuming and easy to follow in a laboratory. Dispersion is obtained by using Calgon (Sodium haxa-metaphosphate).

Soil pH: Soil pH was measured by digital pH meter (Systronics 335).

Soil organic carbon: Soil organic carbon was determined by rapid dichromate oxidation technique [41]. The un-reacted dichromate was determined by back titration with $FeSO_4$ [42].

Total Nitrogen: The air dried soil samples were digested in a block digestor in the presence of 10 – 15 ml of conc. Total nitrogen then was determined by Kjeldahl method. Distillation was done with the help of 'Kel plus Nitrogen Estimation System' by adding 40 ml of 40% NaOH. The samples were then titrated against 0.1 N HCl.

Total phosphorus: We used two methods for determination of available phosphorus in soils: Bray's Method No.1 [43] for acidic soils and Olsen's Method [44] for neutral and alkaline soils. The optical density was measured with the help of Systronics Spectrophotometer 119 at 660 nm.

Exchangeable potassium: Exchangeable potassium of soil was determined by using Flame photometric method [45] after extracting with 1N ammonium acetate solution.

For non-destructive estimation of biomass:

The dependent variable shrub biomass depends upon many independent variables. The identified independent variables to establish the allometric equation were total plant height (H), maximum basal diameter (D1) and minimum basal diameter (D2), average of D = (D1+D2)/2 was used to establish the allometric equation along with the plant height. We tested and used different set of allometric equations given by FAO in its statistical manual for Asia pacific [46] and found the equation $y = a + bD^2H$ suitable for the calculation of shrub biomass.

Data analysis: One way ANOVA was calculated to test the correlation between different soil variables and the measured and calculated attributes of shrub. All the statistical analysis was done with the help of *XL*STAT 2011 for Microsoft excel 2010.

RESULT

The usual mean pH was increased in all the *Lantana* invaded sites. The maximum range of pH was recorded from the invaded sites of Mothronwala which was between 7.12 (±0.40) to 7.22 (±0.24) and was about 1.40 % from the control sites, minimum pH was recorded from Rajpur forest periphery which was between 5.53 (±0.45) to 6.13 (±0.62) and was about 10.84 % from its less invaded areas (P<0.01). However, a maximum *C* to *I* pH change was recorded from Jolly Grant airport which was 5.86 (±0.28) to 6.99 (±0.15) about 19.28 % increase from its control (Table 2). Rajpur forest periphery and nearby places were more acidic than other places perhaps due to less disturbance and also because it is free from herbivory, due to its location at high altitude. However, the soil of most disturbed areas like Sahastradhara (Tourist place), Mothronwala (Swamp) and Jolly Grant Airport are slightly neutral to basic perhaps due to heavy anthropogenic activities, easy approach of vehicles and also because of the open areas. The increase in pH value did not show any positive relation with the measured and calculated attributes of *Lantana* (ANOVA, P < 0.001). Maximum silt content was noticed from Mothronwala swamp which was between 22.85 (±2.80) to 24.53 (±1.56) from *C* to *I* followed by Selaqui/Jhajra forest periphery, between 22.16 (±2.79) to 23.17 (±2.21) and Sahastradhara between 18.62 (±1.89) to 22.05 (±2.86). However, in terms of maximum change in silt % content from *C* to *I* sites was noticed from Rajpur forest periphery which was between 10.38 (±3.08) to 15.23 (±3.13) followed by Sahastradhara 18.62 (±1.89) to 22.05 (±2.86). Clay % and sand % content was decreased in all *Lantana* invaded sites from less invaded sites except in Sahastradhara and Golatappar where the sand % content was higher in invaded areas from less invaded areas, 55.91 (±3.27) to 59.64 (±59.64) and 65.69 (±2.08) to 67.31 (±3.53). The soil texture gave a mixed result in all the invaded areas. But the silt % content of all the control and invaded sites were significantly differ from each other (R^2 = 0.96).

Nitrogen (%) showed strong significant variation in all the *Lantana* invaded sites and also with other calculated attributes of *Lantana* (α=0.05). The highest Nitrogen (%) content was recorded from Sahastradhara, which was between 0.14 (± .01) to1.12 (±0.44) followed by Mothronwala swamp, between 0.17 (± 0.01) to 0.1.06 (±0.41) and closely followed by Golatappar, between 0.12 (±0.06) to 0.98 (±0.48) (Fig 2a). A strong positive correlation was noticed between Nitrogen % and canopy coverage % of *Lantana* (R^2 = 0.81), Nitrogen % and average crown diameter (R^2 = 0.98), Nitrogen % and shrub canopy area (R^2 = 0.96), Nitrogen % and phytovolume (R^2 = 0.81) and Nitrogen % with biomass of *Lantana* (R^2 = 0.92) but Nitrogen % with average height of shrub (R^2 = 0.57) was not very significant (Table 3). Likewise, the organic carbon content (%) was also increased in some of the invaded sites 1.39 (±0.53) to 3.13 (±0.27) in Golatappar, 1.58 (±0.31) to 1.82 (±0.41) in Railway Tracks, 1.09 (±0.65) to 2.43 (±0.45) in Asarori forest periphery, 0.92 (±0.16) to 3.68 (±0.26) in Sahastradhara, however, it was unexpectedly decreased in Rajpur forest periphery 6.38 (±2.97) to 2.88 (±0.65), in Selaqui/Jhajra Forest periphery 1.43 (±0.09) to 2.12 (±0.43), Jolly Grant Airport and nearby places 0.98 (±0.47) to 1.28 (±0.23) and in Mothronwala swamp it was between 1.65 (±0.06) to 3.35 (±0.40) (Fig 2b)

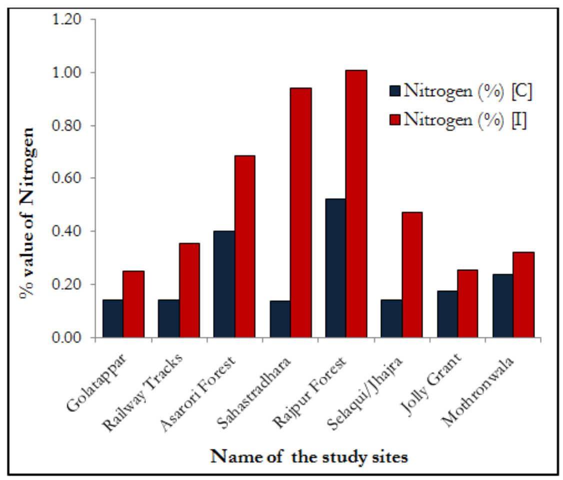

Figure 2(a): Comparison of Total Nitrogen (%) from Control and Invaded sites

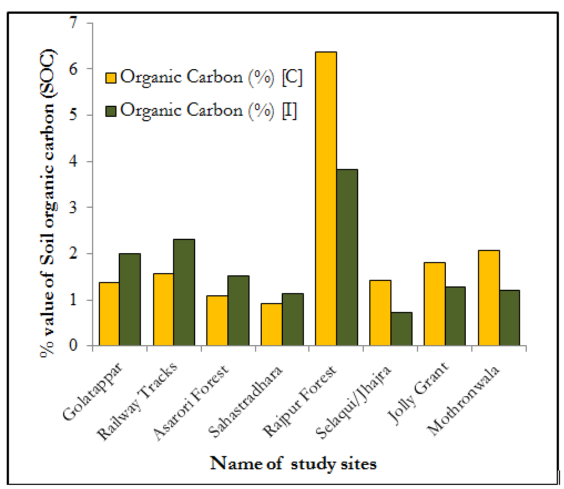

Figure 2(b): Comparison of Organic Carbon (%) between Control and Invaded sites of Lantana camara

Table 2: Comparison of the Physicochemical Properties of Soil [Less Invaded Vs Invaded] from all the sites of Doon Valley (Values in parenthesis are standard deviation)

Name of the Sites	**Soil Reaction (pH) *[C]***	**Soil Reaction (pH) *[I]***	**N (%) *[C]***	**N (%) *[I]***	**SOC (%) *[C]***	**SOC (%) *[I]***	**Available (P) ppm *[C]***	**Available (P) ppm *[I]***	**Available (K) ppm *[C]***	**Available (K) ppm *[I]***	**C:N *[C]***	**C:N *[I]***
Golatappar	6.47 (±0.43)	6.69 (±0.49)	0.12 (±0.06)	0.98 (±0.48)*	1.39 (±0.53)	3.13 (±0.27)*	3.67 (±1.07)	17.19 (±5.81)*	64.08 (±5.82)	103.01 (±6.32)*	10.31 (±3.49)	5.10 (±4.96)*
Railway Tracks	6.65 (±0.52)	6.77 (±0.40)	0.14 (±0.02)	0.36 (±0.10)*	1.58 (±0.31)	1.82 (±0.41)*	38.95 (±4.34)	72.69 (±9.05)*	92.18 (±7.43)	109.83 (±6.85)*	11.25 (±2.18)	5.69 (±2.57)*
Asarori Forest Periphery	5.81 (±0.26)	6.61 (±0.66)	0.40 (±0.23)	0.69 (±0.15)*	1.09 (±0.65)	2.43 (±0.45)*	4.00 (±1.27)	8.64 (±0.86)*	73.81 (±8.98)	97.06 (±7.76)*	3.98 (±2.98)	3.75 (±1.30)*
Sahastradhara (Tourist Place)	6.94 (±0.55)	6.95 (±0.17)	0.14 (±0.01)	1.12 (±0.44)*	0.92 (±0.16)	3.68 (±0.26)*	3.82 (±0.31)	6.48 (±0.90)*	30.77 (±4.74)	71.20 (±6.78)*	6.70 (±1.16)	4.18 (±2.70)*
Rajpur Forest Periphery	5.53 (±0.45)	6.13 (±0.62)	0.52 (±0.10)	0.96 (±0.20)*	6.38 (±2.97)	2.88 (±0.65)*	12.54 (±2.56)	14.22 (±1.63)*	71.21 (±7.31)	88.65 (±7.41)*	12.48 (±6.42)	3.23 (±1.40)*
Selaqui/Jhajra Forest Periphery	6.00 (±0.47)	6.62 (±0.21)	0.14 (±0.02)	0.47 (±0.11)*	1.43 (±0.09)	2.12 (±0.43)*	3.19 (±0.60)	6.96 (±0.55)*	73.17 (±2.84)	105.16 (±7.07)*	10.22 (±1.59)	4.65 (±1.21)*
Near Jolly Grant Airport	5.86 (±0.28)	6.99 (±0.15)	0.17 (±0.03)	0.25 (±0.04)*	0.98 (±0.47)	1.28 (±0.23)*	7.02 (±1.04)	12.88 (±2.63)*	93.04 (±7.36)	120.76 (±8.91)*	10.83 (±3.07)	5.14 (±1.35)*
Mothronwala Swamp	7.12 (±0.40)	7.22 (±0.24)	0.17 (±0.01)	1.06 (±0.41)*	1.65 (±0.06)	3.35 (±0.40)*	3.76 (±0.40)	7.66 (±0.78)*	37.17 (±3.75)	95.17 (±7.09)*	9.96 (±0.96)	4.60 (±4.40)*

* All means are significant from control at P<0.01 after applying student's t test
[LI] = less invaded, [I] = invaded

Table 3: Pearson correlation matrix for different soil and Lantana measured parameters from the Lantana invaded areas of Doon Valley

Variables	C (%)	N (%)	(P) ppm	(K) ppm	C:N	Avg. Crown Diameter	Avg. Shrub Canopy Area (m^2)	Shrub Canopy Projected Volume (m^3)	Density of *Lantana*/ha	Canopy Coverage (%/ha)	Phytovol (m^3/ha)	Avg. Ht. (cm)	Bio mass /m^2 (Kg)
Organic Carbon (%)	1	**0.98**	–0.39	**–0.86**	–0.09	**0.93**	**0.92**	0.53	0.16	**0.84**	**0.74**	0.46	**0.90**
N (%)	**0.98**	1	–0.44	**–0.83**	–0.07	**0.98**	**0.96**	0.63	0.09	**0.81**	**0.81**	0.57	**0.90**
Available (P) ppm	–0.39	–0.44	1	0.35	0.54	–0.47	–0.53	–0.28	–0.08	–0.46	–0.37	–0.29	–0.39
Available (K) ppm	**–0.86**	**–0.83**	0.35	1	0.26	**–0.79**	**–0.88**	–0.55	–0.16	**–0.81**	**–0.74**	–0.54	**–0.81**
C:N	–0.09	–0.07	0.54	0.26	1	–0.12	–0.24	–0.35	0.44	0.05	–0.24	–0.43	–0.01
Avg. Crown Diameter	**0.93**	**0.98**	–0.47	**–0.79**	–0.12	1	**0.97**	**0.75**	–0.03	**0.74**	**0.87**	0.69	**0.87**
Shrub Canopy Area (m^2)	**0.92**	**0.96**	–0.53	**–0.88**	–0.24	**0.97**	1	**0.76**	0.00	**0.78**	**0.90**	**0.72**	**0.88**
Shrub Canopy Volume (m^3)	0.53	0.63	–0.28	–0.55	–0.35	**0.75**	**0.76**	1	–0.46	0.28	**0.93**	**0.98**	0.57
Density of *Lantana*/ha	0.16	0.09	–0.08	–0.16	0.44	–0.03	0.00	–0.46	1	0.61	–0.13	–0.54	0.36
Canopy Coverage (%/ha)	**0.84**	**0.81**	–0.46	**–0.81**	0.05	**0.74**	**0.78**	0.28	0.61	1	0.60	0.21	**0.91**
Phytovol. (m^3/ha)	**0.74**	**0.81**	–0.37	**–0.74**	–0.24	**0.87**	**0.90**	**0.93**	–0.13	0.60	1	**0.88**	**0.82**
Avg. Height (cm)	0.46	0.57	–0.29	–0.54	–0.43	0.69	**0.72**	**0.98**	–0.54	0.21	**0.88**	1	0.48
Biomass/m^2 (Kg)	**0.90**	**0.90**	–0.39	**–0.81**	–0.01	**0.87**	**0.88**	0.57	0.36	**0.91**	**0.82**	0.48	1

In bold, significant values (except diagonal) at the level of significance alpha=0.05 (two-tailed test)

Organic carbon % too showed strong and significant correlation with canopy coverage % (R^2 = 0.85), with average crown diameter (R^2 = 0.94), with shrub canopy area (R^2 = 0.93), with phytovolume (R^2 = 0.75) and with biomass of *Lantana* (R^2 = 0.91) but like nitrogen carbon too did not show any significant correlation with average shrub height (R^2 = 0.47) (Table 3). The ANOVA result also showed that the plots from where the neighbouring plants were removed nitrogen availability significantly increased, indicating that the neighbouring plants reduce the nitrogen availability and by the result it is clearly indicated that exotic and invasive plant like *Lantana* increases the total Nitrogen content in the adjoining soil where they are growing (ANOVA, $P < 0.001$).

The available Phosphorus (P) was substantially increased in all the invaded sites. The maximum change in (P) was recorded from Railway tracks which was between 38.95 (±4.34) to 72.69 (±9.05), and minimum (P) change was recorded from Sahastradhara which was between 3.82 (±0.31) to 6.48 (±0.90). The quantity of available Potassium (K) was also increased in all the invaded sites. The maximum change is recorded from Mothronwala swamp followed by Sahastradhara, and Golatappar. Minimum was recorded from Railway tracks, and Rajpur forest. Like pH the available P and K from all the sites also did not show significant correlation with any of the measured and calculated attributes of *Lantana* (Table 3).

However, unlike the other soil parameters the C:N ratio was decreased in all the invaded sites. The maximum decrease in C:N ratio was recorded from Rajpur forest periphery followed by Jolly Grant airport. The minimum was recorded from Asarori forest, (Fig. 3).

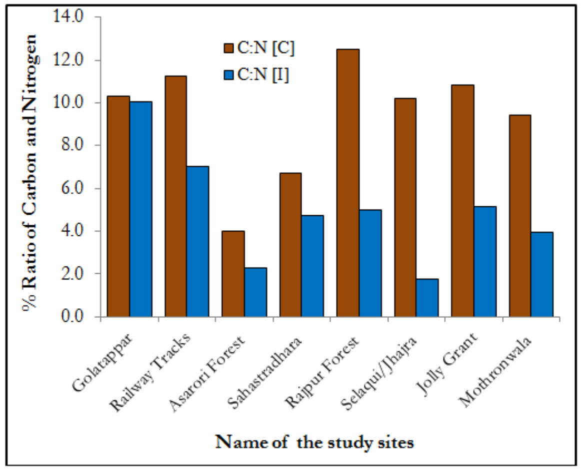

Figure 3: Comparison of (C:N) Ratio between all the Control and Invaded sites

In PCA for soil parameters only the Eigen value for both F1 and F2 axes were 34.13 and 30.93 respectively, representing 65.05% of the cumulative variance of soil data. The PCA shows that soil parameters like pH, available P and K, represent negative correlation with other soil parameters (r = –0.042 with P, 0.109 with K, –0.009 with N and 0.0624 with C). In the PCA for soil parameters with calculated attributes of *Lantana* the Eigen value for both F1 and F2 axes were 66.79 % and 19.22 % respectively representing 86.01 % of the cumulative variance of soil and species data. Both available P and K along with the C:N ratio were showing negative correlation with other calculated attributes.

Density of *Lantana* ha^{-1} was maximum in Sahastradhara (21,800 ha^{-1}) followed by Mothronwala (20,300 ha^{-1}) and Jolly Grant airport (20,200 ha^{-1}) however, startlingly the average crown diameter was highest in 180.28 cm followed by Sahastradhara (178.70 cm) and Mothronwala (175.33 cm). Average shrub canopy area of *Lantana*/m^2 was highest in Sahastradhara (2.68/m^2) followed by Rajpur forest periphery (2.64/m^2) and Mothronwala (2.45/m^2). The maximum phytovolume was recorded from Rajpur forest periphery followed by Sahastradhara and Mothronwala. The minimum phytovolume was recorded from Railway tracks. The biomass for this typical invasive shrub varied greatly from one site to other. The maximum biomass contribution was from Sahastradhara followed by Mothronwala. Both the sites were very disturbed and received maximum human activities. The total biomass of *Lantana* ranged between 6,746.80 kg ha^{-1} to 13,559.60 kg ha^{-1}. The coverage % was ranging from 29.98 % to 58.57 % and the maximum was recorded from Sahastradhara (Table 4).

Table 4: Comparisons of Biomass and Carbon accumulation of Lantana From different study sites of Doon Valley

Name of the sites	Avg. Shrub Canopy Area (m^2)	Avg. Shrub Canopy Volume (m^3)	Density of *Lantana* ha^{-1}	Phytovol. (m^3/ha)	Biomass ha^{-1} (Kg)	Carbon Density Kg ha^{-1}	Carbon Dioxide ha^{-1}
Golatappar	2.332	7.088	17000	120496	9809	4610.23	16904.2
Railway Tracks	1.6565	4.066	18100	73594.6	6823.7	3207.13	11759.5

Asarori Forest	2.1748	5.2728	16600	87528.5	7038.4	3308.04	12129.5
Sahastradhara	2.6869	7.1369	21800	155584	13559.6	6373.01	23367.7
Rajpur Forest	2.6461	13.792	14600	201363	11154.4	5242.56	19222.7
Selaqui/Jhajra Forest	1.9363	5.6025	16600	93001.5	7353.8	3456.28	12673
Jolly Grant Airport	1.6757	3.7588	20200	75927.8	6746.8	3170.99	11627
Mothronwala	2.457	7.1255	20340	144933	12956.58	6089.59	22328.5

DISCUSSION

A fundamental problem in the invasion study is the potential for pre – existing differences in soil properties that made certain areas more conducive to invasion. The experimental design does not allow us to exclude with complete certainty the possibility of such pre-existing differences between less invaded and invaded zones. However, less invaded plots were located close to the selected invaded patches, being separated only by a few meters. Moreover, preliminary field observations and samples analyse (e.g., texture and cationic exchange capacity) showed that soils of less invaded and invaded zones differ significantly except few. It should also be noted that *Lantana* patches are still expanding in Doon Valley but *Eupatorium*, *Parthenium* and other invasive species and their growth is still restricted to some specific areas and specific geographical conditions. pH was found to be a significant factor deciding only the coverage of *Lantana*. In Sahastradhara, we found that pH is slightly less acidic to neutral and recorded a little difference between control and the invaded sites *i.e.*, 6.94 (±0.55) to 6.95 (±0.17). However, the less acidic condition favoured the *Lantana* to grow better in the disturbed site. The density of *Lantana* in Shastradhara is the highest (21,800 ha^{-1}) with a maximum biomass of (1.356 Kg m^{-2}) followed by another highly disturbed area Mothronwala Swamp where the pH is slightly changed from less invaded areas to invaded areas i.e., from 7.12 (±0.40) to 7.22 (±0.24) which is again a neutral to basic condition and is favouring the *Lantana* growth with a density of 20,340 ha^{-1} and biomass (1.296Kg m^{-2}). The increased pH from all the invaded sites have a strong positive correlation with the coverage and total plant density (R^2 = 0.89). The similar change has been recorded from a dry deciduous forest of India [47].

In this study, *Lantana* showed differences in plant growth pattern. It increased the coverage as well as above ground biomass and took up about twice as much (P) and (K) per unit area as the native plants. This may explain the higher proportion of organic (P) & (K) fraction in invaded patches. Both (P) and (K) availability in the invaded soil was recorded much higher than their control which clearly indicates that *Lantana* invaded areas have more (P) and (K) than their control or the places where *Lantana* infestation is less and surely this increased level of both of them will increase their coverage and biomass.

The other plant attributes like plant height, stem diameter, canopy area and phytovolume are also directly related to the availability of SOC and total N. Soil organic carbon (SOC) and the total Nitrogen (N) have a direct impact deciding the coverage of *Lantana* and biomass. An increase in soil organic matter SOC content under stands of invasive plants have been reported in many previous studies [48 – 49], and has been attributed to increase biomass production and litter fall [50] or to reduce litter decomposition rates [51].The SOC and total N was considerably increased in all the invaded sites. The increase in nitrogen and phosphorus levels with increase in *Lantana* intensity could be due to decrease in nutrient impounding followed by the displacement of native species or reduction in their recruitment and growth rates, also because *Lantana* drops a large amount of litter beneath it and this is probably responsible for the elevated nitrogen and phosphorus levels (findings of this study). These findings are consistent with some findings where an increase in soil nitrate followed by *Lantana* invasion was recorded because according to that result nitrogen mineralization and nitrification commonly increase in response to invasions [52], this could explain the increase in available nitrogen that was recorded from the different study sites of the present study. N availability in soil is often increased under invasive plants, but reduced N availability has also been found, for example *Bromus tectorum* in arid grassland in the Western USA [53]. The latter effect was typically attributed to the production of nutrient poor litter, leading to slower N mineralization [54].

The highest SOC (%) was recorded from Sahastradhara 3.68 (±0.26) with an average *Lantana* height of (296.25cm) and an average stem diameter of (3.63cm) and the lowest was recorded from Jolly Grant Airport and nearby sites which was from 0.98 (±0.47) to 1.28 (±0.23) with an average *Lantana* height of (210cm). These two attributes are very strong factor deciding the biomass of the shrub (R^2 = 0.88) when analysed through the regression model and also used in this study to calculate the biomass of shrub. However, plant height was not very significantly correlated with the availability of SOC (%) and total N (%) (R^2 = 0.47) and (R^2 = 0.57) respectively, but when biomass as a whole taken into account these two soil parameters gave a strong positive correlation (R^2 = 0.91) and (R^2 = 0.92) respectively.

In some areas like Rajpur Forest Periphery the height of the plant was unexpectedly higher than other areas probably due to the enormous power of *Lantana* to compete with the native species for natural resources like sunlight, as *Lantana* is a photophilous (growing best in strong light) plant, and in closed canopy areas like Rajpur Forest Periphery it competes with the native trees in order to get more sunlight [47], and because of this it did not show strong positive correlation with SOC and Nitrogen %.On the other side, both SOC (%) and total N (%) has a very strong positive correlation deciding the crown diameter of *Lantana* (R^2 = 0.94) and (R^2 = 0.98) respectively.

Crown diameter is also a very good factor for the calculation of crown projected volume and biomass of shrub [55, 56]. Results also showed that SOC (%) and total N (%) has a strong positive correlation deciding the shrub canopy area (R^2

= 0.93) and (R^2 = 0.96) respectively. The correlation coefficients for SOC and N with *Lantana* coverage in all the invaded sites were strongly significant (R^2 = 0.85 and R^2 = 0.82 respectively). Phytovolume of *Lantana* was also calculated from shrub canopy projected volume (CV), which also has used in many studies to calculate shrub biomass. When correlated the soil properties (both SOC and N) with phytovolume the results gave a significant correlation. Between SOC and phytovolume (R^2 = 0.74, F = 55.19, α= 0.05) and between total N % and phytovolume (R^2 = 0.81, F = 55.19, α= 0.05). Most importantly SOC (%) and total N (%) are important soil factors which has a very strong positive correlation with the shrub biomass calculated non-destructively with the plant height and stem diameter taken as the measured attributes of *Lantana* to develop allometric equation after its regression analysis (R^2 = 0.91) and (R^2 = 0.91) respectively. Results of this study reveal that SOC (%) and total N (%) are two main soil attributes which decide the growth, coverage and biomass of the invasive species *Lantana*. However, not all the soil carbon is associated with organic material; there is also an inorganic carbon component in soils. This is of particular relevance to dry lands because calcification and formation of secondary carbonates is an important process in arid and semi arid regions. Consequently the largest accumulations of carbonates occur in the soils of arid and semi-arid areas. Dynamics of inorganic carbon pool are poorly understood although it is normally quite stable. Sequestration of inorganic carbon occurs via movement of HCO_3 into ground water and closed systems.

Some believed that Plant residues provide a renewable resource for incorporation into the soil organic matter and recorded that sequestration of secondary carbonates can contribute 0.0069 – 0.2659 Pg C y^{-1} in arid and semi-arid lands [57 – 58]. Production of plant residues in an ecosystem at steady state will be balanced by return of dead plant material to the soil. Only 1% of plant production will contribute to carbon sequestration in soil. The actual quantities of residue returned to the soil will depend on the crop, growing conditions and agricultural practices [59]. Differences between invasive species and natives in C stocks may also result from physiological properties. Invaders had faster growth rates than native species. In some studies it was found that a sample of 30 invasive species had, as a group, higher specific leaf area, net carbon dioxide assimilation rate, foliar [N], and foliar [P] than a sample of 34 native species in Hawaii [60].

Differences in litter fall mass interact with differences in the litter decomposition rate to affect the net flux of C into the soil. Many exotic plants have more rapidly decomposing litter than the natives. Decomposition rate may vary with plant tissue, so that differences in plant morphology ultimately control litter dynamics. These results clearly indicates that soil attributes like SOC, total N, P, K and soil textures play a vital role in the growth of *Lantana* in a subtropical deciduous condition like Doon Valley. However, the present results clearly revealed that Sahastradhara recorded maximum coverage and biomass of *Lantana* followed by Mothronwala and Rajpur forest periphery. The reason for Sahastradhara receiving more coverage and biomass is probably due to the significant change in the soil attributes, open areas and heavy tourist activities. Soil moisture, potassium, nitrogen, soil organic carbon and phosphorus levels varied significantly among all the sites of *Lantana* control and infested areas. Soil nitrogen, soil organic carbon, phosphorus and potassium levels increased with increase in *Lantana* intensity. Altitude, soil texture and soil depth are unlikely to change significantly following *Lantana* invasion. As a result, the insignificant difference in these variables among the two categories would indicate the homogeneity of the environment. This was supported by the study where disturbance by gophers can be the important factor in the invasion of serpentine grassland by *Bromus mollis* and other non-native annual grasses following years of above average rainfall [61].

In some studies it was found that Soil texture is a useful indicator of soil permeability, soil water retention capacity, and soil capacity to retain cations and influences plant available moisture and plant available nutrients [62]. Some workers considered clay content as an index of nutrient availability [63]. The greatest influence of pH on plant growth is its effect on nutrient availability. Since the result for moisture and nutrients (Soil depth, pH and texture) did not vary significantly with increase in *Lantana* intensity. It follows that changes in nutrient levels observed could be attributed to *Lantana* invasion effects. Differences in plant species composition reflect difference in soil water and nutrient availability [64], and changes caused by *Lantana* in the soil can be translated into plant composition. The increase in nitrogen and phosphorus levels with increase in *Lantana* intensity could be due to decrease in nutrient sequestration following native species displacement or reduction in their recruitment and growth rates.

Nitrogen mineralization and nitrification commonly increase in response to invasions, which could explain the increase in available nitrogen that was observed in this study. The results of this study is also in agreement with the some findings [65], who reported a positive correlation between level of invasion, and soil nitrogen levels and silt content. It has recently been suggested that invasion process is more closely related to resource availability [66]. Some workers showed that the addition of nutrients on Serpentine soils of California elevated alien plant abundances [67]. Therefore, inherent high nutrient levels could have promoted *Lantana* invasion in Doon Valley instead of high nutrient levels being a result of invasion. Decrease in soil moisture with increase in *Lantana* intensity shown by this study could be accounted for by the fact that *Lantana* is a short rooted plant, which maximises use of moisture on top layers of the soil, from which soil samples were collected. Furthermore, *Lantana* is very efficient in moisture sequestration leading to reduction in the soil availability of moisture.

The current results are in agreement with [21] who documented that soil moisture can either increase or decrease following invasion. These findings where *Lantana* reduces moisture levels are also consistent with findings by [34] who found that *Lantana* affects water supply negatively. The present study has provided strong evidence that *Lantana* invasion is reducing biodiversity and negatively affecting other ecosystem processes in Doon Valley and possibly in other nearby areas of its occurrence. Contrary to these previous studies the present study also reveals a very important perspective of invasive species *Lantana* i.e., the importance of biomass and further its role in the global carbon sink process. There are no two opinions that *Lantana* is a threat to the biodiversity and is reducing the native species but to the Indian perspective where population and pollution both are increasing rapidly, *Lantana* can be a very good source to sink atmospheric Carbon di oxide along with the different types of forest.

According to the present study the *Lantana* biomass vary between 6,746.80 Kg ha^{-1} to 13,559 Kg ha^{-1} and the carbon density from 3,170.99 Kg ha^{-1} to 6,373.01 Kg ha^{-1} this means *Lantana* alone from all its invaded areas storing almost an average 4432.22 Kg ha^{-1} carbon and is helping in the elimination of nearly 16,251.52 Kg CO_2 ha^{-1} (Table 5). In the Indian context, the recent estimates suggest that in a period of 10 years, from 1995 to 2005, there is an annual increment of 37.68 million tonnes carbon stored in Indian forests which means an annual removal of 138.15 million tonnes CO_2 eq. It would be possible to increase this carbon storage by adopting the methods of afforestation, reduced deforestation, and forest management.Therefore, *Lantana* along with the different forest types can be a good source of atmospheric carbon storage.

CONCLUSION

The results show a remarkable change in the soil mineralization from all the invaded areas of Doon Valley, which is not only increasing the uptake of these minerals but also increasing the risk of further invasion of other plants. The re – growth of *Lantana* after altering the soil property is significantly increasing different pattern of growth from these areas. The invasive success of *Lantana* depends on many factors including the SOC, Nitrogen, phosphorus, soil texture and moisture content, however other factors like disturbances, geographical distribution, and roadside effects are equally responsible. Despite the fact that *Lantana* is a documented threat we cannot neglect *Lantana's* tremendous power to store atmospheric carbon and therefore, this study overtly suggests that there is a need to calculate the biomass and fuel property of *Lantana.* The allometric equation used in the present study was found to be the most effective method to calculate the non-destructive biomass of *Lantana* where different plant measured attributes are essential and important factors. The elevated level of many soil nutrients were found directly correlated in deciding the plant measured and calculated attributes and so as the biomass of this invasive shrub. This property of *Lantana*'s storing atmospheric carbon can be considered even better during the autumn because most of the deciduous forest tree species shed of their leaves and stop the photosynthetic process due to this the carbon level in this season will increase drastically.

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REFERENCES

1. Gundale MJ, Sutherland S, DeLuca TH; Fire, native species, & soil resource interactions influence the spatio-temporal invasion pattern of *Bromus tectorum*. Ecography, (2008) 31: 201 – 210
2. FAO (Global Forest Resources Assessment); Progress towards sustainable forest management. FAO Forestry Paper 147, (2005) Food and Agriculture Organisation of the United Nations, Rome
3. Forest Survey of India; State of Forest Report of 2005, Forest Survey of India, Ministry of Environment and Forests Government of India, (2008) Dehra Dun, India
4. Tripathi A; Community Diversity Assesment in Vindhyans. – Ph. D. Thesis, Department of Botany, Banaras Hindu University, Varanasi, (2003) India.
5. Islam KR, Ahmed MR, Bhuiyan MK, Badruddin A; Deforestation effects on vegetative regeneration and soil quality in tropical semi-evergreen degraded and protected forests of Bangladesh. Land Deg. and Dev. (2001) 12: 45 – 56
6. Pimm SL; Community structure and stability. – In*:* Soule M (ed) Conservation Biology: The Science of Scarcity and Diversity. Sinauer, Sunderland, Massachusetts, USA, (1986) 309 – 329
7. Carey JR, Moyle P, Rejmanek M, Vermeij G; Invasion biology. Proceedings of a workshop at the University of California, Davis, USA, May' 1994. Biol Conserv, (1996) 78: 1 – 214
8. Khuroo AA, Reshi ZA, Malik AH, Weber E, Rashid I, Dar GH; Alien flora of India: taxonomic composition, invasion status and biogeographic affiliations. Biol Invasions, (2012) 14: 99 – 113
9. Kohli RK, Batish DR, Singh HP and Dogra K; Status, invasiveness and environmental threats of three tropical American invasive weeds (*Parthenium hysterophorus* L., *Ageratum conyzoides* L. and *Lantana camara* L.), Biol Invasions, (2006) 8: 1501 – 1510
10. Singh JS, Singh VK; Phenology of seasonally dry tropical forest. Curr Sci, (1992) 63: 684 – 688.
11. Batianoff GN, Butler DW; Impact assessment and analysis of sixty six priority invasive weeds in south east Queensland. Plant Protec Quart, (2003) 18: 11 – 17
12. Global Invasive Species Program GISP; "Invasive Species and Poverty, (2006) http://www.gisp.org/publications/Brochures/invasivesandpoverty
13. Sharma GP, Raghubanshi AS, Singh JS; *Lantana camara* invasion: an overview. Weed Biol Manag, (2005) 5: 157 – 165
14. Corbin JD, D' Antonio CM; Effects of exotic species on soil nitrogen cycling: implications for restoration. Weed Technol, (2004) 18: 1464 – 1467
15. Ehrenfeld JG, Implications of invasive species for belowground community and nutrient. Weed Technol, (2004) 18: 1232 – 1235
16. Scott NA, Saggar S, McIntosh PD; Biogeochemical impact of *Hieracium* invasion in New Zealand's grazed tussock grasslands: sustainability implications. Ecol Applications, (2001) 11: 1311 – 1322
17. Wolfe BE, Klironomos JN, Breaking new ground: soil communities and exotic plant invasion. Bioscience, (2005) 55: 477 – 487

18. Reinhart KO, Callaway RM, Soil biota and invasive plants. New Phytol, (2006) 170: 445 – 457
19. Eppstein MJ, Molofsky J; Invasiveness in plant communities with feedbacks. Ecol Letters, (2007) 10: 253 – 263
20. Cuddington K, Hastings A; Invasive engineers. Ecol Model, (2004) 178: 335 – 347
21. Ehrenfeld JG; Effects of exotic plant invasions on soil nutrient cycling processes. Ecosystems, (2003) 6: 503 – 523
22. Haubensak KA, D'Antonio CM, Alexander J, Effects of nitrogen fixing shrubs in Washington and coastal California. Weed Technol, (2004) 18: 1475 – 1479
23. Hawkes CV, Wren IF, Herman DJ, Firestone MK; Plant invasion alters nitrogen cycling by modifying the soil nitrifying community. Ecol Letters, (2005) 8: 976 – 985
24. Kourtev P, Ehrenfeld J, Häggblom M; Exotic plant species alter the microbial community structure and function in the soil. Ecology, (2002a) 83: 3152 – 3166
25. Saggar S, McIntosh P, Hedley C, Knicker H; Changes in soil microbial biomass, metabolic quotient and organic matter turnover under *Hieracium pilosella* L. Biol and Fert Soils, (1999) 30: 232 – 238
26. Duda JJ, Freeman DC, Emlen JM, Belnap J, Kitchen SG, Zak JC, Sobek E, Tracy M, Montante J; Differences in native soil ecology associated with invasion of the exotic annual chenopod, *Halogeton glomeratus*. Bio and Fert Soils, (2003) 38: 72 – 77
27. Kourtev P, Ehrenfeld J, Häggblom M; Experimental analysis of the effect of exotic and native plant species on the structure and function of soil microbial communities. Soil Bio and Biochem, (2003) 35: 895 – 905
28. Hawkes CV, Belnap J, D'Antonio C, Firestone MK; Arbuscular mycorrhizal assemblages in native plant roots change in the presence on invasive exotic grasses. Plant Soil, (2006) 281: 2369
29. Agrawal AA, Kotanen PM, Mitchell CE, Power AG, Godsoe W, Klironomos J; Enemy release? An experiment with congeneric plant pairs and diverse above – and below ground enemies. Ecology, (2005) 86: 2979 – 2989
30. Bray SR, Kitajima K, Sylvia DM; Micorrhizae differentially alter growth, physiology and competitive ability of an invasive shrub. Ecol Appl, (2003) 13: 565 – 574
31. Clegg S; Effects of perennial water on soil vegetation and wild herbivore distribution in Southern – eastern Zimbabwe. M.Sc. Thesis, University of Natal, Pietermaritzburg, (1999) 80 – 115.
32. Gentle CB, Duggin JA; *Lantana camara* L. invasion in dry rainforest ecotones: the role of disturbance associated with fire and cattle grazing. Aust J Ecology, (1997a) 22 (3): 296 – 304
33. Van Wilgen BW, Richardson DM; The effects of alien shrub invasion on vegetation structure and fire behaviour in South African fynbos shrubland: A simulation study. J App Ecol, (1985) 22: 455 – 466
34. Hiremath AJ, Sundaran B; The fire *Lantana camara* cycle hypothesis in Indian forests.Conserv and Society, (2005) 3 (1): 26 – 42
35. Day M, Wiley CJ, Playford J, Zalucki MP, *Lantana*: Current management status and future prospects. ACIAR Monograph, (2003) 102: 1 – 125
36. Vranjic JA, Woods MJ, Barnard J; Soil mediated effects on germination and seedling growth of coastal Wattle (*Acacia sophorae*) by the environmental weed bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata*). Austral Ecol, (2000) 25: 445 – 453
37. Ehrenfeld JG, Kourtev P, Huang W; Changes in soil functions following invasions of exotic understory plants in deciduous forests. Ecol Appl, (2001) 11 (5): 1287–1300
38. Musil CF; Effects of invasive Australian *Acacias* on the regeneration, growth and nutrient chemistry of South African Lowland Fynbos. J App Eco, (1993) 30: 361-372
39. Singhal RM, Samra JS, Sharma SD, Pande P, Sharma SK; Soil bio sequence of a forest land of Doon Valley with reference to its vegetation. Indian Forester, (1982) 108(4): 293– 299.
40. Allen SE, Grimshaw HM, Parkinson JA, Quarnby C; Chemical analysis of ecological materials (Oxford: Blackwell), (1974) 33 – 88.
41. Walkley AJ, Black IA; Estimation of soil organic carbon by the chromic acid titration method.Soil Science, (1934) 37: 29 – 38
42. Maiti SK; Moef report, an assessment of overburden dump rehabilitation technologies adopted in CCL, NCL, MCL, and SECL mines (Grant no. J-15012/38/98-IA IIM) 2003
43. Bray RH, Kurtz LT; Determination of total organic and available forms of phosphorus in soils. Soil Sci, (1945) 59: 30 – 45
44. Olsen SR, Watanable FS, Dean LA; Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circ US Dep Agric, (1954) 939
45. Toth SJ, Prince AL; Estimation of carbon exchange capacity and exchangeable Ca, K and Na contents of soils by flame photometric techniques. Soil Sci, (1949) 67: 439 – 445
46. FAO; forestry research support programme for Asia and the Pacific 'A statistical manual for forestry research' (Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific Bangkok), (1999) 33 – 110
47. Sharma GP, Raghubanshi AS; *Lantana camara* L. invasion and impact on herb diversity and soil properties in a dry deciduous forest of India. App Ecol and Environ Res, (2011) 9 (3): 253 – 264
48. Fickbohm SS, Zhu WX; Exotic purple loosestrife invasion of native cattail freshwater wetlands: effects on organic matter distribution and soil nitrogen cycling. App Soil Ecology, (2006) 32: 123 – 131
49. Heneghan L, Fatemi F, Umek L, Grady K, Fagen K, Workman M; The invasive shrub European buckthorn (*Rhamnus cathartica* L.) alters soil properties in Midwestern US woodlands. App Soil Ecology, (2006) 32: 142 – 148
50. Yelenik SG, Stock WD, Richardson DM; Ecosystem level impacts of invasive *Acacia saligna* in the South African fynbos. Restor Ecology, (2004) 12: 44 – 51
51. Ogle SM, Ojima D, Reiners WA; Modelling the impact of exotic annual Brome grasses on soil organic carbon storage

in a northern mixed grass prairie. Biol Invasion, (2004) 6: 365 – 377
52. Ehrenfeld JG; Effect of exotic plant invasions on soil nutrient cycling processes. Ecosystems, (2003) 6: 503 – 523
53. Evans RD, Rimer R, Sperry L, Belnap J; Exotic plant invasion alters nitrogen dynamics in arid grassland. Ecol Appl, (2001) 11: 1301 – 1310
54. Drenovsky RE, Batten KM; Invasion by *Aegilops triuncialis* (barb goat grass) slows carbon and nutrient cycling in serpentine grassland. Biol Invasion, (2007) 9: 107 – 116
55. Maraseni TK, Cockfield G, Apan A, Mathers N; Estimation of shrub biomass: development and evaluation of allometric models leading to innovative teaching methods. Int J Bus & Manag *Edu*, special issue: Postgraduate Research in Innovative Methods of Teaching & Learning, (2005) 17 – 32
56. Zeng HQ, Liu QJ, Feng ZW, Ma ZQ; Biomass equations for four shrub species in subtropical China. J For Res, (2010) 15: 83 – 90
57. Schlesinger WH; Biogeochemistry. Geotimes, (1997) 42: 44.
58. Lal R, Hassan HM, Dumanski J, Desertification control to sequester C and mitigate the greenhouse effect. In: Carbon Sequestration in soils: Science. Monitoring and beyond, N Rosenberg, RC Izaurralde and EL Malone (eds.) Batelle press, Coloumbus, OH, (1999) 33 – 149 Magazines, Johannesburg, 32.
59. Schlesinger WH; Evidence from chronosequence studies for low carbon storage in soils. Nature, (1990) 343: 232
60. Baruch Z, Goldstein G; Leaf construction cost, nutrient concentration, and net CO_2 assimilation of native and invasive species in Hawaii. Oecologia, (1999) 1221: (40) 183 – 92
61. Hobbs RJ, Mooney HA; Effects of rainfall variability and gopher disturbance on serpentine annual grassland dynamics in N. California. Ecology, (1991) 72: 59 – 68
62. White RE; Principles and Practices of Soil Sciences: The Soil as a Natural Resourece. Blackwell Science, Oxford (1997) 44 – 88
63. Scholes RJ, Walker BH; an African Savanna: Synthesis of the Nysvley Study. Cambridge University Press, Cambridge. (1993) 33 – 77
64. Scholes RJ; The influence of soil fertility on the ecology of Southern African Dry Savannas. J Biogeography, (1990a) 17: 415 – 419
65. Stohlgren TJ, Bull KA, Otsuki Y, Villa CA, Lee M; Riparian zones as havens for exotic plant species in the Central grasslands. Plant Ecol, (1998) 138: 113 – 125
66. Davis MA, Grime JP, Thompson K; Fluctuating resources in plant communities: A general theory on invisibility. J Ecology, (2000) 88: 528 – 534
67. Hueneke LF, Hamburg SP, Koide R, Mooney HA, Vitousek PM; Effect of soil resources on plant invasions and community structure in California Serpentine grassland. Ecology, (1990) 71: 478 – 491.

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