Aceh Int. J. Sci. Technol., 3(2): 87-105
August 2014
doi: 10.13170/AIJST.0302.05

Aceh International Journal of Science and Technology

ISSN: 2088-9860
Journal homepage: http://jurnal.unsyiah.ac.id/aijst

Changes in Physicochemical Properties of Soil Encourage the Invasion Establishment and Carbon Dynamics of *Lantana camara* from Doon Valley, Western Himalaya, India

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Received : May 7, 2014
Accepted : July 10, 2014

Abstract - *Lantana camara* L. is a recognized weed of worldwide significance due to its widespread distribution and impacts on nature conservation. In this study physicochemical properties of soil were analysed from different high and low *Lantana* infested areas. Significant site effect was frequently observed than effect due to invasion status. The present study tested the impact of soil properties in the measured and calculated attributes of *Lantana* by randomly sampling soil from the highly invaded and less invaded sites in different habitats using the Modified Whittaker plot design. Ten samples were collected at high invaded and ten at less invaded sites per habitat totalling to 120 which were obtained and analysed. One way analysis of variance (ANOVA) results indicated that edaphic factors such as soil pH, total nitrogen, soil organic carbon, Phosphorus and Potassium content positively influenced the growth of *Lantana* and helped in the further invasion process. These factors were also positively influencing the measured and calculated attributes of *Lantana* such as canopy coverage, average crown diameter, shrub canopy area, phytovolume and biomass from all sites. However some attributes like shrub height and stem diameter were negatively influenced by these soil factors. The level of these soil nutrients was found elevated in all *Lantana* invaded sites as compared to less invaded sites. The present results reveal that *Lantana* invasion can not only significantly improve the soil nutrient level but also positively increase the chances of its further invasion with more copious plant attributes.

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

Introduction

The invasion of exotic plant species is among the largest causes of ecological degradation not only in India but across the world. With the influx of invasive plant species, ecosystems may endure reductions in biodiversity, alterations in forage production and changes in ecosystem processes (Gundale *et al.,* 2008). 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 (FAO, 2005) with 23.4 percent (76.87 million ha) of its geographical area under forest and tree cover (FSI, 2005). 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 (Tripathi, 2003). Invasion of species may lead to local declines (Islam *et al.,* 2001), and even extinction of native species (Pimm, 1986), thus altering species richness in the forest fragment (Carey *et al.,* 1996).

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 (Khuroo *et al.,* 2012). The negative impacts have been felt through losses of grazing, agricultural production and for some species, human health (Kohli *et al.,* 2006). 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 (Singh and Singh, 1992). *Lantana camara* L. (henceforth, *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 has also increased due to loss of stand and slower growth rate of forests due to weed competition and other environmental factors. *Lantana* 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 (Batianoff and Butler, 2003), and also among the 100 worlds worst invasive alien species, this is because the invasive shrub is very effective competitor with native colonizers and is capable of interrupting the regeneration process of other indigenous species by reducing germination, early growth rates and increasing mortality (Sharma *et al.,* 2005). In India it was introduced in early nineteenth century as an ornamental plant but now it is growing densely in all parts of the country.

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 (Ehrenfeld, 2003; Haubensak *et al.,* 2004; Hawkes *et al.,* 2005), pH (Kourtev, 2002), and soil organic matter and aggregation (Saggar *et al.,* 1999). There is also evidence of direct modification of various components of the biotic composition of invaded soil, e.g., affecting a soil food web (Duda *et al.,* 2003) total soil microbial communities (Kourtev *et al.,* 2003) and mutualistic fungi (Hawkes *et al.,* 2005). 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 (Agrawal *et al.,* 2005) and micro biota associated with roots of several invasive woody species have increased growth of these species (Bray *et al.,* 2003).

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 (Clegg, 1999). 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 (Gentle and Duggin, 1997). These processes may facilitate ongoing suppression of indigenous species by altering nutrient cycles and modifying micro environments and disturbance regimes (Van Wilgen and Richardson, 1985).

Lantana also has negative effect on soil water supply (Hiremath and Sundaran, 2005). 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 (Day *et al.,* 2003). Increase in the soil nitrate following *Lantana* invasion to the benefit of this shrub 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 (Vranjic *et al.,* 2000). 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. 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* Roxb. ex Gaertner f. as predominant species and understory heavily covered by *Lantana* and *Chromolaena odorata* (L.) King and Robinson. Shrub biomass is an important component of the total forest biomass, especially in natural stands.

Using the right and accurate allometric equations for shrub biomass estimation in Doon Valley is very essential for at least two reasons. First, *Lantana* is a problem weed and the rapid growth of *Lantana* thickenings are turning the grasslands into woodlands and further making the woodlands thicker, also the peripheries of Doon Valley forests are heavily infested by this invasive weed, which has finely raised its importance. Second, measurement of carbon fluxes both at tree and shrub level, has local and global importance in the study of the CO_2 cycle. While keeping in view the above mentioned facts, the objectives of the present study aimed 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 success 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 present study. We chose non destructive calculation of *Lantana* biomass 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.

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Materials and Methods
Study sites

The present study was carried out in the Doon Valley, a part of western Himalaya, India (Figure 1). 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* Gaertn. f., or sal *Syzygium cumini* (L.) Skeels, *Terminalia alata* Heyne, *Terminalia bellirica* (Gaertner) Roxb., *Ehretia laevis* Roxb, and *Litsea glutinosa* (Lour.) Robinson. 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 receives 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.

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. *Lantana camara* L. *Ageratum conyzoides* L.	41 17 22.5	100 100 100	30^0 02' 31.72" N, 78^0 13' 10.77" E	1101 ft	Open canopy forest
Railway Track	*Parthenium hysterophorus* L. *Lantana camara* L. *Ageratum conyzoides* L.	38.4 29 26	100 100 100	30^0 17' 10.40" N, 78^0 03' 22.27"E	2061 ft	Open disturbed area
Asarori Forest Periphery	*Lantana camara* L. *Opuntia dillenii* Ker Gawl. *Adhatoda zeylanica* L.	21.2 17.8 16	100 100 100	30^0 15' 26.03" N, 78^0 00' 29.45" E	2031 ft	Dense forest
Sahastradhara (Tourist Place)	*Lantana camara* L. *Adhatoda zeylanica* L. *Parthenium hysterophorus* L.	27.9 20.8 15.5	100 100 100	30^0 23' 08.17" N, 78^0 07' 53.81" E	2916 ft	Disturbed forest
Rajpur Forest Periphery	*Lantana camara* L. *Murraya koenigii* L. Spreng. *Parthenium hysterophorus* L. *Reinwardtia indica* Dum.	23.5 10.6 10.3 9.1	100 100 100 100	30^0 23' 02.83"N, 78^0 05' 09.93" E	3122 ft	Forest
Selaqui/Jhajra Forest	*Lantana camara* L. *Parthenium hysterophorus* L. *Cassia occidentalis* L. *Adhatoda zeylanica* L.	26.9 16.6 14.8 12	100 100 100 100	30^0 20' 19.65" N, 77^0 55' 40.44" E	1735 ft	Forest
Jolly Grant Airport	*Lantana camara* L. *Arundinella spicata* Dalzell. *Ageratum conyzoides* L *Parthenium hysterophorus* L.	26.8 15.7 11.2 9	100 100 100 100	30^0 11' 17.16" N, 78^0 11' 17.91" E	1840 ft	Open area
Mothronwala (Swamp)	*Parthenium hysterophorus* L. *Lantana camara* L. *Ageratum conyzoides* L. *Chromolaena odorata* (L.) King & Rob.	25.2 25.1 20.2 14.5	100 100 100 100	30^0 15' 22.81" N, 78^0 01' 42.46" E	1744 ft	Swamp

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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. *Lantana* invaded areas are represented as *I* and less invaded areas as *LI,* (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 each was collected at invaded and 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. They were then passed through a 2 mm pore sieve for homogenization before they were analyzed for various contents.

Soil analysis

Soil texture: Bouyoucos hydrometer method (Allen *et al.,* 1974) was used for calculating the particle size since it is less time consuming and easy to follow in a laboratory. Dispersion was obtained by using Calgon (Sodium haxa-metaphosphate).

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

Soil Organic Carbon (SOC): Soil organic carbon was determined by rapid dichromate oxidation technique (Walkley and Black, 1934). The un-reacted dichromate was determined by back titration with $FeSO_4$.

Total Nitrogen: The air dried soil samples were digested in a block digestor in the presence of 10 – 15 ml of conc. Total nitrogen was then 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 (Bray and Kurtz, 1945) for acidic soils and Olsen's Method (Olsen *et al.,* 1954) 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 (Toth and Prince, 1949) after extracting with 1N ammonium acetate solution.

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 (FAO, 1999) and found the equation $y = a + bD^2H$ suitable for the calculation of shrub biomass.

Data analysis

We used Principal Component Analysis (PCA) as the ordination method to describe major gradients in the soil, using different variables for both invaded and less invaded sites. One way ANOVA was calculated to test the correlation between different soil variables and the measured/calculated attributes of shrub. All the statistical analysis was done with the help of *XLS*TAT 2011 for Microsoft excel 2010.

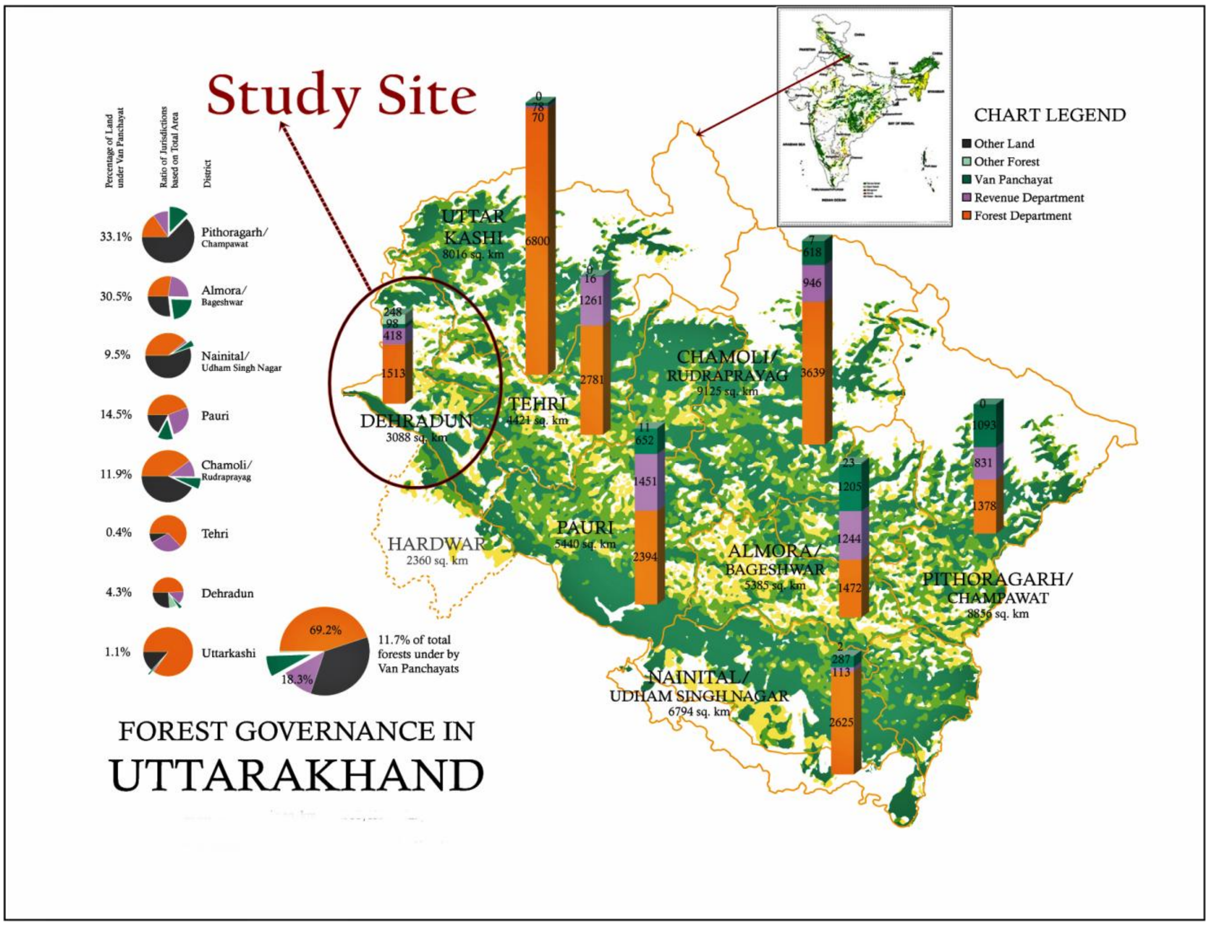

Figure 1. Forest cover map of Uttarakhand showing present study sites (Doon valley, source: google images)

Results and Discussion

Results

The usual mean pH was found increased in all the *Lantana* invaded sites. 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 less invaded 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 *LI* 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 2a). Rajpur forest periphery and nearby places were more acidic than other places perhaps due to less human disturbance, also because it is free from herbivory and 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 *LI* 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 *LI* 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 found to be 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) (Table 2b). The soil texture gave a mixed result in all the invaded areas. The silt % content on the other hand of all the invaded and less 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* such as canopy coverage, phytovolume, shrub canopy area and biomass (α=0.05). The highest Nitrogen (%) content was recorded from Sahastradhara, which was between 0.14 (± .01) to 1.12 (±0.44) followed by Mothronwala swamp, between 0.17 (± 0.01) to 1.06 (±0.41) and closely followed by Golatappar, between 0.12 (±0.06) to 0.98 (±0.48). 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 found significant (Table 3). Likewise, the organic carbon content (%) was also increased in places such as Golatappar, Railway tracks, Asarori forest peripheries, Sahastradhara, Selaqui/Jhajra forest and Mothronwala but unexpectedly it was found to be decreasing in Rajpur forest peripheries (Table 2a).

Organic carbon % too showed strong and significant correlation with canopy coverage % ($R^2 = 0.85$), with average crown diameter ($R^2 = 0.94$), shrub canopy area ($R^2 = 0.93$), phytovolume ($R^2 = 0.75$) and biomass of *Lantana* ($R^2 = 0.91$) also as with nitrogen, carbon too did not show any significant correlation with average shrub height ($R^2 = 0.47$) (Table 3). The ANOVA results also showed that the plots from where the neighbouring plants had been removed and were only left with *Lantana*, nitrogen availability significantly increased, indicating that the neighbouring plants reduced the nitrogen availability as also clearly indicated by the results that exotic and invasive plants like *Lantana* increases the total Nitrogen content in the adjoining soil where they grow (ANOVA, $P < 0.001$). Table 4 represents the ANOVA between soil parameters and different shrub attributes.

The available Phosphorus (P) was found 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), while 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 found increased in all the invaded sites. The maximum change was recorded from Mothronwala swamp which was between 37.17 (±3.75) to 95.17 (±7.09) followed by Sahastradhara, 30.77 (±4.74) to 71.20 (±6.78) and Golatappar, 64.08 (±5.82) to 103 (±6.32). Minimum change was recorded from Railway tracks, 92.18 (±7.43) to 109.83 (±6.85) and Rajpur forest, 71.21 (±7.31) to 88.65 (±7.41). 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 4). However, unlike the other soil parameters the C:N ratio was found decreased in all the invaded sites. The maximum decrease in C:N ratio was recorded from Rajpur forest periphery, 12.48 (±6.42) to 3.23 (±1.40), followed by Jolly Grant airport, 10.83 (±3.07) to 5.14 (±1.35). The minimum change was recorded from Asarori forest, 3.98 (±2.98) to 3.78 (±1.30) (Table 4).

Table 2a. Comparison of the physicochemical properties of soil [*Less Invaded Vs Invaded*] from all the sites of Doon Valley (Values in parenthesis are standard deviation). * All means are significant from control at *P<0.01* after applying student's *t* test. [LI] = less invaded, [I] = invaded

Name of the Sites	Soil Reaction (pH) *[LI]*	Soil Reaction (pH) *[I]*	N (%) *[LI]*	N (%) *[I]*	SOC (%) *[LI]*	SOC (%) *[I]*	Available (P) ppm *[LI]*	Available (P) ppm *[I]*	Available (K) ppm *[LI]*	Available (K) ppm *[I]*	C:N *[LI]*	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)*

doi: 10.13170/AIJST.0302.05

Table 2b. Comparative account of the physicochemical analysis of soil at (0-30cm) depth from all the sites of Doon Valley (Values in parenthesis are standard deviation) *[LI]* = less invaded, *[I]* = invaded)

Name of the Sites	Average Texture (%) *[LI]*			Average Texture (%) *[I]*		
	Sand	Clay	Silt	Sand	Clay	Silt
Golatappar	65.69 (±2.08)	19.99 (±2.95)	14.32 (±1.70)	67.31 (±3.53)	16.50 (±3.96)	16.19 (±2.65)
Railway Tracks	74.16 (±2.50)	15.95 (±2.02)	10.21 (±0.64)	66.12 (±3.32)	14.40 (±2.79)	14.02 (±3.13)
Asarori Forest Periphery	67.56 (±6.26)	16.90 (±1.67)	15.54 (±5.78)	66.24 (±8.10)	17.54 (±2.04)	16.22 (±8.42)
Sahastradhara (Tourist Place)	56.91 (±3.27)	21.91 (±1.44)	18.62 (±1.89)	59.64 (±5.58)	18.31 (±4.72)	22.05 (±2.86)
Rajpur Forest Periphery	73.27 (±2.11)	16.35 (±1.27)	10.38 (±3.08)	70.49 (±5.16)	14.23 (±4.01)	15.28 (±3.13)
Selaqui/Jhajra Forest Periphery	55.15 (±2.71)	22.69 (±1.34)	22.16 (±2.79)	54.63 (±1.97)	22.19 (±1.00)	23.17 (±2.21)
Near Jolly Grant Airport	59.79 (±4.24)	22.73 (±2.04)	17.48 (±5.66)	57.53 (±3.44)	22.72 (±1.93)	19.75 (±2.41)
Mothronwala Swamp	55.77 (±3.22)	21.37 (±4.62)	22.85 (±2.80)	55.60 (±1.43	19.87 (±2.24)	24.53 (±1.56)

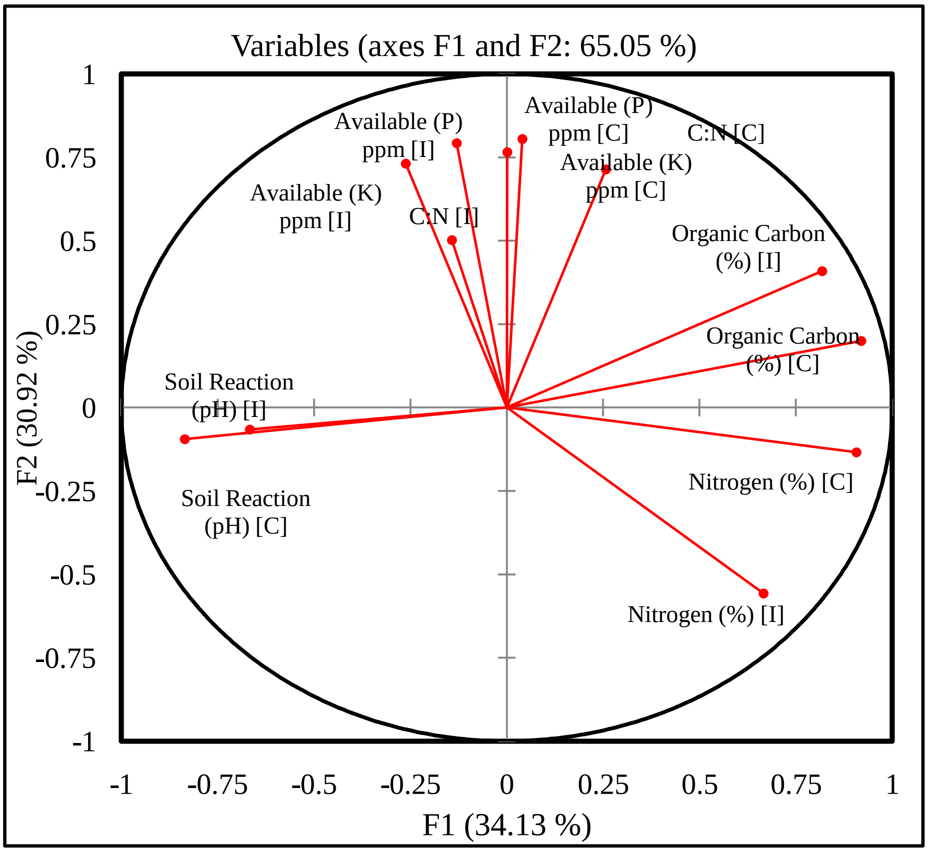

Figure 2. Principal component analysis (PCA) representation of soil attributes from control and invaded sites of *Lantana* (n = 20) from Doon Valley

Table 3. Summary of regression ANOVA of different sites for Soil parameters and its relation with shrub's measured and calculated attributes

Measured and calculated parameters	Source of variation	*SS*	*df*	MS	*F*	*P*
Organic Carbon (%) *Vs* Avg. Plant height (cm)	Between groups	337346.06	1	337346	90.7557	0.00032
	Within groups	52039.074	14	3717.08		
	Total	389385.14	15			
Nitrogen (%) *Vs* Avg. Plant height (cm)	Between Groups	341657.79	1	341658	91.9226	0.00010
	Within Groups	52035.19	14	3716.8		
	Total	393692.98	15			
Avg. Height (cm) *Vs* Avg. Crown Diameter	Between Groups	67606.5	1	67606.5	17.5285	0.00091
	Within Groups	53997.22	14	3856.94		
	Total	121603.72	15			
Nitrogen (%) *Vs* Avg. Plant height (cm)	Between Groups	105301.87	1	105302	750.756	0.00102
	Within Groups	1963.6553	14	140.261		
	Total	107265.53	15			
Organic Carbon (%) *Vs* Avg. Crown Diameter	Between Groups	102914.24	1	102914	732.285	0.00001
	Within Groups	1967.5395	14	140.539		
	Total	104881.78	15			
Organic Carbon (%) *Vs* Avg. Shrub Canopy Area (m^2)	Between Groups	0.6102344	1	0.61023	1.45873	0.00247
	Within Groups	5.8566423	14	0.41833		
	Total	6.4668767	15			
Nitrogen (%) *Vs* Avg. Shrub Canopy Area (m^2)	Between Groups	8.5195394	1	8.51954	60.47	0.0000
	Within Groups	1.9724423	14	0.14089		
	Total	10.491982	15			
Nitrogen (%) *Vs* Canopy Coverage (%/ha)	Between Groups	633273.41	1	633273	134.029	0.00001
	Within Groups	66148.655	14	4724.9		
	Total	699422.06	15			
Organic Carbon (%) *Vs* Canopy Coverage (%/ha)	Between Groups	627398.29	1	627398	132.778	0.00021
	Within Groups	66152.539	14	4725.18		
	Total	693550.83	15			
Organic Carbon (%) *Vs* Phytovolume (m^3/ha)	Between Groups	5.669324	1	5.74352	55.1941	0.00011
	Within Groups	1.438345	14	1.26653		
	Total	7.107233	15			
Nitrogen (%) *Vs* Phytovolume (m^3/ha)	Between Groups	5.669234	1	5.73442	55.1958	0.00021
	Within Groups	1.438455	14	1.22371		
	Total	7.107366	15			
Organic Carbon (%) *Vs* Biomass/m^2 (Kg)	Between Groups	10.800708	1	10.8007	28.7303	0.00011
	Within Groups	5.2630903	14	0.37594		
	Total	16.063798	15			

The Principal Component Analysis (PCA) of all the soil parameters and the calculated attributes of *Lantana* have been shown in Figs. 2 and 3 respectively. In PCA 1 for soil parameters the Eigen values 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 2 for soil parameters with calculated attributes of *Lantana* the Eigen values 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 different calculated attributes but total nitrogen and carbon contents were represented as the key factors for deciding the different shrub attributes and thereby contributing strongly in the total shrub level biomass calculation. Density of *Lantana* ha^{-1} was found 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 found highest (180.28cm) in Rajpur forest peripheries followed by Sahastradhara (178.70 cm) and Mothronwala (175.33 cm). Average shrub canopy area 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 and minimum 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 because of heavy infestation rate of this invasive species and also due to high measurement of attributes responsible for biomass calculation. The total biomass of *Lantana* ranged between 6,746.80 kg ha^{-1} to 13,559.60 kg ha^{-1}. The coverage % calculated from different sites varied from 29.98 % to 58.57 % and maximum was recorded from Sahastradhara (Table 5).

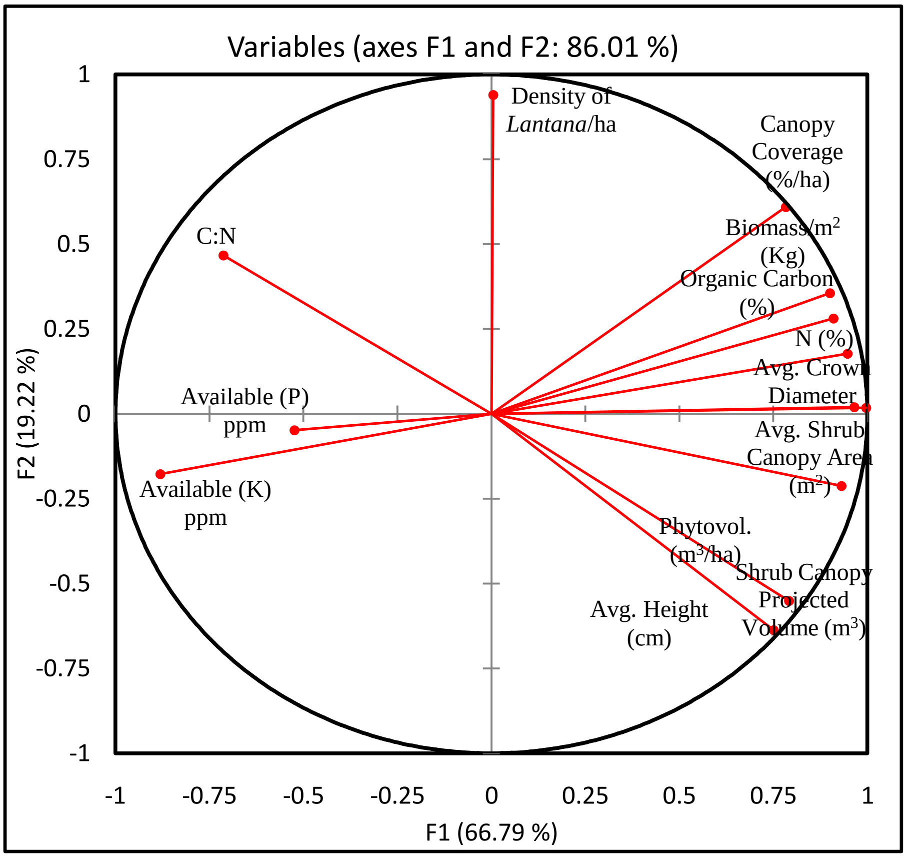

Figure 3. Principal component analysis (PCA) representation of soil attributes & calculated and measured attributes of *Lantana* from different sites (n = 20) of Doon Valley

doi: 10.13170/AIJST.0302.05

Table 4. Pearson correlation matrix for different soil and *Lantana* measured parameters from 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^{-1}	Canopy% Coverage ha^{-1}	Phytovol (m^3ha^{-1})	Avg. Height (cm)	Biomass/ 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
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^{-1}	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^{-1}	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
Phytovolume (m^3 ha^{-1})	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)

Table 5. 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^{-1})	Biomass ha^{-1} (Kg)	Carbon Density Kg ha^{-1}	Carbon Dioxide ha^{-1}
Golatappar	2.332	7.088	17000	120496	9809	4610.23	16904
Railway Tracks	1.656	4.066	18100	73594	6823	3207.13	11759
Asarori Forest	2.174	5.272	16600	87528	7038	3308.04	12129
Sahastradhara	2.686	7.136	21800	155584	13559	6373.01	23367
Rajpur Forest	2.646	13.792	14600	201363	11154	5242.56	19222
Selaqui/Jhajra Forest	1.936	5.602	16600	93001	7353	3456.28	12673
Jolly Grant Airport	1.675	3.758	20200	75927	6746	3170.99	11627
Mothronwala	2.457	7.125	20340	144933	12956	6089.59	22328

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 and 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) reveal that soils of less invaded and invaded zones differ significantly except few. It should also be noted that *Lantana* patches are incessantly escalating in Doon Valley but for the opportunistic species such as *Chromolaena odorata* (L.) King and Robinson*, Parthenium hysterophorus* L.*, Cassia tora* L.*, Cassia occidentalis* L.*, Urena lobata* L.*, Ipomoea carnea* Jacquin Enum*, Sida cordifolia* L. and *Solanum torvum* Swartz, the growth was found still restricted to some specific areas and specific geographical conditions. The pH amongst other parameters was found to be the only significant deciding factor for coverage of *Lantana*. In Sahastradhara, we found that pH was slightly less acidic to neutral and also little difference was recorded between less invaded and the invaded sites *i.e.,* 6.94 (±0.55) to 6.95 (±0.17). However, the less acidic condition favoured *Lantana* to grow better in these disturbed sites. The density of *Lantana* in Shastradhara was 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 was slightly changed from less invaded areas to invaded areas *i.e.,* from 7.12 (±0.40) to 7.22 (±0.24) which was again a neutral to basic condition and found favouring the *Lantana* growth with a density of 20,340 ha^{-1} and biomass (1.296 Kg m^{-2}). The increased pH from all the invaded sites were found having a strong positive correlation with the coverage and total shrub density (R^2 = 0.89). The similar change had been recorded from a dry deciduous forest of India (Sharma and Raghubanshi, 2011).

In this study, *Lantana* showed differences in plant growth pattern. It increased the coverage as well as above ground biomass in all the invaded areas 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 to be much higher than their control (LI) which clearly indicates that *Lantana* invaded areas have more (P) and (K) than less invaded or the places where *Lantana* infestation is negligible, surely this increased level of both P and K strongly favoured in increasing their coverage and biomass.

Different attributes like plant height, stem diameter, canopy area and phytovolume were also directly related to the availability of SOC and total N. Soil organic carbon (SOC) and the total Nitrogen (N) had a direct impact in fixing on the coverage of *Lantana* and biomass. An increase in soil organic matter SOC content under stands of invasive plants had been reported in many previous studies (Fickbohm and Zhu, 2006; Heneghan *et al.,* 2006), it has also been attributed to increase biomass production and litter fall (Yelenik *et al.,* 2004) or to reduce litter decomposition rates (Ogle *et al.,* 2004). The SOC and total N was found to be considerably increased in all the invaded sites. The increase in nitrogen and phosphorus levels with increase in *Lantana* intensity could be due to the decrease in nutrient impounding followed by the displacement of native species or reduction in their recruitment and growth rates, also *Lantana* drops a large amount of litter beneath it, this could probably be the reason for elevated nitrogen and phosphorus levels in all invaded sites (findings of this study). These findings are consistent with some of the findings where an increase in soil nitrate followed by *Lantana* invasion was recorded. According to this result nitrogen mineralization and nitrification commonly increase in response to invasions (Ehrenfeld, 2003), this could further explain the increase in available nitrogen that was recorded from the different study sites. 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 (Evans *et al.,* 2001). The latter effect was typically attributed to the production of nutrient poor litter, leading to slower N mineralization (Drenovsky and Batten, 2007).

The highest SOC (%) was recorded from Sahastradhara with highest average *Lantana* height, an average stem diameter 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 were very strong factors with the biomass of the shrub (R^2 = 0.88) when analysed through the regression model and have also been 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 was 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, in closed canopy areas like Rajpur Forest Periphery it competes with the native trees in order to get more sunlight (Sharma and Raghubanshi, 2011), 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 was found to be very good factor for the calculation of crown projected volume and biomass of shrub (Maraseni *et al.,* 2005; Zeng *et al.,* 2010). The present results also indicate that SOC (%) and total N (%) had a strong positive correlation with 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 found strongly significant (R^2 = 0.85 and R^2 = 0.820 respectively. Phytovolume, a very essential part of biomass calculation, when correlated with soil properties (both SOC and N) were found to be a significant factor, positively influenced by these soil properties. Most importantly SOC (%) and total N (%) were important soil factors which had a very strong positive correlation with the shrub biomass calculated non-destructively with the plant height and stem diameter as the main measured attributes of *Lantana* taken to develop allometric equation after its regression analysis (R^2 = 0.91 and R^2 = 0.91) respectively. Results of this study also reveal that SOC (%) and total N (%) are two main soil attributes which decide the growth, coverage and biomass of this invasive species. Not all the soil carbon is associated with organic material; there is also an inorganic carbon component in soils which is of particular relevance to dry lands because calcification and formation of secondary carbonates is an important process in arid and semi arid regions. Dynamics of inorganic carbon pool are poorly understood although it is normally quite stable.

Some researchers 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 (Schlesinger, 1997; Lal *et al.,* 1999). 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 (Lal *et al.,* 1999; Schlesinger, 1990). 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 (Baruch and Goldstein, 1999).

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 been 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 an important factor in the invasion of serpentine grassland by *Bromus mollis* and other non-native annual grasses following years of above average rainfall (Hobbs and Mooney, 1991).

In some studies it has been found that Soil texture is a useful indicator of soil permeability, soil water retention capacity, soil capacity to retain cations and influences plant available moisture and plant available nutrients (White, 1997). Some workers considered clay content as an index of nutrient availability (Scholes and Walker, 1993). 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 (Scholes, 1990), and the 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. 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 Ehrenfeld (2003), 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 Hiremath and Sundaran (2005), who found that *Lantana* affects water supply negatively. The present study has provided strong evidence that *Lantana* invasion is reducing biodiversity while negatively affecting other ecosystem processes in Doon Valley also 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 its further 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.

The results of the present study revealed the biomass of *Lantana* 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}. *Lantana* alone from all invaded areas store an average 4432.22 Kg ha^{-1} carbon and was found 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 was 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.

Conclusions

The results obtained in this study suggest that there is a remarkable change in the soil nutrient property from all *Lantana* invaded areas of Doon Valley which is not only maximizing its uptake but further its utilization by this invasive shrub. 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* up to certain extent depend on the different soil properties especially the SOC, Nitrogen, Phosphorus, soil texture and moisture content. However, other factors like disturbances, geographical distribution, and roadside effects are equally responsible for the further invasion of *Lantana*. Higher soil Phosphorus has been found to be correlated with invasion process yet it is not usually clear whether invaders prefer microsites with high soil phosphorus or if they cause increases in available soil phosphorus. The alteration of soil property due to *Lantana* invasion may be favouring this and other invasive species to grow in the nearby places but the elevated growth form of *Lantana* is very important for biomass calculation also. *Lantana* along with other dominant tree species of Doon Valley forests such as *Shorea robusta* Roxb. ex Gaertner f., *Syzygium cumini* (L.) Skeels, *Dalbergia sissoo* Roxb., *Bombax ceiba* L., *Emblica officinalis* Gaertner., *Litsea glutinosa* (Lour.) Robinson, *Mangifera indica* L., and *Mitragyna parvifolia* (Roxb.) Korthals, can contribute in the sequestration of good amount of carbons from the atmosphere. This property 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.

Acknowledgements

We are thankful to the department of Botany and National Forest Library, ICFRE, Dehradun, India, for providing both laboratory and literary facilities. We extend our thanks to the Department of Botany, DAV (PG) College, Dehradun, India, for providing the laboratory and statistical facility. We also thank APEX laboratory services, Dehradun, India, for providing assistance in soil analysis.

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