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THE ROLE OF HABITAT TYPES AND SOIL PHYSICOCHEMICAL PROPERTIES IN THE SPREAD OF A NON NATIVE SHRUB *LANTANA CAMARA* IN THE DOON VALLEY, WESTERN HIMALAYA, INDIA

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Abstract

Invasive alien species colonize very aggressively and forcefully, menacing native biodiversity. The success of invasive alien plants is due to their opportunistic exploitation of anthropogenic disturbances, the absence of natural enemies, free from herbivory and frequently their allelopathic competition. Invasive species can have a significant impact on development, affecting sustainability of livelihood, food security and essential ecosystem services and dynamics. *Lantana camara* is a documented weed of worldwide significance; it is indigestible due to its toxic chemicals and highly competitive. 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. 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 its own 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 present results show that *Lantana* invasion can significantly improve the soil nutrient level but also positively increasing the chances of its further invasion with more copious plant attributes.

Keywords: invasive alien plants, soil physicochemical properties, biomass of shrub, geomorphology, principal component analysis

INTRODUCTION

The invasive alien species are well thought-out to be the second principal cause of biodiversity loss after habitat destruction (Schwartz et al., 1996; Shinwari et al., 2012). The negative impact of such plant species on native biodiversity has been well documented (D'Antonio and Mahall, 1991; Ridenour and Callaway, 2001). Invasive alien plants have been found to change the structure and composition of native communities and been associated with reduced native plant diversity (Bone et al., 1997; Ferreira and Marques, 1998; Shinwari and Qaisar, 2011).

Introduced species severely threaten some native flora and fauna communities, either directly or by modifying ecosystem process and functions (Gordon, 1998; Hulme, 2006; Vitousek et al., 1997). The introduction of non-native plants or animals has usually been deliberately facilitated by humans, and although most introduced species do not deleteriously affect ecosystems, a small proportion become invasive (Hulme, 2006). Traits that enable introduced species to persist or spread successfully include high fecundity, good defence mechanisms, high survival rates, adaptability and a lack of natural enemies such as predators and diseases (Cheal et al., 2006). Introduced species that become invasive can have catastrophic effects on native biodiversity assets and ecological processes by altering nutrient levels, hydrological cycles, fire regimes and community composition, including the removal of keystone species (Brooks et al., 2004; D'Antonio and Vitousek 1992; Le Maitre et al., 1996; Vitousek and Walker 1989; Yurkonis et al., 2005). For conservation strategies to be successful, it is essential that the introduced species, both plant and animal, that pose major threats, be identified and the mechanism through which they threaten biodiversity assets be understood.

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). The Himalayas on the other hand is well recognized for its ecosystem services to the Asian region as well as to the world at large for maintaining slope stability, regulating hydrological integrity, sustaining high levels of biodiversity and human wellbeing. Mountains, due to their exclusive and inimitable biodiversity, are recently receiving priority for biodiversity conservation in global agendas. The western Himalayan part is a dynamic landscape with a rich and remarkable biodiversity (Guangwei, 2002). The western Himalayan region is endowed with a rich variety of gene pools and species, and ecosystems of global importance. The region, with its varied landscapes and soil formation, and variety of vegetation types and climatic conditions, is well known for its unique flora and fauna, and has a high level of endemism (Myers et al., 2000) and numerous critical eco regions of global importance (Olson et al., 2001; Olson and Dinerstein, 2002).

Total forest cover of the country is 697,898 sq. km (69.79 million ha) which is 21.23% of the geographical area of the country. The total tree cover of the country is estimated to be 91,266 sq.km (9.13 million ha) which is 2.78% of the total geographical area. The present study site Doon valley is a part of Uttarakhand state which is situated in the western Himalaya. The state of Uttarakhand has a geographical area of 53,483 sq. km, of which 4785 sq. km area is covered by very dense forest (VDF), 14,111 sq. km area is covered by moderately dense forest (MDF) and 5612 sq. km area comes under open forest (OF) giving a total forest cover of 24,508 sq. km which is 45.82% of the total geographical area (ISFR, 2013). The Doon valley is surrounded by sal (*Shorea robusta* Gaertn. f.) hereafter, *Shorea robusta* forest, where number of tree species are co-dominant such as *Syzygium cumini, Mallotus philippensis, Terminalia alata, Tectona grandis, Ficus benghalensis, Cassia fistula, Ehretialaevis, Adina cordifolia, Bauhinia variegate, Flacourtia indica.* These forests are invaded by number of exotic species. A large number of exotics have become naturalized in India and have affected the distribution of native flora to some extent, only a few have conspicuously altered the vegetation patterns of the country. *Lantana camara*, *Cytisus scoparius*, *Chromolaena odorata*, *Eupatorium adenophorum*, *Mikania micrantha*, *Mimosa invisa*, *Parthenium hysterophorus* and *Prosopis juliflora* are important among terrestrial exotics and are heavily distributed in the Doon valley forests.

Lantana is one of the most obnoxious weeds that has encroached most of the areas under community and reserve forestlands of western 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 weeding so as to avoid suppression of young seedlings of planted species. Apart from its popularity as a garden plant, *Lantana* is said to form a useful hedge and to provide a good preparation for crops, covering the ground with fine leaf mulch. It improves the fertility of rocky, grave, or hard laterite soils, enriches the soil, and serves to retain humus in deforested areas and checks soil erosion. It can serve to nurse the parasitic sandalwood seedlings and in the Pacific islands has been used as a support for yam vines. *Lantana* leaves and twigs are often used in India as green mulch. The plant is not readily eaten by cattle unless pasturage is very scarce. In tropical countries, the ripe blue black berries are eaten, but ingestion of the green berry has led to human fatalities (Ross, 1999). *Lantana* has been introduced in India through one of the human orchestrated movement of plants which has often been found responsible for movement of plants from their native areasto other countries as introduced ornamental plants (Fig. 1).

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

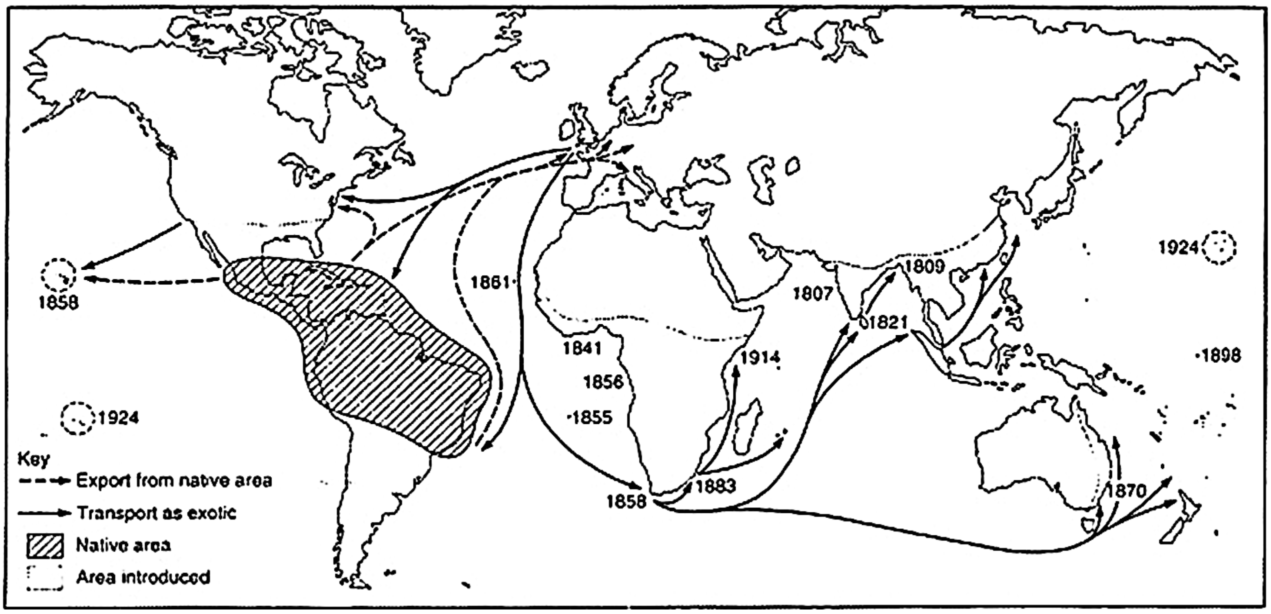

Fig.1 Map showing years of transport and introduction of the woody shrub *Lantana camara*, across the world, from its native countries. Adopted with modification from Cronk and Fuller (1995)

et al., 2005), pH (Kourtev, 2002a), 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). According to the review given by Chatanga, 2007 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, 1997a, Chatanga, 2007). These processes may facilitate ongoing suppression of indigenous species by altering nutrient cycles and modifying microenvironments and disturbance regimes (Van Wilgen and Richardson, 1985). *Lantana* also has negative effect on soil water supply (Hieramath and Sundaram, 2005, Chatanga, 2007).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). 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, understory shrub and herb strata) with *Shorea robusta* as predominant tree species and understory heavily covered by *Lantana camara* and *Chromolaena odorata*.

The studies in different vegetation communities of Indian subcontinent and Australia, which were based on infertile sandstone derived soils, nutrient enrichment was found to be the key factor that facilitates exotic species invasion (King and Buckney, 2002; Lake and Leishman, 2004; Leishman et al., 2004; Leishman and Thomson, 2005; Hill et al., 2005). This was also consistent with the intermittent resource hypothesis of invasibility proposed by Davis et al. (2000). Davis et al. (2000) suggested that a plant community is more susceptible to invasion when there is an increase in the amount of unused resources, such as nutrients. In above mentioned studies it was found that invasion success of plants like *Lantana* in sandstone-based vegetation depends on nutrient enrichment, which occurs mainly through nutrient rich storm water runoff from impervious surfaces, such as roads within a developed catchment, entering the bushland and flowing into the bay systems (Hill et al., 2005). These same anthropogenic influences, roads and nutrient enriched runoff, as well other factors associated with agricultural production, occur in areas of the Doon valley in western Himalaya (Fig. 2). Thus, we might hypothesize that invasion by exotic plants may be facilitated by nutrient enrichment in the valley's vegetation communities also. Alternatively, the naturally more fertile shale derived soil of Doon valley may make it less vulnerable to nutrient facilitated exotic plant invasion.

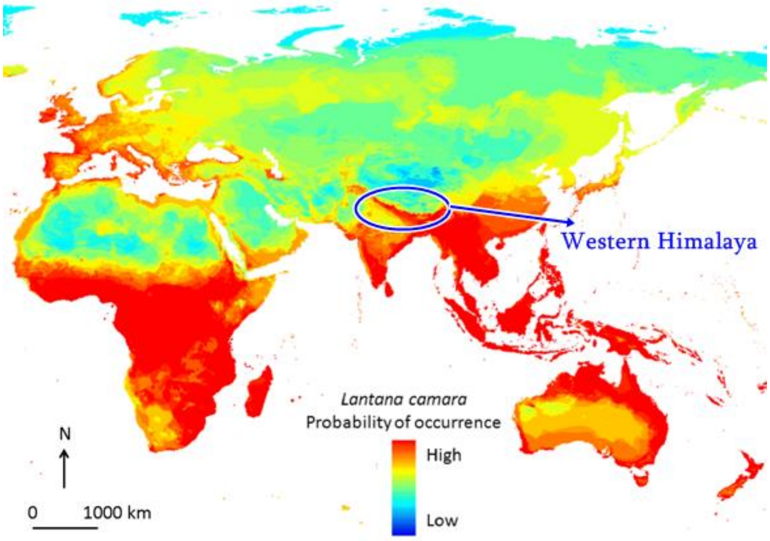

Fig. 2 Bioclimatic niche model of probable *Lantana camara* occurrence generated by automated open Modeller algorithm, adopted and modified from Bhagwat et al. (2012)

The aims of this study were to determine the relative effect of different anthropogenic disturbances in Doon valley on vegetation composition and soil characteristics and to investigate whether there are significant correlations between various soil attributes and the success of exotic woody shrub species *Lantana*. We selected six study sites comprising of three habitat types such as (i) forest (ii) riparian areas (iii) shrub grassland. We measured a range of soil characteristics that are likely to be affected by the invasion of *Lantana* from different habitat types and also the vegetation of these habitats which are likely to be affected due to the infestation of this woody shrub. These were pH, total phosphorus, total potassium, calcium, magnesium, manganese, nitrogen, water retention capacity, organic matter content and electrical conductivity. The specific questions addressed were:

1. What is the effect of *Lantana* invasion on vegetation and soil characteristics from the valley?

2. What is the relative importance of the three habitat types (Forest, riparian area and shrub grassland) for exotic species invasion?

3. Are there consistent relationships between soil characteristics and success of exotic invasives among the disturbance types?

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.*, *Ehretia spp.*, and *Litsea spp.* 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 $2100 km^2$. The Doon valley falls under the sub-tropical to temperate climate due to its variable elevation and is a part of western Himalaya (Fig. 3). The average maximum temperature for the Doon valley was 27.65^0C and the average minimum temperature was 13.8^0C with average maxima in June (40^0C) and average minima in January (1.80^0C). 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 six sampling sites covering all parts of the valley and divided into three habitat types *i.e.*, forest, riparian, shrub grassland (Table 1). To see the level of differences in soil properties we categorised each site into 3 types (i) control (un-invaded site), (ii) moderately invaded sites and (ii) heavily invaded sites of *Lantana*.

Research Methods

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 non invaded, moderately invaded and highly invaded sites, which were obtained and analysed. The soil samples from moderate and highly 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.

Soil chemical analysis

Air dried 2 mm sieve soil samples collected from the two studies were subjected to routine chemical analysis. Total N was determined by micro Kjeldahl approach and available P was determined by molybdenum blue colorimetry. Exchangeable K, Ca and Mg were extracted using ammonium acetate, K was determined on flame photometer while Ca and Mg by atomic absorption spectrophotometer

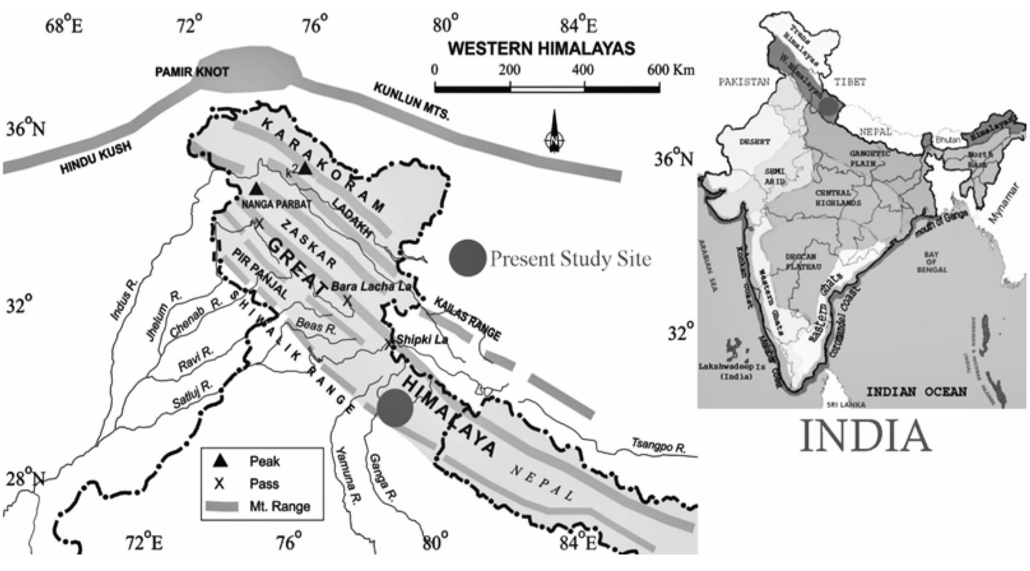

Fig. 3 Map showing western Himalayan part and present study areas (Doon valley) in India

Table 1 Site characteristics of Doon valley with dominant invasive species

Name of the Sites	Dominant species	Point Coordinates	Elevation (m)	Habitat Type
Sahastradhara	*Lantana camara* L. *Adhatoda zeylanica* L. *Parthenium hysterophorus* L.	30^0 23′ 08.17″ N, 78^0 07′ 53.81″ E	889	Riparian areas
Asarori riparian area	*Parthenium hysterophorus* L. *Lantana camara* L. *Ageratum conyzoides* L.	30^0 17′ 10.40″ N, 78^0 03′ 22.27″E	629	Riparian areas
Chandrabani Forest Periphery	*Lantana camara* L. *Opuntia dillenii* Ker Gawl. *Adhatoda zeylanica* L.	30^0 15′ 26.03″ N, 78^0 00′ 29.45″ E	893	Dense forest
Rajpur Forest Periphery	*Lantana camara* L. *Murraya koenigii* (L.) Spreng. *Parthenium hysterophorus* L.	30^0 23′ 02.83″N, 78^0 05′ 09.93″ E	952	Dense forest
Mothronwala	*Parthenium hysterophorus* L. *Lantana camara* L. *Ageratum conyzoides* L *Chromolaena odorata* L.	30^0 15′ 22.81″ N, 78^0 01′ 42.46″ E	532	Shrub Grassland
Jolly Grant	*Lantana camara* L. *Arundinella spicata* Dalzell. *Ageratum conyzoides* L *Parthenium hysterophorus* L.	30^0 11′ 17.16″ N, 78^0 11′ 17.91″ E	561	Shrub Grassland

(Okalebo et al., 1993), pH and electrical conductivity of the soil (soil: water, 1:5) was determined by the help of water analysis Kit (Systronics India Ltd, Gujarat, India). The organic carbon of the soil was determined by Walkley and Black (1934) rapid titration methodas given by Piper (1944). Pearson's correlation matrix, students''t' test and one way ANOVA was calculated to establish the relation between the soil parameters and the measured attributes of lantana. Statistical analysis was done using XLSTAT *V.* 2011 (Addinsoft, Rue Damremont, Paris – 75018, France) for Microsoft Windows.

Biomass calculation

Above ground and fine root biomass (Kg per sq. m.) of large colonies of lantana was recorded, for which plant roots were carefully collected using a 25×25×40 cm soil monolith within the $1m^2$ quadrat. Plant materials such as green material (leaves), dead residues (mulch), and roots collected were oven dried at 60 °C for 72 h and weighed. The location of each site was recorded using a Global positioning system (GPS) device (Garmin 72, Garmin, Olathe, KS, USA).

RESULTS

All the *Lantana* invaded sites including the moderate and high, showed considerable increase in the mean pH value. The maximum range of pH was between 7.12 (±0.40) to 7.22 (±0.24), recorded from shrub grassland type habitat and was about 1.40 % high from other moderately invaded sites of all habitat, minimum pH range was between 5.53 (±0.45) to 6.13 (±0.62), recorded from forest periphery type habitat and was about 10.84 % higher than the other moderately invaded areas (P<0.01). The moderately invaded and highly invaded areas of all the habitats recorded high pH values than the control or non invaded sites of all the habitats (Table 2). The forest peripheries were situated at a comparatively higher altitude than other habitats and were found more acidic than the other two; this was explained perhaps due to fewer disturbances, free from herbivory and high altitude (952 m). The increase in pH value did not show any positive relation with the measured attributes of *Lantana* (ANOVA, P < 0.001). However, both increases and decreases in pH following plant invasion have been equally reported in the literature (Ehrenfeld, 2003). It is not clear whether *Lantana* prefers microsites with elevated soil pH or, in fact, it was responsible for the increase observed in this study. Thus the precise soils require further study, including the contribution of its biomass parts and associated chemical contents to the change. Under the *Lantana* patch only, availability of soil base ions of Ca, P, as well as carbon and EC correlated significantly and positively with increasing pH (r=0.74, 0.69, 0.78, 0.84, respectively; P<0.05, N=30), while S and Fe showed the opposite pattern (r=−0.89, −0.73, respectively; P<0.05, N= 30).

Macronutrients measured in this study (Mg, Ca, K, P and N) showed significant differences between the moderately invaded, highly invaded and un-invaded sites (ANOVA, P < 0.05), except carbon concentrations which did not differ between all sites (ANOVA, P = 0.673) (Table 1). The macronutrients among the different habitat types such as the forest, riverine and shrub grassland habitats also strongly and significantly differed (ANOVA, P < 0.001) except carbon concentrations which did not show significant variations across habitats (ANOVA, P = 0.376). Further, when the possible relationship between the habitat type and invasion pattern was analysed (Si × Ha level interaction), the Ca, K, N and P concentrations were found highly significant (ANOVA, P < 0.001) while Mg and S was found less

Table 2 Mean soil chemical and physical properties by site type. P-values are from t-tests comparing the properties by site type (C.V. stands for coefficient of variation, and is provided as a percentage, SD: standard deviation, NS = Non significant,* P<0.05, *** P≤0.001)

Soil property	Control (Non invaded)			Moderately invaded			Heavily invaded			p value	Site	Habitat type	Si × Ha (interaction level)
	Mean	SD	C.V.	Mean	SD	C.V.	Mean	SD	C.V.				
Bulk Density (gm/cm^3)	0.97	0.16	16.5	1.1	0.15	13.6	1.6	0.23	14.2	< 0.001	***	*	***
CEC ($meq/100cm^3$)	4.9	1.28	26.1	7.8	2.8	35.9	8.1	1.3	34.7	< 0.001	***	***	***
Base Saturation (%)	58	14.52	25	84	11.96	14.2	87	10.22	13.9	< 0.001	***	NS	NS
pH	6.19	0.37	7.4	6.34	0.61	10.3	6.78	0.61	10.3	< 0.001	***	***	***
P (mg/dm^3)	8.7	2.6	29.9	14.9	7.25	54.12	16.34	8.21	55.1	< 0.001	***	***	*
Ca (mg/dm^3)	383	219.68	57.4	936	457.12	45.21	1044	481.88	41	< 0.001	***	***	*
Mg (mg/dm^3)	162	77.74	48	102	43.44	42.6	100	72.13	44.21	< 0.001	***	***	NS
Zn (mg/dm^3)	2.8	1.51	53.9	13.24	15.23	97.6	15.6	16.23	96.33	< 0.001	***	***	NS
Cu (mg/dm^3)	1.1	0.38	34.5	3.8	2.68	70.5	3.98	2.78	73.21	< 0.001	***	***	NS
Fe (mg/dm^3)	703	3.12	24.5	531	3.66	28.8	459	3.68	28.8	< 0.001	***	***	NS
Na (mg/dm^3)	19	4.03	26.9	17	4.23	42.2	16	3.21	42.2	< 0.001	***	***	***
Mn (mg/dm^3)	52.4	27.08	51.7	42.18	15.33	37.43	38.7	14.15	36.6	< 0.001	***	***	***
Humic Matter (%)	0.38	0.11	28.9	0.32	0.21	65.6	0.32	0.21	65.6	< 0.001	***	***	*
Weight per volume (g/cm^3)	1.02	0.07	6.9	1.04	0.1	9.6	1.04	0.1	9.6	< 0.001	***	NS	NS
K (mg/dm^3)	62	24.29	39.2	66	25.75	39	66	25.75	39	< 0.001	***	***	*
S (mg/dm^3)	18	3.75	26.8	15	2.67	67.9	13	2.06	67.9	< 0.001	***	*	NS
Clay (%)	17.12	4.49	44.9	16.33	5.86	53.3	15.88	5.86	53.3	< 0.001	***	NS	NS
Sand (%)	46.12	9.65	13.1	48.11	12.08	16.7	49.21	12.08	16.7	< 0.001	***	NS	NS
Silt (%)	37.13	6.78	40.01	35.79	8.21	48.6	35.34	8.21	48.6	< 0.001	***	***	NS
Lantana cover (%)	0 (± 2.92)			35 (± 2.01)			85 (±3.01)			< 0.001			

significantly different (ANOVA, P = 0.028; P = 0.039, respectively). Carbon concentration was not significantly different (ANOVA, P=0.395) with regard to the interaction level of site and habitat (Si × Ha) interaction. Except for silt which was not significantly different between highly invaded, moderate and un-invaded sites (ANOVA, P=0.966), the values of pH, conductivity, sand and clay recorded significant differences at site level interaction (ANOVA, P < 0.05) but they were non significant when calculated for both site versus habitat level interaction (ANOVA, P=0.452) (*Table 2*). On the other hand, pH, conductivity, sand and silt recorded strong significant variations across the forest, riparian and shrub grassland habitats (ANOVA, P < 0.001) while clay recorded less significant difference (ANOVA, P=0.237). At the invasion verses habitat interaction level (Si × Ha level interaction), significant differences were recorded in pH (ANOVA, P≤ 0.05) while across sites, conductivity, sand, silt and clay did not vary significantly (ANOVA, P > 0.05). The macronutrient concentrations of Mg, Mn, P, N Ca and K measured in this study were also found to be higher in heavy invaded sites than moderate and un-invaded ones (Table 2). The ANOVA results also supported this findings that plots from where the neighbouring plants were removed and only left with *Lantana*, 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 grow (ANOVA, P < 0.001) (Table 3). Species diversity and richness varied significantly among the three levels of *Lantana* infestation as revealed by the Shanon Wiener Index of diversity (H') and species richness (S) [F=9.982, P<0.05, F=24.33, P<0.05 respectively]. The un-invaded category had the highest species diversity and species richness followed by the moderately invaded and highly invaded.

The Principal Component Analysis (PCA) of all the soil parameters and the calculated attributes of *Lantana* are shown in (Fig. 4) 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 first principal component was related to K, N, Ca, pH and sand while the second principal component was mainly related to conductivity, silt and soil pH. The PCA shows that soil parameters like pH, available P and K, represent ne-

Table 3 Two way ANOVA results for the vegetation characters, disturbance types and soil properties. (df = Degrees of freedom, F = Fisher's statistic value , P value = null hypothesis)

Factor	**Variables**	**d.f.**	**F**	**P value**
Habitat type	Native species richness	3, 32	22.45	<0.001
	Exotic species richness	3, 32	63.98	<0.001
	percentage cover of native species	3, 32	55.38	<0.031
	Percentage cover of *Lantana*	3, 32	23.33	<0.001
	Lantana density (ha^{-1})	3, 32	19.46	<0.001
	Lantana height	3, 32	18.55	<0.001
Disturbance type	Native species richness	3, 32	4.89	<0.013
	Exotic species richness	3, 32	13.55	<0.001
	percentage cover of native species	3, 32	5.89	<0.001
	Percentage cover of *Lantana*	3, 32	30.12	<0.021
	Lantana density (ha^{-1})	3, 32	23.34	<0.001
	Lantana height	3, 32	20.03	<0.005
Soil properties	Native species richness	3, 32	34.22	<0.001
	Exotic species richness	3, 32	56.34	<0.001
	percentage cover of native species	3, 32	49.56	<0.001
	Percentage cover of *Lantana*	3, 32	31.24	<0.002
	Lantana density (ha^{-1})	3, 32	23.22	<0.001
	Lantana height	3, 32	15.35	<0.001

gative correlation with other soil parameters (r = –0.042 with P, 0.109 with K, –0.009 with N and 0.0624 with C). The analysis revealed that the principal components were sufficient in explaining the variation of the soil properties between the highly invaded, moderate and un-invaded sites in Doon valley. After correlation, the results were subjected to an ordination biplot, which revealed that the sites separated into clusters based on the sites and their measured properties. Many of the macro nutrients ratio were showing negative correlation with different calculated attributes but total nitrogen and carbon contents were represented as the key factor for deciding the different shrub attributes and thereby contributing strongly in the total shrub level biomass calculation.

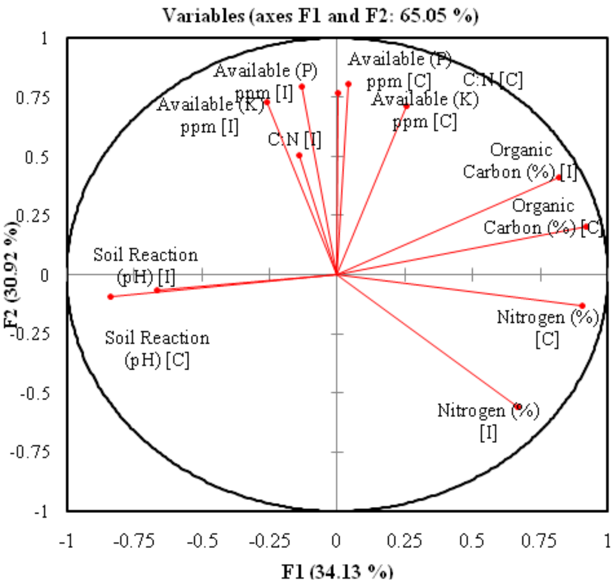

Fig. 4 PCA ordination for soil properties from different habitats (I = invaded sites, C = control or un-invaded sites)

DISCUSSION

The moderately invaded plots and the highly 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 moderate and no invasion areas differ significantly from the highly invaded areas except few. It should also be noted that *Lantana* patches are incessantly escalating in Doon valley but other opportunistic species such as *Chromolaena odorata*, *Parthenium hysterophorus*, *Cassia tora*, *Cassia occidentalis*, *Urena lobata*, *Ipomoea carnea*, *Sida acuta* and *Solanum torvum* and their growth is still restricted to some specific areas and specific geographical conditions. The pH amongst other parameters was found to be a significant factor deciding only the coverage of *Lantana*. In shrub grassland and riverine areas, we found that pH is slightly less acidic to neutral and recorded a little difference between moderate invasion and high invaded sites. However, the less acidic condition favoured *Lantana* to grow better in these habitats than the forest (site data of this study). The density of *Lantana* in shrub grassland was found highest (21,800 ha^{-1}) with a maximum biomass of (1.356 Kg m^{-2}) followed by another highly disturbed area the riparian zone 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 highly invaded sites and even from the moderately invaded sites were found to have a strong positive correlation with the coverage and total shrub density (r= 0.89). The similar change had been recorded from a dry deciduous forest of India (Sharma and Raghubanshi, 2011).

All the moderate and highly invaded areas showed the elevation in soil macronutrients including N, P, K, Ca, Mg, Mn, and took up about twice as much of these macronutrients per unit area as the native plants. This may explain the higher proportion of these above mentioned soil macronutrients fraction in invaded patches. The availability of these macronutrients in the highly invaded soil was recorded much higher than their control *i.e.,* non invaded sites, this clearly indicates that *Lantana* invaded areas have more N, P, K, Ca, Mg, Mn, than less invaded or the places where *Lantana* infestation is negligible and surely this increased level of these macronutrients strongly favoured in increasing their coverage and biomass.

Different attributes like plant height, stem diameter, canopy area and phytovolume were also found directly related to the availability of SOC and total N. Soil organic carbon (SOC) and the total Nitrogen (N) had a direct impact in determining the coverage of *Lantana* and biomass (Table 4). An increase in soil organic carbon (SOC) content under stands of invasive plants had been reported in many previous studies (Fickbohm and Zhu, 2006; Heneghan et al., 2006), and had 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 considerably increased in all the highly invaded sites from all habitat types. The increase in nitrogen and phosphorus levels with increase in *Lantana* intensity could be due to de-

Table 4 Summary of regression analysis 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	0.032
	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	0.001
	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	0.091
	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	0.102
	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	0.001
	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	0.024
	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^{-1})	Between Groups	633273.41	1	633273	134.029	0.001
	Within Groups	66148.655	14	4724.9		
	Total	699422.06	15			
Organic Carbon (%)*Vs* Canopy Coverage (ha^{-1})	Between Groups	627398.29	1	627398	132.778	0.021
	Within Groups	66152.539	14	4725.18		
	Total	693550.83	15			
Organic Carbon (%) *Vs* Phytovolume (m^3ha^{-1})	Between Groups	5.669324	1	5.74352	55.1941	0.011
	Within Groups	1.438345	14	1.26653		
	Total	7.107233	15			
Nitrogen (%)*Vs* Phyto-volume (m^3ha^{-1})	Between Groups	5.669234	1	5.73442	55.1958	0.021
	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	0.011
	Within Groups	5.2630903	14	0.37594		
	Total	16.063798	15			

crease 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 the reason for elevated nitrogen and phosphorus levels in all invaded sites (findings of this study). These findings are consistent with some 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 riparian areas with highest average *Lantana* height, average stem diameter and the lowest was recorded from shrub grassland type habitat which was from 0.98 (±0.47) to 1.28 (±0.23) with an average *Lantana* height of (210cm). These two attributes were found very strong factors in the biomass calculation of shrub (r=0.88) when analysed in the regression model in some studies (Mandal and Joshi, 2014). Plant height was not found significantly correlated with the availability of SOC (%) and total N (%) (r=0.47) and (r=0.57) respectively, but when biomass as a whole taken into account these two soil parameters gave a strong positive correlation (r=0.91) and (r=0.92) respectively (Mandal and Joshi, 2014).

In forest habitat the height of the shrub was found unexpectedly higher than other habitats, this was explained 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 forest areas it competes with the native trees in order to get more sunlight, this finding was also supported by the earlier study conducted by Sharma and Raghubanshi (2011). Both SOC (%) and total N (%) showed very strong positive correlation while taken as a variable to measure the crown diameter of *Lantana* (r=0.94) and (r=0.98) respectively. 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.

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 riparian habitat recorded maximum coverage and biomass of *Lantana* followed by grass land and forest habitat. The reason for riparian habitat 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 these habitats from control to heavy infested areas. Soil nitrogen, soil organic carbon, phosphorus and potassium levels increased with increase in *Lantana* density. 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 (Hobbs and Mooney, 1991).

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 (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, 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, 1990a), 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. 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. With increased growth rate, lantana propagates splendidly, which, as verified in this study results into changes in species composition and soil properties.

The structural design of *Lantana* growth is such that it prevents light penetration to the ground. Resulting in noticeable heterogeneity in terms of light availability beneath the *Lantana* bush and affects species diversity underneath its canopy (Fig. 5). Light availability on the forest floor has already been recognized by many researchers as a key factor that influences fundamental character in propagating exotic species (Jones et al., 1994; Walters and Reich, 1996). The dense cover created by upright stratification of *Lantana* may reduce the strength or duration of light under its canopy and thus decrease the cover of plants specially the herbs. This could be explained due to the formation of a light regime which is photosynthetically inactive and situated at ground level (Fetcher et al., 1983; Turton and Duff, 1992). It is most likely that herbs are directly influenced by the amount of light reaching to the forest floor, and due to the non availability of light to the ground level because of heavy *Lantana* invasion in many habitats especially the riparian habitat the herbaceous cover is declined. This could also be the possible reason in the decline of tree seedlings and the herb flora, this finding was advocated by the findings of Sharma and Raghubanshi (2006, 2007). The current results are also in agreement with (Ehrenfeld, 2003) who documented that soil moisture can either increase or decrease following invasion. These findings where *Lantana* was foundreducing moisture levels are also consistent with the findings by Hiremath and Sundaram (2005) who found that *Lantana* affects water supply negatively.

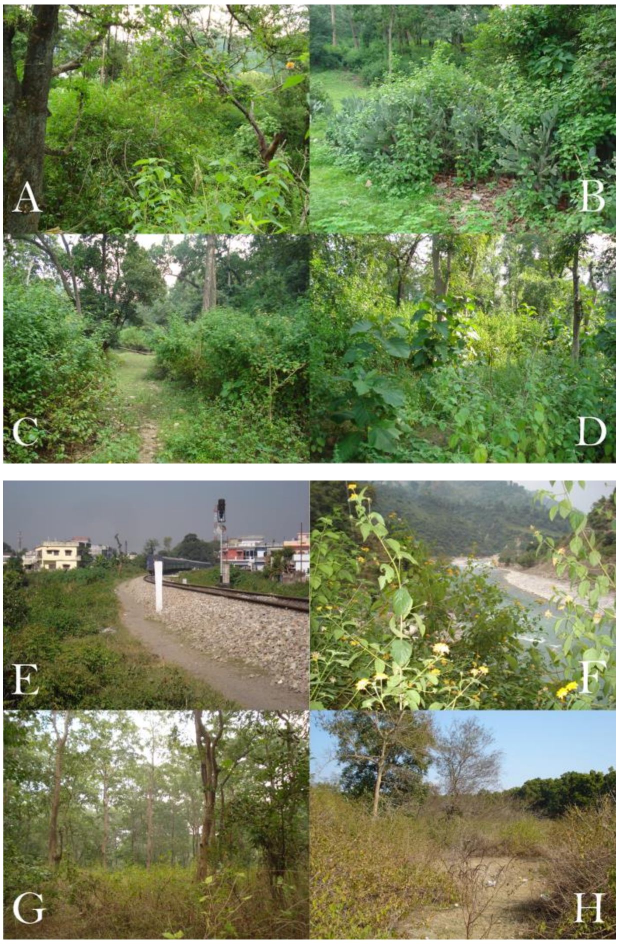

Fig. 5 Photos of *Lantana camara* taken from the different habitats chosen for this study. [The letters represent different habitat types, such as A, B & C= Forest peripheries, D & E = Shrub grassland and F, G & H = Riparian habitat]

CONCLUSIONS

The present study had 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. In conclusion it is clear from the present findings of this study and the past literature that the invasion of all three habitats including forest communities, riparian areas and the shrub grassland by woody plant invaders, such as *Lantana camara*, adversely affects the vascular plant species diversity by reducing species richness and abundance, in turn altering species compositions. There is also a remarkable change in the soil nutrient property in all the highly invaded areas of Doon valley from its adjacent areas which are either moderately invaded or not invaded by *Lantana*, this change is not only maximizing the uptake of these soil macronutrients by other opportunistic species but also favouring the further utilization of these nutrients by *Lantana* for its own growth. Administration and management of *L. camara* can diminish such adverse effects by facilitating the establishment of native juvenile species to increase species richness. However, management cannot restore species compositions, at least in the short term unless we understand the right factors that influence the distribution of *Lantana* and also initiate continuous monitoring of native forest regeneration following plant invader management, which can prevent secondary weed invasion and indicate whether long term habitat restoration can occur.

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