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Impact of *Lantana camara* L. invasion on soil properties in Nagarahole Tiger Reserve

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Abstract
Lantana camara L. is a woody straggling shrub native to tropical America, it is known as one of the 100 worst weeds in the World by the Invasive Species Specialist Group and has been introduced into other countries as an ornamental or hedge plant. It is a very hardy shrub, growing luxuriantly at elevations up to 2000 m in tropical, subtropical and temperate parts of the world. The Western Ghats in Southern India is one of the twelve mega biodiversity centres in the world and has rich biodiversity for its fauna and flora. Lantana has dispersed to tropical forests and created significant damage to forests by altering native plant diversity and nutrient cycling process. The present study was carried out to assess the effect of Lantana invasion on soil properties at two locations of Nagarahole Tiger, Karnataka, India. Four different levels of lantana infestation that is, highly infested, moderately infested, lantana uprooted areas and areas without lantana infestation were considered for the present study. 15 quadrates of 20 m ×20 m was laid randomly in each of these categories. Four soil samples were randomly collected at 0-15 cm and 15- 30 cm depths, and a composite sample was made and analyzed for different physicochemical properties. Maximum soil moisture content, bulk density, pH and electric conductivity were observed in highly infested areas but the percentage of organic carbon and organic matter was highest in non-infested areas. From the study, it is evident that soil in and around lantana infestation has an influence of adverse effect of lantana. The present investigation can be used as baseline data for future management of Lantana with essential details about infestation of the species.

Keywords: *Lantana camara* L., soil properties, Nagarahole Tiger Reserve

Introduction
The Western Ghats in Southern India is one of the twelve mega biodiversity centers in the world and has rich biodiversity for its fauna and flora. Lantana has dispersed to tropical forests and created significant damage to forests by altering native plant diversity and nutrient cycling process. Lantana is a very hardy shrub, growing luxuriantly at elevations up to 2000 m in tropical, subtropical and temperate parts of the world (Holm *et al.*, 1977) [5]. The plant can propagate rapidly by means of stumps or cuttings but the natural propagation appears to be from seeds disseminated by birds through their droppings. In India, Lantana has been recorded from the Central Himalayas in the north to the southernmost part of India and has displaced several native species (Bhatt *et al.*, 1994) [1]. It has invaded about 13.2 million ha in Indian pasture lands besides forest and fallow areas. Lantana is widely distributed in the tropical and sub-tropical zones including the protected forest areas of India. In some places, it has also entered in the temperate zones (Kimothi *et al.*, 2010) [7]. In the Western Ghats also, two species are reported *viz*., Lantana camara found wild in south Madras or near hills, Palani Mountain and courfallum in the Western Ghats and *L. camara aculata* (1891) [9] species has extensively used as a hedge plant in Bangalore (Kannan *et al.*, 2013) [6], then they occupied all habitats of forests, reported as the first identified species of Lantana in Western Ghats. *Lantana camara* L. is a woody straggling shrub native to tropical America, it is known as one of the 100 worst weeds in the World by the Invasive Species Specialist Group and has been introduced into other countries as an ornamental or hedge plant. The species belongs to the family Verbenaceae and is known as wild sage or red sage. The East India Company first introduced it at Royal Botanical Garden, Calcutta in 1807 as an ornamental plant soon after its introduction it started to spread across all the parts of India over the wastelands, railway tracts and also the tropical forests. Reports of the rapid spread of lantana began appearing in the early part of the 20th century in several parts of the country. It adapts to varied habitats ranging from open, unshaded areas, such as pastures and crop fields to disturbed areas, such as roadside, railway tracks, and fired forests (Nagouchi and Kurniadie, 2021) [8].

Today Lantana is, a common invader of dry forest landscapes, slash-and-burn fallows and pasture lands all over India. *L. camara* displays high morphological variation because of extensive breeding. The genetic diversity of the *L. camara* population is high. The species has diploid, triploid tetraploid and pentaploid varieties. Different ploidy levels are of ecological significance in the invasive potential of the species (Sharma *et al.*, 2005) [11]. In Nagarahole Tiger Reserve also *Lantana camara* has spread in almost all parts of the reserve, though the department is taking up several measures like manual removal, burning the invasive species. But it has made its own way of infestation, causing threats to local natural diversity. With this background, the present study was carried out to through light on effect of Lantana invasion on soil functions in Nagarahole Tiger reserve.

Materials and Methods

The study was mainly focused on the effect of infestation of *L. camara* in the Nagarahole Tiger Reserve (Fig 1). The total geographical area of the reserve is 843.96 sq km, located in the Kodagu and Mysore districts of Karnataka, India. It is a part of the Nilgiri Biosphere Reserve. It lies between the latitudes 11^0 58′ 25.75″ N and longitudes 76^0 12′7.99″ E. The area receives 1000 to 1540 mm annual rainfall favors the area to have high humidity with a temperature ranging between 12 °C and 32 °C, elevation of the park ranges from 687 to 960 m. According to the Champion and Seth's classification (1968), the vegetation of Nagarahole Tiger Reserve has been broadly classified into four types includes, Southern Tropical Semi-evergreen forests (2A/C3), Southern Tropical Moist deciduous forests (sub group 3B type 3B/C3), Southern Tropical Dry deciduous forests (Group 5, Subgroup 5A/C3), Scrub Forests. The forest types found within the tiger reserve follow the decreasing elevation and level of precipitation from west to east.

Based on the preliminary survey, it was noticed that *L. camara* populations were found high in the Antharasanthe and Kallahalla ranges. Thus, the present study was conducted in these two ranges of Nagarahole Tiger Reserve, *viz.*, Antharasanthe (total area is 85.96 sq. km.) consists of dry deciduous forest and Kallahalla (total area is115.15 sq. km.) consists of moist deciduous forest. These areas were divided into highly infested, moderately infested, uprooted and non-infested areas based on cover/density of *L. camara*.

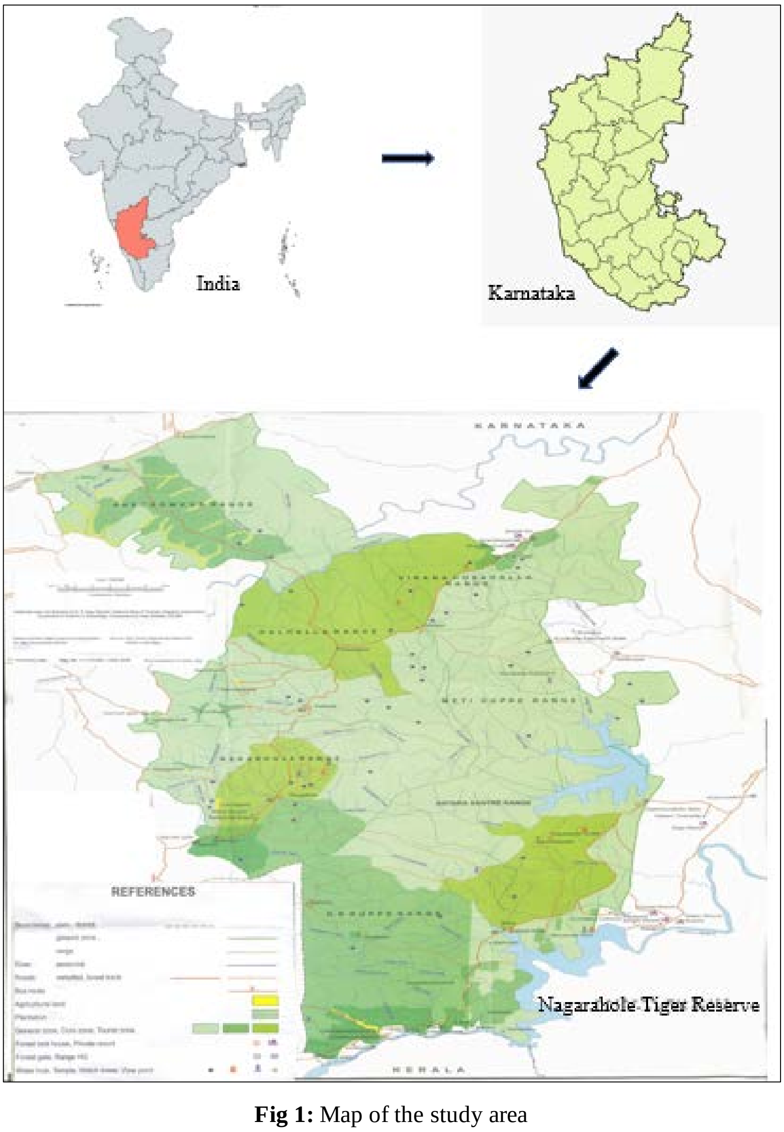

Fig 1: Map of the study area

Detailed methodology

A preliminary survey was conducted to collect information about the infestation level. Based on the cover of *Lantana camara*, infestation levels were grouped into different Categories and a stratified random sampling technique was Adopted with different levels of infestations as different strata. The quadrates having 60-80% Lantana cover was categorized as highly infested, 40-60% as moderately infested, areas with no Lantana cover were considered as non-infested area and the areas where uprooting of Lantana was done two years before was considered as uprooted area. In each stratum/category, 15 quadrates of 20 m ×20 m were laid randomly in the reserve's dry deciduous and moist deciduous forests. In each of the main quadrates, four soil samples at 0-15 cm depth and 15- 30 cm depth were collected randomly and the composite sample was prepared. The composite samples were air dried at room temperature. Soil samples were analyzed for pH, electric conductivity, percentage of organic matter and available organic carbon by adopting standard procedures.

Soil analysis

1. Moisture content (%)

Soil normally contains a finite amount of water, which can be expressed as the soil moisture content. Moisture content can be measured by subtracting the weight of the dry soil from the weight of the moist soil, and then dividing by weight of the dry soil and it was expressed in percentage

$$\text{Percent Moisture} = \frac{\text{weight of moist soil} - \text{weight of oven dry soil}}{\text{weight of oven dry soil}} \times 100$$

2. Bulk density (g cc^{-1})

This was done using the core sampling and gravimetry method (5 cm diameter). The samples were then placed in an airtight container and oven dried at 105℃ until the constant weight was obtained in the laboratory. Then the bulk density was determined by dividing the weight by the sample volume and expressed as gram per cubic centimeter.

$$\text{Bulk Density (g cc}^{-1}\text{)} = \frac{\text{Dry Weight of the soil}}{\text{Volume of the soil}}$$

3. PH (Hydrogen ion concentration)

The soil pH values were determined by using a glass electrode digital pH meter with a soil and water ratio of 1:2.5. Ten grams of sieved, air-dried soil sample was taken in a 50 ml beaker and 25 ml of water was added. It was stirred at a regular interval of half an hour. It was then allowed to settle for half an hour. The residue was taken for pH measurement. The pH meter was standardized by using pH 4 and 7 buffer solutions.

4. Electrical conductivity (dSm^{-1})

The soil electrical conductivity (EC) measures the number of salts in soils (soil salinity) directly related to its specific conductance. The EC of the soil samples was determined in 1:2.5 soil water suspension with an electric conductivity meter, respectively by adopting a standard procedure given by (Gliessman, 2000).

$$\text{Electric conductivity (dS m}^{-1}\text{)} = \text{Observed conductivity} \times \text{Cell constant}$$

5. Organic carbon (%)

The organic carbon was estimated by using Walkley- Black method. One gram of sieved, air-dried soil sample was taken into a dry 500 ml conical flask. Ten ml of 1 N $K_2Cr_2O_7$ was pippeted into it and swirled a little. The flask was kept on an asbestos sheet. The 20 ml of concentrated sulphuric acid was again added and swirled 2-3 times. The conical flask was allowed stand for 30 minutes. After that, 200 ml of distilled water was added to terminate the reactions. Then 4-5 drops of ferroin indicator were added. The content was titrated with ferrous ammonium sulphate solutions until the dark green to chocolate brown colour was illuminated intermittently.

$$\text{OC\%} = \frac{(BTV - STV) \times N\ of\ FAS \times 0.003}{Weight\ of\ Soil\ sample} \times 100$$

$$\text{OM\%} = \%\text{OC} \times 1.724$$

OC: Organic carbon
OM: Organic matter
BTV: Burette reading of blank
STV: Burette reading with the soil
N of FAS: Normality of Ferrous Ammonium Sulphate

Data Analysis

The data obtained on soil properties like pH, electric conductivity, bulk density, organic carbon was subjected to the one-way ANOVA to understand the variation among different infestation levels among the locations.

Results

Soil physicochemical properties varied significantly across locations as well as across different depths. The soil moisture content varied significantly among the different levels of infestation. The highest moisture content was recorded in a highly infested areas followed by non-infested areas in both vegetation types (Table 1). The mass per unit volume of dry soil was calculated for all the soil samples and expressed in grams per cubic centimeter. The bulk density varied significantly across all the infestation levels. The soils of highly infested areas recorded more bulk density with less pore space in the dry deciduous forest. Whereas in the moist deciduous forest, higher bulk density was observed in non-infested areas followed by highly infested areas (Table 2). The hydrogen ion concentration was analysed for all the soil samples for different levels of infestation. All the infestation levels recorded acidic soil pH ranging from 6 - 6.3 except for the highly infested areas of dry deciduous forest where it had a neutral pH of 6.61-6.65 (Table 3).

Table 1: Moisture content (%) under different infestation levels of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous		Moist deciduous	
	0-15	**15-30**	**0-15**	**15-30**
Highly infested	11.54	12.75	3.46	4.01
Moderately infested	8.02	8.17	3.39	4.82
Uprooted	8.11	8.69	2.84	3.15
Non-infested	9.28	9.84	1.92	2.37
SEm	0.79	1.01	0.43	0.38
CD (p=0.05)	2.33*	3.01*	1.26*	1.12*

Table 2: Bulk density (g cc^{-1}) under different infestation levels of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous		Moist deciduous	
	0-15	**15-30**	**0-15**	**15-30**
Highly infested	1.14	1.16	1.12	1.11
Moderately infested	1.02	1.01	1.01	1.04
Uprooted	0.92	0.92	1.08	1.13
Non-infested	0.86	0.86	1.18	1.25
SEm	0.04	0.05	0.04	0.03
CD (p=0.05)	0.13*	0.14*	0.12*	0.09*

Table 3: Soil pH under different infestation levels of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous		Moist deciduous	
	0-15	15-30	0-15	15-30
Highly infested	6.65	6.61	6.15	6.15
Moderately infested	6.51	6.38	5.98	5.96
Uprooted	6.46	6.57	6.03	6.21
Non-infested	6.41	6.45	5.76	5.80
SEm	0.08	0.11	0.12	0.11
CD (p=0.05)	0.24	0.32	0.34*	0.33

Electric conductivity (EC) was expressed in ds m^{-1} for the soil samples. The electric conductivity varied significantly among different levels of infestation in dry deciduous forest. Highly infested as well as uprooted areas recorded the highest electric conductivity indicating high salinity in Lantana-infested areas (Table 4). The organic matter content of the soils differed significantly across locations and different infestation levels. Among different infestation levels, non-infested areas recorded the highest organic matter followed by uprooted areas. In the dry deciduous forest of the Antharasanthe range, the highest percentage of organic matter was found in the non-infested areas (6.15%) followed by uprooted areas (6.05%) at 0-15 cm depth, whereas in 15-30 cm depth also it was observed that, the maximum percentage of organic matter was observed in non-infested areas (5.80%) followed by uprooted areas (5.56%). At 0-15 cm depth, the highest percentage of organic matter was recorded in the non-infested areas (4.65%) followed by uprooted areas (4.62%). At 15-30 cm depth, the maximum percentage of the organic matter was recorded in the non-infested areas (4.57%) followed by the moderately infested areas (4.52%) in the moist deciduous forest of Kallahalla. In both dry deciduous and moist deciduous forests, the non-infested areas recorded the highest percentage of organic matter (Table 5). The percentage of calculated organic carbon differed significantly across different levels of infestation in both locations. The highest organic carbon percentage was observed in the non-infested areas followed by uprooted areas. In the dry deciduous forest of Antharasanthe, the highest percentage of organic carbon was observed in the non-infested areas (3.57%) at 0-15 cm depth followed by uprooted areas (3.51%) at 0-15 cm depth. Whereas, at 15-30 cm depth also a maximum percentage of organic carbon was observed in the non-infested areas (3.37%) followed by uprooted areas (3.23%).

Table 4: Electric Conductivity (ds m^{-1}) under different infestation levels of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous		Moist deciduous	
	0-15	15-30	0-15	15-30
Highly infested	0.18	0.17	0.11	0.10
Moderately infested	0.09	0.09	0.12	0.09
Uprooted	0.12	0.08	0.17	0.11
Non-infested	0.10	0.10	0.14	0.13
SEm	0.02	0.02	0.04	0.02
CD (p=0.05)	0.07*	0.05*	0.13	0.06

Table 5: Organic matter (%) under different infestation levels of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous		Moist deciduous	
	0-15	15-30	0-15	15-30
Highly infested	5.15	5.06	4.46	4.40
Moderately infested	3.7	3.12	4.52	4.52
Uprooted	6.05	5.56	4.62	4.40
Non-infested	6.15	5.80	4.65	4.57
SEm	0.45	0.52	0.40	0.35
CD (p=0.05)	1.35*	1.53*	1.18	1.04

Table 6: Organic Carbon (%) under different infestation levels of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous		Moist deciduous	
	0-15	15-30	0-15	15-30
Highly infested	2.99	2.94	2.65	2.59
Moderately infested	2.18	1.81	2.62	2.62
Uprooted	3.51	3.23	2.68	2.55
Non-infested	3.57	3.37	2.70	2.56
SEm	0.26	0.30	0.23	0.20
CD (p=0.05)	0.78*	0.89*	0.68	0.60

In the moist deciduous forests, the highest percentage of organic carbon was observed in the non-infested areas (2.7%) followed by uprooted areas (2.68%) at 0-15 cm depth. But at 15-30 cm depth, the highest percentage of organic carbon was observed in moderately infested areas (2.62%) followed by highly infested areas (2.59%). Organic carbon is a derived parameter from organic matter and hence it showed a similar trend as that of organic matter (Table 6).

Discussion

The increase in the growth rate of the Lantana leads to changes in species composition and soil properties. Raghubanshi (1992) [13] reported a strong positive relation between total nitrogen content and organic carbon content of the soil in the dry deciduous forest ecosystem of India. *Lantana camara* will modify the soil's biological properties either by retention of allelochemicals or the production of plant secondary metabolites in the rhizosphere of different forest ecosystems. Ehrenfeld (2003) [4] clearly showed that exotic plant invasions can greatly alter ecosystem processes. But the invasion may result in increase, decrease or no difference between the exotic plant species and the indigenous species in any of the soil nutrient variables (Debnath and Debnath, 2018) [3]. Dassonville *et al.* (2011) [2] highlighted the importance of site as a most important source of variation in the impacts of alien invasive species on soil nutrient pools. Shackleton *et al.* (2016) [10] reported that, the gravimetric soil moisture content was higher in the *L. camara*-invaded sites than in the uninvaded sites. Moisture content was significantly higher in *L. camara*-infested patches (Osunkoya and Perrett, 2010) [9]. Debnath and Debnath (2018) [3] reported higher moisture content in non-invaded natural sites than in the invaded sites of *Chromolaena odorata* at Tripura. Sharma and Raghubanshi (2006) [12] reported that *L. camara* biology promotes that it can hold water for a longer time. Similar results were obtained in the present study, where the soil moisture content varied significantly among the different levels of infestation. The highest moisture content was recorded in a highly infested area, followed by a non-infested area in both locations.

Bulk density showed a significant difference across all the infestation levels. In moist deciduous forests, the non-infested area had more bulk density followed by highly infested areas, where the movement of wildlife will be high making the area more compact with less pore space. Contrasting to the expectation, in dry deciduous forest, the highly infested areas recorded more bulk density with less pore space. Debnath and Debnath (2018) [3] showed no significant differences among invaded and non-invaded sites of *Chromolaena odorata*. The bulk densities were higher in all the three strata of *Chromolaena odorata* invaded sites of Atharamura forest of Tripura.

There was no significant difference in pH among the different vegetation types. In all the infestation levels pH was acidic ranging between 6 – 6.3 except for the highly infested areas of the dry deciduous forest where it had a neutral pH of 6.61-6.65. Presence of high Lantana will enhance the pH. Similar results were reported for *L. camara* infested soils in Australia. The higher soil pH was found in Lantana invaded sites compared to noninvaded sites (Osunkoya and Perrett, 2010) [9]. A supporting study by Shackleton *et al*. (2016) [10] showed that the soils in Lantana invaded and uninvaded sites were generally acidic, with an average pH of 5.9 ± 0.1 in the *L. camara*-invaded sites and 5.6 ± 0.2 in the natural sites, with no significant difference between the two sites of South Africa.

From the present study, it is evident that electric conductivity varied significantly among different levels of infestation for the dry deciduous forest, whereas the results on electric conductivity did not show any significant difference between the infestation levels for the moist deciduous forest. Highest EC was recorded for highly infested and uprooted areas followed by non-infested areas. It indicates that, the biology of Lantana will affect the soil's salinity, leading to an increase in the electric conductivity of soils. Osunkoya and Perrett (2010) [9] also showed that no significant difference among Australia's Lantana invaded and non-invaded sites Debnath and Debnath (2018) [3] reported that soil conductivity was higher in both the non-invaded sites of lower and middle strata respectively while is higher in invaded site of top strata of *Chromolaena odorata.*

Sharma and Raghubanshi (2006) [12] reported that L. *camara* biology promotes the accumulation of litter under the shrub, resulting in a buildup of organic carbon and nitrogen and can also hold water for a longer time. Contrasting results obtained from the present study, among different infestation levels, non-infested areas recorded the highest organic matter and organic carbon, followed by uprooted areas. Ehrenfeld (2003) [4] documented both increase and decrease in organic carbon in exotic invasives. Invasives will modify soil carbon and nutrient pools but the direction and magnitude of the impacts were determined by the composition of the invasive species and soil properties. The role played by the secondary plant compounds of exotics in mediating changes in litter dynamics is completely unknown. The mechanisms causing these differences in decomposition, may include differences in size, degree and mode of vegetative spread, tissue chemistry and root distribution. Windham and Lathrop (2003) [14] stated that differences in litter mass or the litter decomposition rate are not always accompanied by changes in soil organic carbon dynamics. Soils within *L. camara* patches had greater air-dried water content, higher organic, and total carbon, higher exchangeable calcium, and higher pH than soils from adjacent vegetation lacking the weed in Australia. *L. camara* can improve soil fertility and influence nutrient cycling, making the substratum ideal for its own growth and competing with other indigenous species (Osunkoya and Perrett 2010) [9]. Debnath and Debnath (2018) [3] showed that total carbon and organic matters are higher in the non-invaded sites of *Chromolaena odorata* than the invaded sites at Tripura.

Conclusion

Maximum soil moisture content, bulk density, pH and Electric conductivity were observed in highly infested areas but percentage of organic carbon and organic matter was highest in non-infested areas. The present investigation can be used as baseline data for future management of Lantana with essential details about infestation of the species. Based on the present study, management plan can be made for removal of Lantana through different ways in the future. Value addition of uprooted Lantana can be taken up to improve the livelihood of local tribal communities. A long-term study can also be taken up to see the impacts of Lantana and its removal on floristic diversity and regeneration over a time scale by establishing permanent plots.

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