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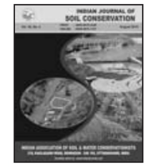

Impact of *Lantana camara* Linn. invasion on plant diversity, vegetation composition and soil properties in degraded soils of lower Himalayan region, India

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ABSTRACT

Lantana camara, introduced in north India in 1850 has acclimatized in the region and is now considered as the abnoxious weed. The study was carried out in lower Himalayan region of India to see the impact of *L. camara* on plant diversity and soil fertility. Four different sites having varying lantana invasion status *i.e., L. camara* alone (Complete invasion - CI); *L. camara* + *Dalbergia sissoo* (Medium invasion - MI); *L. camara* + Local shrubs + *D. sissoo* (Partial invasion - PI) and local shrubs + *D. sissoo* (No invasion - NI) were selected. It was found that Importance Value Index (IVI) of *Murraya koenigii* was 80.49 at sites with no invasion, which decreased to 48.84 in partially invaded sites. Increase in biomass of Lantana to decrease in the biomass of indigenous species (*M. koenigii* and *Justicia adhatoda*) from 561 and 713 kg ha^{-1} in uninvaded area to 392.5 and 596 kg ha^{-1} in partially invaded sites, respectively. Soil bulk density decreased and pore space increased as the invasion of Lantana increased. Bulk density at uninvaded sites was 1.60 and it decreased to 1.25 at Complete Invasion sites. Soil Organic Carbon (SOC) content was much higher in completely Lantana infested sites (1.37%) followed by uninfested sites (0.69%). Nitrogen was higher (420.5 kg ha^{-1}) in completely invaded sites and least (291 kg ha^{-1}) in medium invaded site. A significant effect of Lantana invasion and soil layer on micronutrient content except Cu was also recorded.

1. INTRODUCTION

Biological invasions is one of the anthropogenically mediated ecological perturbations, are threatening native biodiversity, preventing natural ecological succession and changing the community structure and composition, besides impacting ecosystem services (Mack *et al*., 2000). In fact, the Convention on Biological Diversity (CBD) recognizes biological invasions as the second most important causal factor for the loss of biological diversity in natural ecosystems across the world, and thus the management of invasive alien weeds in forest ecosystems is critical for the conservation of biological diversity.

Invasive alien species threaten ecosystems, habitats or species with economic/ environmental consequences (GISP, 2000). *Lantana camara* Linn., a shrub indigenous to tropical America, is placed among the world's 100 worst invasive species by the Invasive Species Specialist Group (IUCN, 2001). It was brought to India by the British in 1807 as an ornamental plant for the Calcutta Botanical Garden. In 1850, it was introduced in Dehradun's cantonment area in Uttarakhand state of India and with its extremely adaptable and prolific nature, lantana has spread to all areas of India except the Thar desert. Lantana is now found all over the Indian subcontinent, stretching from the sub-montane regions of the outer Himalaya to the southernmost part of India (Thakur *et al*., 1992; Aravind *et al*., 2006). In disturbed native forests, it has become the dominant understorey species, disrupting regeneration and decreasing biodiversity (Sharma *et al*., 2005). Lantana has the potential to block succession and displace native species, resulting in a reduction in biodiversity (Day *et al*., 2003).

Invasion of *L. camara* results in loss of native biodiversity by way of forming dense impenetrable thickets thus adversely impacting the regeneration of forests (Sharma *et al*., 2005), contributing to erosion of soil (Day *et al.,* 2003), harbouring vectors that carry infectious diseases (Syed and Guerin, 2004) and promoting fire hazard (Hiremath and Sundaram, 2005). Interruption of regeneration processes through allelopathic suppression of neighbouring plant species in Australia has also been reported (Gentle and Duggin, 1997). Sharma *et al*. (2009) reported that on ingression and proliferation of *L. camara* during late eighties, there was an overall change in vegetation patterns with drastic decline in grass yields. They have also reported drastic reduction in Importance Value Index of the local shrubs and trees. Areas disturbed due to lopping and cutting, particularly in Doon valley and outer Himalaya were dominated by *L. camara* (Rawat and Bhainsora, 1999). Invasion of *L. camara* and its further impact on biodiversity was discussed extensively in IUFRO Conference on Risk Analysis of Forest Invasive Alien Species at Panjab University, Chandigarh (Feb. 27-March 1, 2013) with more emphasis to restrict its invasion through economic use of the species.

L. camara was reported to improve the fertility of the soil and serve to retain humus in deforested areas but very limited data are available. Sharma and Raghubanshi (2007) recorded increase in soil pH under lantana cover. Fan *et al*. (2010) had reported that lantana residues improved the nutrient status including total N, Olsen's P and NH_4OAc-extractable K of soil. Lantana's deep root system enables it to use nutrients in the deeper soil layer (Castillo *et al*., 2007), which can result in the increase of total N and P in surface soil. The present study was conducted to assess the impact of *L. camara* invasion on the natural vegetation and changes in soil physical and chemical properties.

2. MATERIALS AND METHODS

Study Area

The study area is a typical mixed deciduous forest in lower Himalayan region of India with $30^0 45'$ N latitude and $70^0 45'$ E longitude and is located at 370 m above msl. As per the USDA soil taxonomy, the soil of the study area has been classified as light textured hyper thermic Udic Ustochrept. The soil is sand to sandy loam in texture, well drained with low water holding capacity. The area receives 1100 mm of mean annual rainfall, out of which 80% occurs during the monsoon season (June to September). *D. sissoo, Acacia catechu, A. vasica, Grewia optiva, M. koenigii, Carrisa opaqua, Caesalpinia sepiaria, Cynodon dactylon, Eulaliopsis binata, etc*. are the native species of the region.

Invasion Status

Four different sites having varying lantana invasion status *i.e., L. camara* alone (Complete invasion - CI); *L. camara* + *D. sissoo* (Medium invasion - MI); *L. camara* + Local shrubs + *D. sissoo* (Partial invasion - PI) and local shrubs + *D. sissoo* (No invasion - NI) were selected. The status of the invasion was classified on the basis of the per cent of *L. camara* present as compared to total number of individuals per unit area. In completely invaded sites, all individuals were of *L. camara*, 77% in M.I, 29.41% in P.I. and no individual of *L. camara* in N.I.

Vegetation Composition

Numbers of individuals of different plants were counted in 30 x 30 m quadrate at four sites and were averaged. To study the structure of the forest relative dominance, relative frequency and relative density of the plants were calculated and were added to arrive at IVI of plants following the method given by Philips (1959). The biomass of the individual shrubs was calculated by cutting the shrubs at 10 cm above the ground. The biomass was oven dried at 80 ± 5^0C and was expressed as dry weight for each species. Similarly, the grass biomass was also determined. The soil binding factor of the shrubs was calculated following Bhimaya *et al*. (1956).

$$\text{Soil binding factor} = W/r^2$$

Where, W = weight of roots in gm present in given volume of soil, and r = average radius of roots (mm) present in same volume of soil. Root spread of the shrubs was assessed by carefully uprooting the shrubs and the root expansion was measured in two opposite directions.

Soil Sampling, Processing and Analysis of Soil Properties

Soil samples were collected from three depths: 0-15, 15-30 and 30-45 cm, following standard procedures in all the four treatments from four different sites. Soil samples were air-dried and ground to pass through a 2 mm sieve. A combined glass calomel electrode was used to determine the pH of aqueous suspensions (1:2.5 soil: solution ratio). Electrical conductivity (dSm^{-1}) was measured in the supernatant liquid of soil water suspension (1:2) with conductivity bridge (Richards, 1954). Soil organic carbon (OC) was determined using the wet digestion method of Walkley and Black (1934). Available nitrogen (N) was measured by the alkaline permanganate method (Subbiah and Asija, 1956); available phosphorus (P) by the Olsen method (Olsen, 1954) and available potassium was determined by flame photometer (Rich, 1965). Available micronutrient content (Cu, Mn, Fe and Zn) were determined by DTPA extraction method (Lindsay and Norvell, 1978) followed by determination in atomic absorption spectrophotometer.

Soil physical properties, soil bulk density, water holding capacity, per cent pore space, specific gravity and volume expansion of 100 cc of soil were determined using

KeenRaczkowski box, using standard procedure (Baruah and Barthakur, 1997).

Statistical Analysis

Data obtained in the experiment was subjected to analysis of variance (ANOVA) appropriate to the experimental design. For statistical analysis of data Microsoft Excel (Microsoft Corporation, USA) and MSTATC packages were used. The relationship between soil properties and soil fertility indices were determined by Pearson's correlation matrix using SPSS window version 14.0 (SPSS Inc., Chicago, USA).

3. RESULTS AND DISCUSSION

Plant Diversity and Vegetation Composition

Data on plant diversity and composition of the vegetation is presented in Table 1. Relative dominance (RD), Relative Density (RD) and Relative Frequency (RF) of *L. camara* increased with the invasion whereas these indexes, reflecting composition of the vegetation, decreased for rest of the shrubs species. The number of plants ha^{-1} in complete invaded site were 1300. The number of local species reduced as *L. camara* invaded. *L. camara* plants in PI stage were 29.41%, which increased to 77.77% at MI stage whereas, the local species *M. koenigii* and *J. adhatoda* decreased from 40% to 23 and 31%, respectively. Relative dominance (RD), Relative Density (RD) and Relative Frequency (RF) of *L. camara* increased with the invasion, whereas, these parameters, reflecting composition of the vegetation, decreased for rest of the shrub species. However, this trend was not observed for *D. sissoo*. IVI of the local species decreased with the invasion of *L. camara*. IVI of *M. koenigii* was 80.49 in NI and decreased to 48.84 in PI. Inhibition of growth of different species like *Cyclosorus dentatus, Morrenia odorata*, *Lolium multiflorum*, *Triticum aestivum*, *Zea mays* and *Glycine max* was also reported due to allelopathic compounds of *L. camara* (Sharma *et al*., 2005). Sahu and Singh (2008) also observed that the density of *L. camara* had no effect on the tree density but had a negative effect on the density of indigenous species. Field studies indicate that *L. camara* could suppress regeneration potential of native species (Macdonald *et al.,* 1986). Replacement of indigenous species may also be because of unavailability of light under the dense canopy cover of *L. camara*. Sharma *et al.* (2005) had reported that *L. camara* reduces the intensity and duration of light and thus prevent the establishment of other tree seedlings. In Shivalik hills, more than 47% species have been lost in *L. camara* invaded areas (Batish *et al*., 2006).

Table: 1
Vegetational parameters in different invasion status

	Complete Invasion	Medium invasion	Partial invasion	No invasion
L. camara				
Number of individuals ha^{-1}	1300	167	500	-
Relative Density	100	77.77	29.41	-
Relative Dominance	100	0.27	0.21	-
Relative Frequency	100	50	25	-
Importance Value Index	300	128.05	54.61	-
D. sissoo				
Number of individuals ha^{-1}	-	333.3	267.0	267.0
Relative Density	-	22.22	15.68	19.04
Relative Dominance	-	99.72	99.33	89.31
Relative Frequency	-	50	25	33.33
Importance Value Index	-	171.95	140.03	141.69
M. koenigii				
Number of individuals ha^{-1}	-	-	400	567
Relative Density	-	-	23.52	40.47
Relative Dominance	-	-	0.31	6.68
Relative Frequency	-	-	25	33.33
Importance Value Index	-	-	48.84	80.49
J. adhatoda				
Number of individuals ha^{-1}	-	-	533	567
Relative Density	-	-	31.37	40.47
Relative Dominance	-	-	0.14	3.99
Relative Frequency	-	-	25	33.33
Importance Value Index	-	-	56.52	77.81

Complete invasion: *L. camara* alone; Medium invasion: *L. camara* + *D. sissoo;* Partial invasion: *L. camara* + Local shrubs + *D. sissoo;* No invasion: Local shrubs + *D. sissoo*

The data on per plant biomass variation at invaded and uninvaded sites is given in Table 2. Above ground biomass ha^{-1} of *L. camara* increased as the intensity of invasion progressed. It was 305 kg ha^{-1} in PI and increased to 1632 kg ha^{-1} in CI. However, increase in biomass of *L. camara* led to decrease in the biomass of indigenous species, *M. koenigii* and *J. adhatoda* from 561 and 713 kg ha^{-1} in NI to 392.5 and 596 kg ha^{-1} in PI, respectively. Biomass production of grasses also decreased from 26 kg ha^{-1} in NI to 17 kg ha^{-1} in CI. The effect of *L. camara* invasion

Table: 2
Biomass (kg ha^{-1}) as affected by different degree of lantana invsion

Treatments	*L. camara*	*M. koenigii*	*J. Adhatoda*	*D. sissoo*	Grasses
Complete invasion	1632.40				17.31
Medium invasion	1117.35			120300.96	15.00
Partial invasion	304.97	392.50	596.39	114008.40	22.64
No invasion	-	561.02	712.93	109962.52	26.44
Mean	1018.34	476.76	654.66	114757.29	20.35
SEm	59.5272	47.03	26.16	4457.47	1.17
CD	194.12	NS	*	14536.65	3.82

*Significant at 5% level of significance.

on established *D. sissoo* had no consistent effect and they did not follow a particular trend. Allelopathy from volatile allelochemicals may be the main competitive strategy for *L. camara* invasion since growth of other plants in lantana-invaded soils was better than cutting and leaving all lantana biomass in place (Gentle and Duggin, 1997). It was found in the study that *L. camara* had replaced the native species altogether between PI and MI where *L. camara* density was between 30 to 77%, respectively. The results are in conformity with the reports of Gooden *et al.* (2009) where they observed that *L. camara* did not decrease native species richness until *L. camara* reached a cover of over 75%. It is thus indicated that the suppressive effect from *L. camara* to other species may not be caused by allelopathy but by the spatial competition by *L. camara* cover.

Root binding capacity and root spread of shrubs are presented in Table 3 and Table 4. It was found that there was no particular relationship of root binding capacity with invasion status. However, *L. camara* has less root binding capacity than other shrubs. The root spread of *L. camara* increased as the invasion stage progressed. The root spread of *L. camara* was 1301 cm^2 at PI stage and it increased to 6312 cm^2 at CI. The root spread of local species did not vary much and only increased slightly with the invasion of *L. camara*. Castillo *et al.* (2007) had reported that *L. camara* has a deep rooting system, which enables it to use nutrients in the deeper soil layer. The robust root system of *L. camara* makes it difficult to eradicate it through mechanical means.

On the basis of the observations and experience, a flow chart of mechanism of invasion by *L.camara* and its potential to replace the indigenous species is depicted in Fig. 1. *L. camara* is rated as profuse seed producer throughout the year as the species is drought resistance (Anon., 1962), wide and deep rooting (Castillo *et al*., 2007), spreading through root suckers and form thick canopy (Sharma *et al*., 2005). The management and/or eradication of *L. camara* need to be done at every stage to check the depletion of the diversity of local species.

Table: 3
Roots binding capacity of different species

Treatments	L. Camara	M. koenigii	J. adhatoda
L. camara alone	22.05	-	-
L. camara + trees	19.83	-	-
Mixed lantana+tree+shrubs	27.22	56.53	36.36
Mixed without lantana	-	43.68	68.53
Mean	23.03	50.10	52.45
SEm	2.79	4.60	3.42
CD	9.10	NS	**

**Significant at 1% level of significance

Table: 4
Roots spread (cm^2) capacity of different species as affected by different degree of Lantana invasion

Treatments	L. camara	M. koenigii	J. adhatoda
L. camara alone	6312.40	-	-
L. camara + trees	3993.53	-	-
Mixed lantana+tree+shrubs	1301.30	1483.50	1936.06
Mixed without lantana	-	1349.85	1752.26
Mean	3869.08	1416.67	1844.16
SEm	258.30	175.10	218.86
CD	842.36	NS	NS

**Significant at 1% level of significance

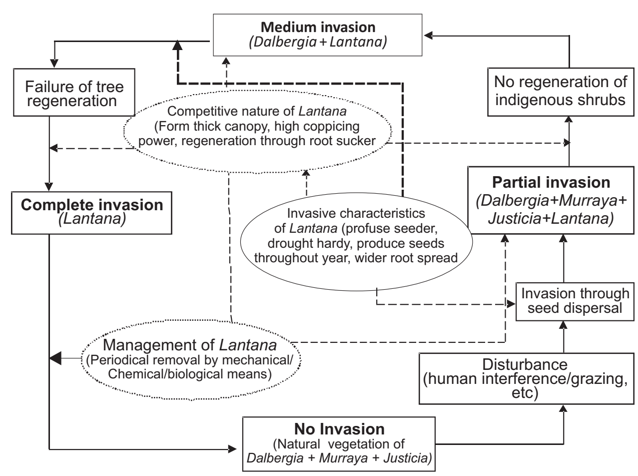

Fig. 1. Mechanism of *L. camara* invasion

Soil Physical Properties

Soil bulk density and specific gravity decreased and pore space increased as the invasion of *L. camara* increased. Bulk density at NI was 1.60 and it decreased to 1.25 at CI stage. Specific gravity was highest 3.12 in deeper depth of PI and was least (2.18) at surface soil of CI. Pore space was highest (52.57%) in surface soil of CI and least (41.25) in 15-30 cm depth of PI. However, all three parameters did not show significant difference either with increase in the depth of soil or *L. camara* invasion. A significant difference was observed for variation in Water Holding Capacity (WHC) and Volume Expansion (VE) with invasion status. However, depth and interaction of land use and depth did not show significant difference for both the parameters. WHC and VE was higher 36.81% and 9.19% in CI, respectively. The lowest WHC (26.38%) at 30-45 cm depth was observed at PI, whereas, minimum value of VE was 0.01% in surface layer of CI. Bhushan and Sharma (2002) reported that addition of organic matter through lantana over 10 years positively affected the soil structure, leading to improvement of other soil physical properties. *L. camara* additions increased the organic carbon (OC) of the 0-15 cm soil layer by 11-24%, as a result bulk density of the plough layer (0-15 cm) decreased by 7% (Sharma *et al.*, 1995). Bulk density was found to decrease significantly with an accompanying increase in total porosity at all levels of lantana addition compared to control in an experiment conducted at Palampur, Himachal Pradesh. The available water holding capacity increased by 3-6% by the addition of different levels of lantana biomass. Resistance to penetration decreased with an increase in lantana addition, the energy required to plough different plots also decreased with the highest rate of lantana addition as compared to control. Also, the improvement in physical properties favourably affected the succeeding crop (Bhagat *et al*., 2003) (Table 5).

Soil Chemical Properties

Data presented in Table 6 showed significant influence of *L. camara* invasion on soil pH; however, variation in soil profile with respect to depth was non-significant. Soil pH varied from 6.6 in CI and 8.3 in NI. Interestingly, CI showed lesser pH than the NI, which could be attributed to the presence of alkaloids in the leaves of lantana and higher pH in other status could be attributed to the release of bases and their deposition over a long period of tree growth. The greater pH level in some of the treebased landuse systems could also be due to humic matter released as a result of tree root exudates that complex the aluminum (Al^{+3}) and consequently result in greater soil pH, especially in acidic soils (Young, 1997). EC did not vary significantly under different *L. camara* invaded sites at varying soil depths. In general the EC decreased with the increase in the depth of soil. In surface soil EC was minimum 0.37 in CI followed by 0.51 in PI , 0.52 in MI and highest 0.65 EC was recorded in NI. Slightly higher EC in MI, NI and PI might be because of the presence of the trees as has been reported earlier by Sharma and Gupta (1989) and Chakraborthy and Chakraborthy (1989). The lower pH in *L. camara* invaded sites might be because of the higher organic matter accumulation, which on decomposition releases organic acids hence decrease the pH.

OC content was higher in CI sites (1.376%) followed by NI (0.69%). The least content of OC was 0.30% in subsurface soil of MI. A general trend of decrease in OC with depth except for 1530 cm soil depth in MI and PI was observed. The enrichment of OC content could be due to higher biomass recycling in CI as compared to other stages. It is important that though total biomass of NI, PI

Table: 5
Soil physical properties as affected by different degrees of *L. camara* invasion

System	Soil depth (cm)		
	0-15	15-30	30-45
Bulk density (g cc^{-1})			
L. camara alone	1.25	1.37	1.18
L. camara + trees	1.48	1.42	1.61
Mixed lantana+tree+shrubs	1.52	1.49	1.55
Mixed without lantana	1.40	1.39	1.57
LSD (5%)	L=NS	D=NS	LXD=NS
WHC (%)			
L. camara alone	36.81	33.25	33.76
L. camara + trees	26.82	29.93	26.49
Mixed lantana+tree+shrubs	27.89	29.85	26.38
Mixed without lantana	28.82	27.37	29.45
LSD (5%)	L=2.21	D=NS	LXD=NS
Specific gravity			
L. camara alone	2.18	2.43	2.78
L. camara + trees	2.52	2.37	3.00
Mixed lantana+tree+shrubs	2.84	2.44	3.12
Mixed without lantana	2.75	2.31	2.66
LSD (5%)	L=NS	D=NS	LXD=NS
Pore space (%)			
L. camara alone	52.57	45.20	42.74
L. camara + trees	50.09	42.50	43.41
Mixed lantana+tree+shrubs	54.39	41.25	41.28
Mixed without lantana	43.53	42.11	41.94
LSD (5%)	L=NS	D=NS	LXD=NS
Volume expansion (%)			
L. camara alone	9.19	2.86	0.01
L. camara + trees	6.43	3.31	3.01
Mixed lantana+tree+shrubs	8.24	4.49	3.51
Mixed without lantana	4.37	5.34	2.46
LSD (5%)	L=1.53	D=NS	LXD=NS

Table: 6
Soil chemical properties as affected by different stages of *L. camara* invasion

System	Soil depth (cm)		
	0-15	15-30	30-45
PH			
L. camara alone	6.6	7.2	7.4
L. camara + trees	7.3	7.4	7.2
Mixed lantana+tree+shrubs	7.4	7.9	7.8
Mixed without lantana	8.1	8	8.3
LSD (5%)	L=1.13	D=NS	LXD=NS
EC (dS m^{-1})			
L. camara alone	0.37	0.47	0.34
L. camara + trees	0.52	0.42	0.41
Mixed lantana+tree+shrubs	0.51	0.44	0.55
Mixed without lantana	0.65	0.42	0.34
LSD (5%)	L=NS	D=NS	LXD=NS
Nitrogen (kg ha^{-1})			
L. camara alone	420.57	338.33	328.22
L. camara + trees	291.29	287.80	247.39
Mixed lantana+tree+shrubs	331.36	250.88	265.52
Mixed without lantana	354.72	337.63	250.17
LSD (5%)	L=16.85	D=8.21	LXD=NS
P_2O_5 (kg ha^{-1})			
L. camara alone	32.00	29.12	23.11
L. camara + trees	21.32	21.24	21.34
Mixed lantana+tree+shrubs	25.67	23.21	22.00
Mixed without lantana	28.76	26.98	26.57
LSD (5%)	L=3.12	D=2.08	LXD=NS
K_20 (kg ha^{-1})			
L. camara alone	324.59	324.70	213.80
L. camara + trees	214.70	173.92	169.44
Mixed lantana+tree+shrubs	237.28	191.84	194.08
Mixed without lantana	316.16	235.71	214.92
LSD (5%)	L=13.8	D=16.5	LXD=NS
OC (%)			
L. camara alone	1.376	0.921	0.573
L. camara + trees	0.590	0.302	0.475
Mixed lantana+tree+shrubs	0.676	0.460	0.475
Mixed without lantana	0.691	0.633	0.475
LSD (5%)	L=0.21	D=0.11	LXD=NS

and MI is higher due to presence of trees, the greater part of the tree biomass is locked in tree bole and branches which do not contribute to organic matter content to soil. Rich OC content in surface soil layer than subsoil layers in all stages may be attributed to the contribution made by litter fall (Russel, 1986; Madhumitha *et al*., 1997). Available N, P and K content significantly varied between different invasion status and soil depths (Table 6). N was higher (420.5 kg ha^{-1}) in CI and least (291 kg ha^{-1}) in MI stage. N content tended to decrease with increasing soil depth. Higher N content in CI over other invasion stage is attributed to more accumulation of biomass through litter fall and root biomass (Juo and Lal, 1977; Srinivasan and Caulifield, 1989). The highest P content was 32.0 kg ha^{-1} in surface layer of CI and least 21.24 kg ha^{-1} in M.I. at 30-45 cm soil depth could be due to more absorption by roots and it's recycling of P through litter fall. Available K ranged from 169 kg ha^{-1} to 324 kg ha^{-1} and decreased with the depth. The highest K was in surface soil of CI closely followed by NI (316 kg ha^{-1}). The least K content was 169 kg ha^{-1} in sub-soil of MI. The contents of SOM, total P, available P and total N and available N in the soils under *L.camara* were also reported to be 15, 16, 53, 19 and 162% higher, respectively than those soils which were away from *L. camara* (Fan *et al*., 2010). Sharma *et al*. (2003) had also suggested that lantana residues improved the nutrient status including total N, Olsen's P and NH_4OAc-extractable K of soil. Lantana's deep root system enables it to use nutrients in the deeper soil layer (Castillo *et al*., 2007), which can result in the increase of total N and P in surface soil. The higher litter accumulation from lantana defoliation than the companion herbaceous plants (Gomez *et al*., 2006) can contribute to the increase of the SOC content in the soils beneath *L. camara*, which may benefit the immobilization of N and P. Higher concentration of total N, Olsen's P and NH_4OAc extractable K in lantana-amended plots than in the controls was reported by Sharma *et al*. (2003). Their result also suggested that lantana residues, which improved the nutrient status of soil and system yield, have the potential for resource conservation and sustaining rice-wheat productivity. Sharma and Verma (2001) observed that continuous incorporation of lantana @ 30 t ha^{-1} increased all the hydrolysable N fractions significantly except unidentified-N which remained unaffected. Out of the total N added through lantana over the period of six years, maximum was transformed into amino acid followed by hydrolysable NH_4-N and a minimum into unidentified N. Continuous additions of lantana for six years reported to increase the total and available phosphorus about 13 and 69%, respectively over no addition of lantana.

Available Micronutrient

A significant effect of *L. camara* invasion and soil layer on micronutrient content except Cu was observed (Fig. 2a to Fig. 2d). The Fe content was highest (6.26 ppm) in CI and lowest (0.99 ppm) in sub soil of PI. Manganese content varied from 5.24 ppm in surface soil layer of CI and least (2.22 ppm) in 30-45 cm soil layer in PI. Copper content ranged from 0.706 in 15-30 cm soil layer of PI to 1.388 ppm in surface layer of CI showing no significant difference among the values for invasion stage and depth. Available Zn varied from 0.42 ppm in 30-45 cm soil depth of CI to 0.71 ppm in surface soil of MI. No consistent trend was followed for micronutrients within invasion status of *L. camara*; however, in general depth showed a decreasing trend.

4. CONCLUSIONS

Relative density, relative dominance, relative frequency and IVI varied in the order of complete > medium > partial invasion. The biomass added to the soil followed the order of complete > no invasion > partial invasion > medium invasion. Root binding capacity of local species like *Murraya* and *Justicia* were higher as compared to *L. camara*. Root spread followed the order: *L. camara* > *Justicia* > *Murraya*. Better physical and chemical properties of soil were found in sites which were completely invaded by *L. camara* as compared to those where natural vegetation occurred. Organic Carbon content was much higher in completely *L. camara* infested sites (1.376%) followed by uninfested sites (0.69%). Nitrogen was higher (420.5 kg ha^{-1}) in completely invaded sites and least (291 kg ha^{-1}) at medium invaded stage. However, *L. camara* had decreased the frequency and production capability of indigenous species, which is an area of concern for future.

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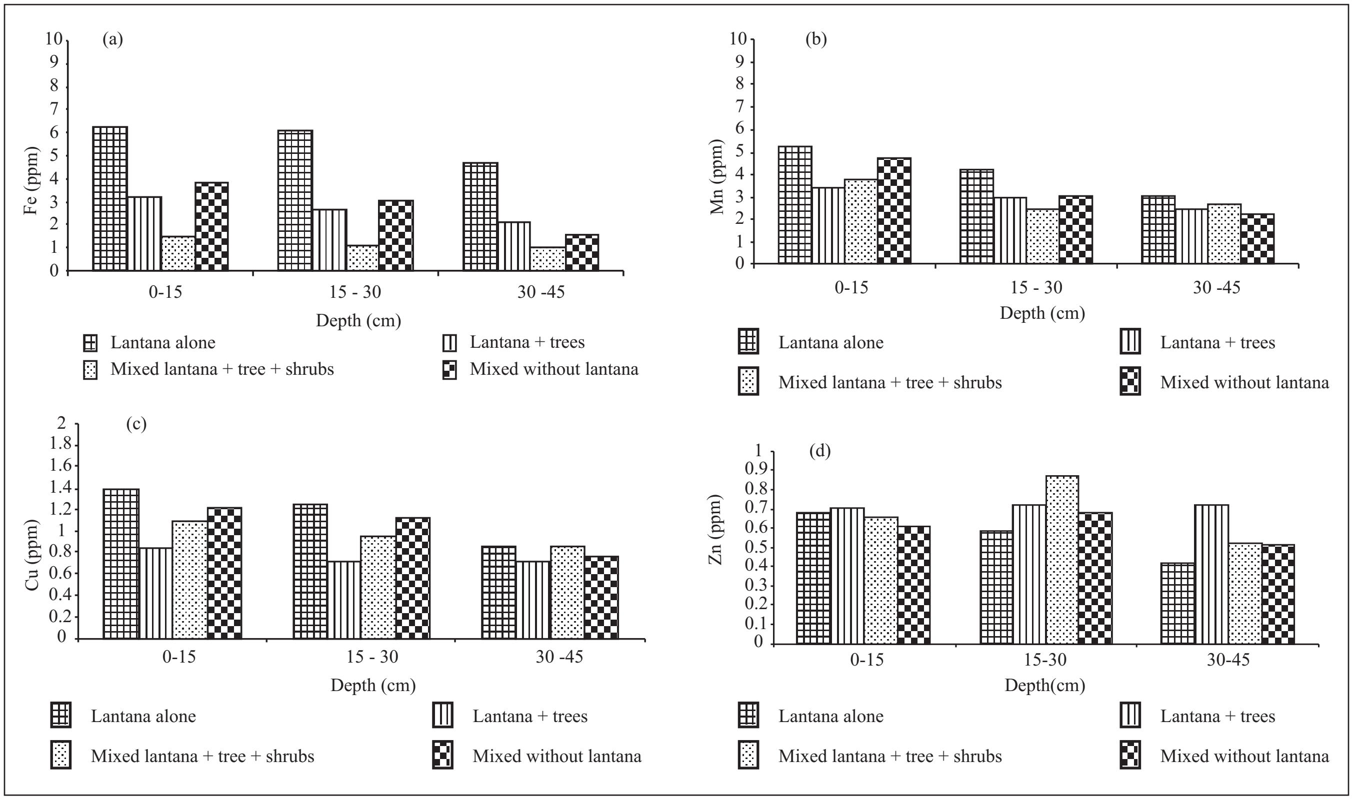

(a) Fe : LSD (5%): L = 3.01, D = 1.12, LXD = NS; (b) Mn : LSD (5%): L = 1.09, D = 0.09, LXD = NS; (c) Cu : LSD (5%): L = NS, D = NS, LXD = NS; (d) Zn : LSD (5%): L = 0.32, D = 0.25, LXD = NS

Fig. 2. The concentration of micronutrients as affected by different stages of *L. Camara* invasion

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