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Influence of Land Use and Land Cover Change on Diversity of Earthworms in Raebareli District of Indogangetic Plains, India

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ABSTRACT

Land use-land cover change and management practices influence earthworm species composition and abundance. The natural and agro-ecosystems under study in the Indogangetic region have a depauperate earthworm fauna. This study provides evidence that agriculture intensification and soil sodicity can severely influence earthworm diversity, in which natural and less disturbed ecosystems had lower earthworm diversity. Predominance of endemic earthworms at all sites under study could probably be explained by barriers in dispersal of exotic species and a wider distribution of native species. The change in functional guild with the change in land use could be attributed to the change in the input rates and chemical characteristic of organic matter associated with varied land management practices. The ecological group studies revealed that earthworm communities of agro-ecosystems have lower species richness, fewer ecological groups and predominance of endogeics. Epigeic and anecic species are not widespread in the agriculture systems and their dependence on litter layer for survival implies that litter management practices must be implemented for their role of soil function to be important.

Keywords: derived agro ecosystems, earthworm communities, ecological categories, endemics exotics, primary forest, reclaimed agro ecosystems

Abbreviations: AAFP, abandoned agricultural fallow plot; **AP**, *Acacia* plantation on reclaimed site; **LPAE**, low productive agro ecosystem; **PAE**, productive agro ecosystem; **PF**, primary forest; **SE**, sodic agroecosystem; **5 Yr RA**, 5-year-old reclaimed agro ecosystems; **10 Yr RA**, 10-year-old reclaimed agro ecosystems

INTRODUCTION

Soil organisms are an integral part of agricultural and forest ecosystems and they play a critical role in maintaining soil health, ecosystem function and production. The interacting functions of soil organisms and the effects of human activities in managing land for agriculture and forest affect soil health and quality. These changes strongly influence soil faunal biodiversity by altering habitat heterogeneity and vegetation type (Decaens *et al.* 2004; Eggleton *et al.* 2005). Poor irrigation management practices coupled with the lack of a properly designed drainage system and high rate of evaporation cause soluble salts to concentrate on the soil surface, resulting in sodic soil conditions in the vast tracts of the Indogangetic plains of semi-arid India, thus rendering these ecosystems unfit for soil faunal biodiversity and agricultural purposes. Earthworms constitute the largest part of the macrofauna in the soil and various soil management options can have a dramatic effect upon their community structure (Vazquaz and Simberloff 2003; Decaens *et al.* 2004). Intensive agricultural practices influence the population density, species diversity and activity of earthworms as soil organisms are largely dependant upon organic matter input, largely derived from the vegetation cover of the site (Freckmann 1994). Annual crops have lower earthworm biomass and therefore considered to be relatively unfavorable for soil macrofauna (Radford *et al.* 2001). Seasonal rhythm or environmental factors such as temperature, soil moisture and soil pH affect to different extents soil biological communities and their functions, and are key factor of changes in the species assemblage of below-ground communities (Miranda *et al.* 2007). The present study in the Indogangetic plains of semi-arid India is an effort to provide evidence that agriculture intensification and managing land for plantation and forest not only affect soil health and quality but also can severely influence the earthworm community structure and species diversity. The study also evaluates the impact of soil sodic condition and subsequent reclamation of a degraded landscape on the diversity and distribution pattern of earthworm species. The ecosystems thus identified and impacted by various factors will be compared with reference to non-impacted or less impacted ecosystems, to compare the level of loss or change in the earthworm species and the recolonization processes.

STUDY SITE

The study was carried out in Gangaganj and Bachhrawan Villages of Raebareli district, (Latitude 25° 49′ and 26° 36′ North and longitudes 80° 41′ and 81° 34′ East) state of Uttar Pradesh located in the Indogangetic plains at an altitude between 8 to 10 m with a fairly flat land and with a slope from NW to SE, the study site is covered under agroecoregion 4, a hot semi-arid ecoregion whose soils are formed through the alluvial deposits formed by the rivers comprising of Ganga, Gomti and their tributaries (Sehgal *et al.* 2002). Soils are loamy to sandy loam, dark grey and coarsely textured with inherently low nutrients like nitrogen and organic carbon; the soils are poorly drained with low to very low permeability and with alkalinity problems. The climate is hot and dry summer extends from May to June (max. temp. 42.2°C, min. temp. 38°C) with severe winter extending from November to February (max. temp. 25.2°C, min. temp. 7.8°C), the rainy season extends from the last week of June to October with an average annual rainfall of 60 to 100 cm. The landscape in this agro-ecological region had a mosaic of natural and human managed ecosystems (**Table 1**). Agriculture in the Raebareli district is a modern, intensive farming system characterized by mechanized tillage and chemical fertilizers. The chronosequence of land use classes of both natural and

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Table 1 Distinguishing features of vegetation and management practices in different land uses in Raebareli district of Indogangetic plains.

Ecoregion	Indogangetic plains
Location of sites	Raebareli (Uttar Pradesh)
Elevation	8-10 m (asl)
Natural forest	Dry deciduous thorn bush forest, thickness of litter layer < 3 cm; occasional grazing by cattle and collection of fire wood by local people. **Bahunia verigata*, *Butea monosperma*, *Acacia* sp. ** *Ziziphus* sp., *Calotropis* sp., *Indigoflora* sp., *Jatropa* sp., *Tectona grandis*
Soil fertility management practices	Intensive irrigated farming.
Productive agroecosystem	Well-drained soils with addition of mostly inorganic fertilizer and negligible organic manure, well managed paddy-wheat crop rotation and two crops are harvested per year, addition of NP occasionally K. Field left fallow for a short period of 3-4 months.
Low productivity agroecosystem	Well-drained soils but due to low productivity only one leguminous crop is harvested per year, with the view to replenish lost soil fertility. No fertilizer added and field is left fallow for a period of 6 months, this practice is continued for a period of 3 years.
Abandonend agricultural fallow plot	Agriculture fields abandoned for soil fertility recovery together with grazing by live stock.
Sodic agroecosystem	Highly degraded agroecosystem rendered unfit for crop growth due to agriculture intensification and faulty land management practices leading to soil sodic conditions.
5-year-old reclaimed agroecosystem	Sodic agroecosystem that was reclaimed 5 years back for cultivation through continuous application of gypsum or pyrite for three years, organic manure is used by some farmers though it is not a common practice, after five years of land reclamation only one paddy crop is harvested per year; occasional mulching using *Sesbania* sp. (*dhaincha*).
10-year-old reclaimed agroecosystem	Sodic agroecosystem that were reclaimed ten years back for cultivation through the application of gypsum or pyrite for three years continuously, organic manure is used by some farmers though it is not a common practice, agriculture field was reclaimed 10 years back; rice-wheat crop rotation is practiced, two crops are harvested per year.
Acacia plantation	Ten year old plantation on reclaimed sodic soils with profuse natural regeneration, < 1 cm thick litter layer.

* trees, ** shrubs

man-made ecosystems were selected for the study. Based on anthropogenic disturbances the natural ecosystem identified was less impacted ecosystem represented by primary forest (PF); agro-ecosystems that can be ordered approximately according to the intensity of management as: productive agro ecosystem (PAE); low productive agro ecosystem (LPAE); abandoned agricultural fallow plot (AAFP); (SE); 5-year-old reclaimed agro ecosystems (5 Yr RA); 10-year-old reclaimed agro ecosystems (10 Yr RA); *Acacia* plantations (AP). Sequences of changes in land use were identified based on the government records and information extracted through participatory discussions.

MATERIALS AND METHODS

Experimental design

Soil sampling

In each land use type a plot of 40 × 50 m^2 was demarcated for earthworms and for soil sampling, three composite soil samples were prepared in each experimental plot. Ten 25 cm × 25 cm × 30 cm deep soil monoliths were randomly sampled from each replicate plot at regular monthly intervals. Each monolith was subdivided into 0-10, 10-20, and 20-30 cm blocks, the soil samples were air dried and sieved through a 2-mm sieve. A representative of the sub-sample was stored for subsequent analysis (Okalebo *et al.* 1994). Soil temperatures were recorded weekly at 0-10 and 10-20 cm depths; however, the values presented here are mean monthly values for 0-10 cm depth. Soil moisture was recorded every month at 0-10 and 10-20 cm depths, but the values presented here are mean monthly values for 0-10 cm depth and are expressed as % oven dry weight at 105°C. The analysis of soil texture was done using a hydrometer method (Bouyoucos 1951), soil pH was measured as 1: 2.5 (soil: water) solution, and organic C through the Walkey-Black method (1934). Soil N was analyzed using the semi-micro Kjeldahl method following the procedures described in Anderson and Ingram (1993).

Soil fauna sampling

Earthworms were sampled using the soil biology and fertility methodology (Anderson and Ingram 1993). On each site in a plot of 40 m × 50 m earthworms were collected at regular monthly intervals over a period of 12 months, i.e. between March 2004 and February 2005 in PF, AAFP, AP and 5 Yr RA, between June 2004 and May 2005 in PAE and LPAE and between May 2004 and April 2005 in 10 Yr RA. Earthworms were collected from 10 sampling points 5 m apart along a transect with a random origin, they were extracted by hand sorting after digging a trench up to 30 cm deep around a 25 cm × 25 cm area at each sampling point to get a soil monolith. These soil monoliths were divided into three layers (0-10, 10-20, 20-30 cm) and earthworms were extracted from each layer, they were then washed and preserved in 5% formalin for further identification (Anderson and Ingram 1993).

Statistical analysis

Statistical analysis was done following the biostatistical methods described in Zar (1974). Significant differences ($P < 0.05$) in physicochemical characteristics of the soil across different sampling sites were carried out using one-way ANOVA. Significant differences in the density and biomass of earthworm species across different sampling sites (interhabitat variations), and in between the same site (intrahabitat variations) were tested using non-parametric one-way ANOVA (F-test), and the Newmann-Keul's multiple range test. Significant differences ($P < 0.05$) in functional guild changes of earthworms species in the same site were tested using the non-parametric Mann-Whitney test (U-test). Significant differences ($P < 0.05$) in functional guild changes of earthworm species across different sampling sites were done using one-way ANOVA (F-test). Seasonal variations in total density and biomass of earthworm species in PF, AAFP and in AP were tested using the non-parametric Kruskal-Wallis test of variance (H-test) and New Mann Keul's multiple range test. The correlation between soil parameters such as temperature moisture and organic matter and earthworm species was calculated as a simple correlation coefficient (r). The SYSTAT 12 software for Windows package (Systat Software Inc., San Jose, USA) was used for all statistical tests. Sample standard error was calculated as the standard error of the Mean (±S E).

RESULTS

Physico-chemical properties of soils varied significantly between different sites. Sand (%) was significantly higher ($F = 18.4$, $P < 0.05$) under SE whereas silt and clay content were higher under PF ($F = 12.4$, $P < 0.05$), all other sites had a very similar soil texture. Soil had a mildly alkaline to alkaline pH in PF, PAE and LPAE. Soil had a highly alkaline pH in the degraded SE and subsequent reclamation

Table 2 Soil characteristics across different sampling sites in Raebareli district of Indogangetic plains.

Sampling sites	Sand (%)	Silt (%)	Clay (%)	pH	Organic carbon (%)	N (%)
Natural forest	59.8 ± 4.2 a	24.2 ± 1.4 a	16.0 ± 1.3 a	8.0	0.93 ± 0.25 a	0.10 ± 0.01 a
Productive agroecosystem	68.2 ± 4.2 b	18.1 ± 1.0 b	13.8 ± 1.0 b	7.8	0.73 ± 0.34 b	0.07 ± 0.01 b
Low productivity agroecosystem	66.2 ± 4.0 b	18.8 ± 1.1 b	15.0 ± 1.0 b	8.2	0.62 ± 0.20 b	0.05 ± 0.01 c
Abandonend agricultural fallow plot	62.0 ± 2.2 a	20.0 ± 1.4 c	18.0 ± 1.3 b	8.5	1.30 ± 0.30 d	0.12 ± 0.01 d
Sodic agroecosystem	78.0 ± 3.2 a	12.0 ± 0.2 a	10.0 ± 0.8 b	9.8	0.18 ± 0.02 e	0.02 ± 0.001 e
5-year-old reclaimed agroecosystem	72.1 ± 3.4 b	14.7 ± 1.0 b	13.1 ± 1.2 b	8.7	0.58 ± 0.01 c	0.04 ± 0.01 c
10-year-old reclaimed agroecosystem	68.1 ± 2.4 b	18.5 ± 1.2 c	13.4 ± 1.1 b	8.3	0.79 ± 0.02 b	0.06 ± 0.01 c
Acacia plantation	68.5 ± 5.3 b	18.5 ± 1.2 b	13.4 ± 1.0 b	8.6	1.10 ± 0.20 d	0.09 ± 0.01 a

Numbers followed by same letter are not significantly different ($P < 0.05$) between different sites.
± SE, $n = 10$

Table 3 Taxonomic groupings of earthworms across different sampling sites in Raebareli district of Indogangetic plains.

Taxonomic groups	Genus/species
Almidae	*Glyphidrilus* sp.
Octochaetidae	*Eutyphoeus incommodes*, *E. orientalis*, *E. nicholsoni*

of these soils resulted in lower pH values both in 10 Yr RA and in AP. Organic carbon ($F = 14.32$, $P < 0.05$) and total N ($F = 14.32$, $P < 0.05$) were significantly higher in PF declining in the both PAE and LPAE but improving significantly in AAFP ($F = 12.45$, $P < 0.05$). Organic C had a significantly lower value in SE ($F = 12.66$, $P < 0.05$). Soil sodic condition also led to a loss of total N, but improved significantly ($F = 16.3$, $P < 0.05$) in 10 Yr RA; these values were much higher in reclaimed AP than all other sites (**Table 2**).

Earthworm communities

The family Megascolecidae with a single genus having three species *Eutyphoeus incommodes*, *E. orientalis* and *E. nicholsoni* in both natural and agro-ecosystems and the family Almidae represented by a single genus *Glyphidrilus* in 5 Yr RA and 10 Yr RA alone characterizes the PF, PAE and LPAE, AP and degraded agro-ecosystems (**Table 3**). Earthworm species diversity was maximum in PF and AAFP and minimum in 5 and 10 Yr RA (**Fig. 1**). PF had all three endemic species (*E. incommodes*, *E. orientalis* and *E. nicholsoni*), and conversion of PF to agro-ecosystems led to the loss of endemic *E. orientalis* in both PAE and LPAE. AAFP was however recolonized by all three species present in PF. Soil sodic conditions representing highly degraded agro-ecosystems were devoid of any earthworm fauna; however, subsequent reclamation of soil for agricultural purposes led to the invasion by another endemic *Glyphidrilus* sp. in both 5 and 10 Yr RA. AP were recolonized by *E. incommodes* and *E. nicholsoni* (**Fig. 2**). Endemic species had a significantly higher density ($F = 8.74$, $P < 0.05$) in AAFP as well in 10 Yr RA ($F = 7.63$, $P < 0.05$). However, in terms of biomass the endemics contributed significantly ($F = 8.93$, $P < 0.05$) more to AAFP than to PF and PAE. In 5 and 10 Yr RA the contribution by endemics in terms of biomass was very low. Exotic species were absent in all sites under study (**Fig. 3**).

Total earthworm density ($F = 110$, $P < 0.05$) and biomass ($F = 116.5$, $P < 0.05$) values varied significantly across different sampling sites. AAFP had significantly higher density ($F = 35.71$, $P < 0.01$) and biomass ($F = 48.43$, $P < 0.05$) values compared to PF, PAE and LPAE. 10 Yr RA had higher density ($F = 22$, $P < 0.05$) and biomass ($F = 43.02$, $P < 0.05$) values of earthworms than 5 Yr RA although earthworms had a significantly higher biomass ($F = 48$, $P < 0.05$) in AP than both 5 and 10 Yr RA. Total earthworm density did not vary significantly between AAFP and 10 Yr RA, between AP and PF, and between LPAE and 5 Yr RA. The total biomass of earthworms was significantly lower in both 5 and 10 Yr RA ($F = 15.09$, $P < 0.05$ and $F = 43.02$, $P < 0.05$, respectively) than PF and PAE, although these values did not vary significantly between AP and LPAE (**Table 4**).

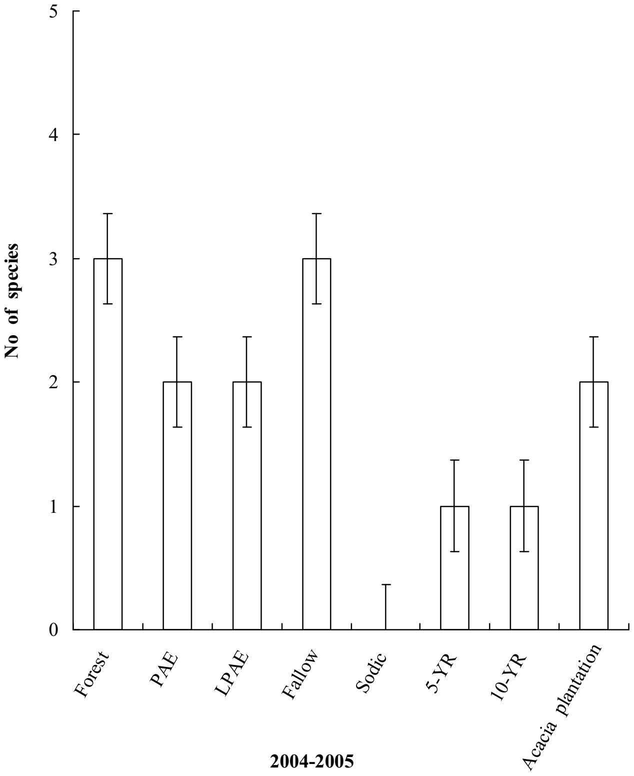

Fig. 1 Effect of land conversion and management practices on earthworm species richness.

Table 4 Total density and biomass of earthworm species across different sampling sites in Raebareli district of Indogangetic plains.

Sampling sites	Density (Individuals/m^2/yr)	Biomass (g/m^2/yr)
Natural forest	168 ± 10.2 a	378.9 ± 26 a
Productive agro ecosystem	276 ± 18.4 b	480.5 ± 35 b
Low productivity agro ecosystem	151 ± 13.4 c	412.5 ± 37 c
Abandonend agricultural fallow plot	288 ± 11.0 d	560.7 ± 42 d
Sodic agro ecosystem	0	0
5-year-old reclaimed agro ecosystem	143 ± 14.0 c	144.4 ± 11 e
10-year-old reclaimed agro ecosystem	282 ± 23.0 d	225.6 ± 19 f
Acacia plantation	177 ± 12.0 e	411.3 ± 29 c

Numbers followed by the same letter are not significantly different ($P < 0.05$) between different sites.
± SE, $n = 10$

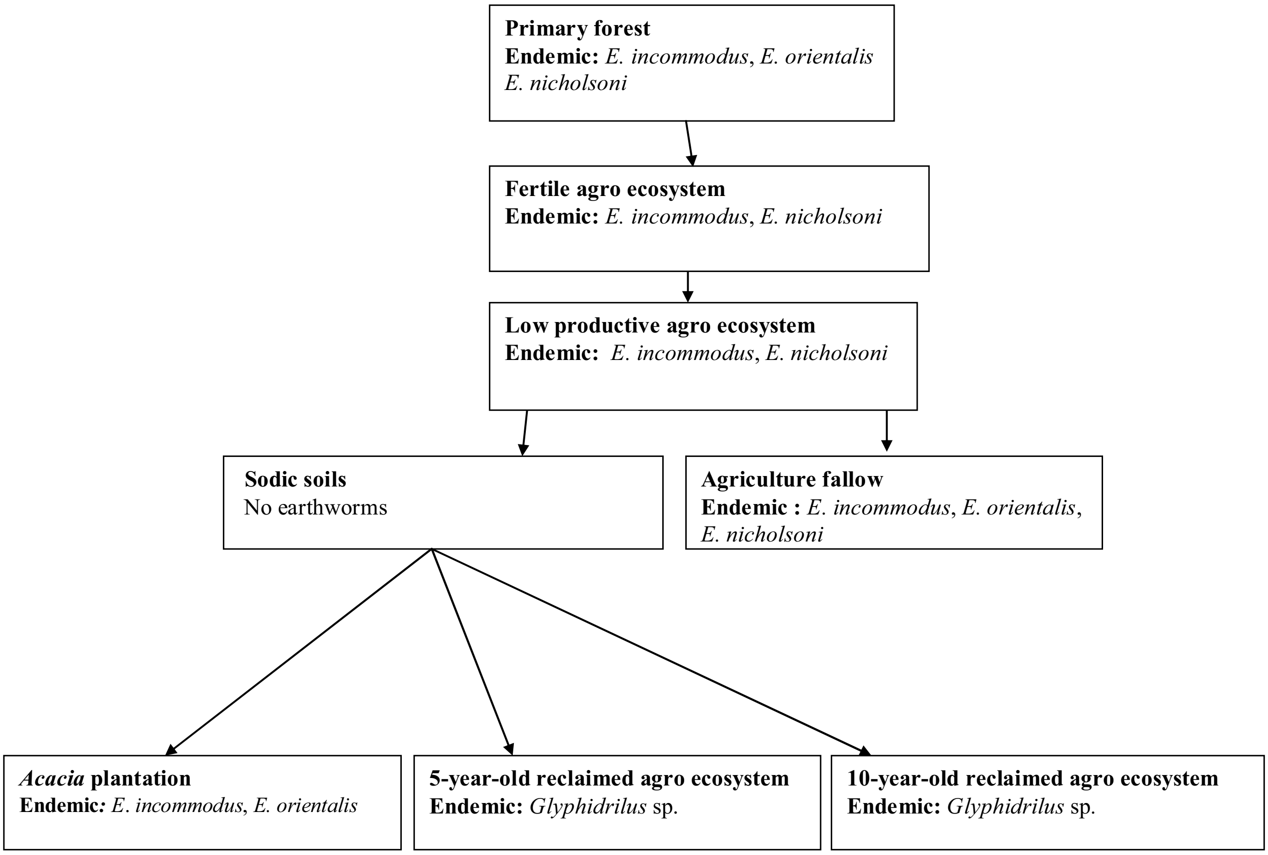

Fig. 2 Changes in endemic and exotic earthworm species composition and distribution pattern following the changes in land use patterns.

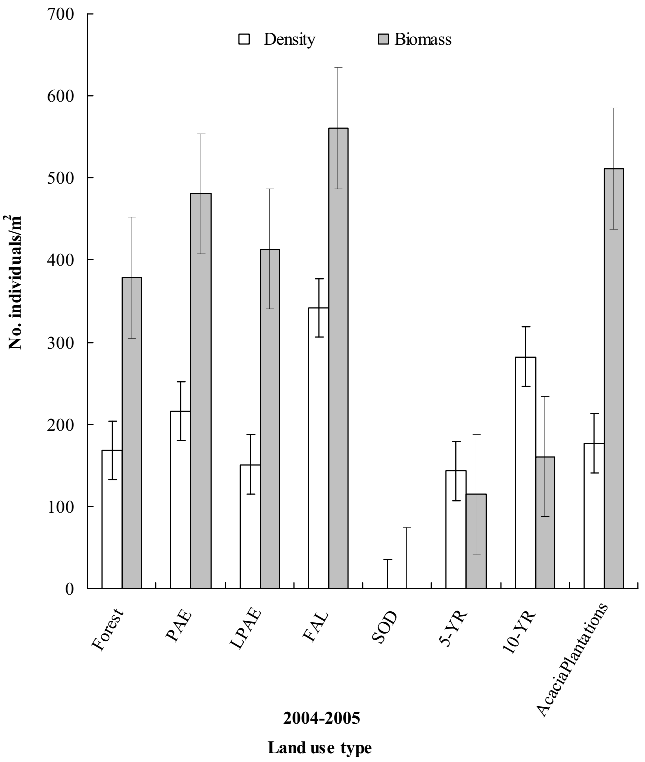

Fig. 3 Effect of land conversion and management practices on Density (No./m²) and Biomass (g/m²) of endemic earthworms.

Intrahabitat variation

Of the three species present in PF, *E. incommodes* was the dominant species having significantly higher density (F = 15.09, P < 0.05) and biomass (F = 8.73, P < 0.05) values than the other two species. *E. nicholsoni* had significantly higher density (F = 8.42, P < 0.05) and biomass (F = 7.98, P < 0.05) values than *E. incommodes* in both PAE and LPAE. *E. orientalis* was absent under the agro-ecosystems, but was present in AAFP. *E. orientalis* had higher density (F = 29.78, P < 0.01) and biomass (F = 28.71, P < 0.01) values than *E. nicholsoni* and *E. incommodes*. *Glyphidrilus* sp. was the only species present in both 5 and 10 Yr RA. In AP *E. incommodes* had significantly higher density (F = 9.7, P < 0.05) and biomass (F = 5.42, P < 0.05) values than *E. nicholsoni* (**Table 5**).

Interhabitat variation

Population density and biomass values of *E. incommodes* did not vary significantly between PF, PAE and AAFP. However, density (F = 4.94, P < 0.05) and biomass (F = 4.35, P < 0.05) values of this species declined significantly in LPAE. *E. orientalis* was restricted to PF and AAFP only with significantly higher density (F = 5.62, P < 0.05) and biomass (F = 3.52, P < 0.05) values in AAFP. *E. nicholsoni* had significantly higher density (F = 9.1, P < 0.05) and biomass (F = 30.25, P < 0.05) values in PAE than in PF, AAFP and AP. However, the biomass value of *E. nicholsoni* did not vary significantly between PAE and LPAE. *E. incommodes* had significantly higher density (F = 9.62, P < 0.01) and biomass (F = 8.27, P < 0.01) values in reclaimed AP than all other sites, under 5 and 10 Yr RA biomass (F = 43.04, P < 0.05) and density (F = 22.10, P < 0.05) values of *Glyphidrilus* sp. were significantly higher (P < 0.05) in 10 Yr RA (**Table 5**).

Functional guild changes within same site

The study of earthworm species in a gradient of PF disturbance showed the presence of an anecic species *E. nicholsoni* and two endogeic species *E. incommodes*, *E. orientalis* in PF. Their relative abundance and biomass values changed with associated land use types within the same site, endo-

Table 5 Inter- and intrahabitat variations in density (individuals/m^2/year), and biomass (g/m^2/year; values in parenthesis) of earthworm species across different sampling sites in the Indogangetic plains.

Density (biomass)				
Natural forest	$_{\alpha}$91 ± 4.5 a	$_{\beta}$36 ± 1.9 a	$_{\beta}$41 ± 2.3 a	0
	($_{\alpha}$91.1 ± 10.2 a)	($_{\beta}$64.8 ± 2.5 a)	($_{\gamma}$123 ± 6.6 a)	
Productive agroecosystem	$_{\alpha}$75 ± 3.6 a	0	$_{\beta}$141 ± 6.2 b	0
	($_{\alpha}$157.5 ± 11.2 a)		($_{\beta}$323 ± 15.6 b)	
Low productivity agroecosystem	$_{\alpha}$45 ± 3.2 b	0	$_{\beta}$106 ± 5.6 c	0
	($_{\alpha}$94.5 ± 4.5 b)		($_{\beta}$318 ± 18.2 b)	
Abandoned agricultural fallow plot	$_{\alpha}$85 ± 6.3 a	$_{\beta}$89 ± 10.5 b	$_{\gamma}$64 ± 4.4 a	0
	($_{\alpha}$178.5 ± 12.6 a)	($_{\beta}$340.2 ± 16.4 b)	($_{\gamma}$42 ± 3.8 c)	
Sodic agroecosystem	0	0	0	0
5-year-old reclaimed agroecosystem	0	0	0	143 ± 7.7 a
				(114.4 ± 8.4 a)
10-year-old reclaimed agroecosystem	0	0	0	282 ± 15.4 b
				(160. 6 ± 10.5 b)
Acacia plantation	$_{\alpha}$133 ± 9.1c		$_{\beta}$47 ± 3.2 a	
	($_{\beta}$279.9 ± 13.7 c)		($_{\beta}$132 ± 7.8 a)	

Values followed by different Roman letters are significantly different ($P < 0.05$) between different sampling sites.
Values followed by different Greek subscripts are significantly different ($P < 0.05$) between same sampling sites.
± SE, n =10

Table 6 Effect of management practices in different land uses on density (individuals/m^2/year), and biomass values (g/m^2/year) of functional categories of earthworms in the Indogangetic plains.

	Density (Anecic)	Biomass (Anecic)	Density (Endogeics)	Biomass (Endogeics)
Natural forest	$_{\alpha}$41 ± 3.2 a	$_{\alpha}$23 ± 11.6 a	$_{\beta}$127 ± 13.8 a	$_{\beta}$255.8 ± 20.6 a
Productive agroecosystem	$_{\alpha}$141 ± 1.6 b	$_{\alpha}$323 ± 23.5 b	$_{\beta}$75 ± 6.3 b	$_{\beta}$157.5 ± 13.3 b
Low productivity agroecosystem	$_{\alpha}$106 ± 7.9 c	$_{\alpha}$318 ± 27.8 b	$_{\beta}$45 ± 3.2 c	$_{\beta}$94.5 ± 6.8 c
Abandoned agricultural fallow plot	$_{\alpha}$64 ± 3.8 d	$_{\alpha}$42 ± 2.9 c	$_{\beta}$274 ± 14.6 d	$_{\beta}$518.7 ± 42.6 d
Sodic agroecosystem	0	0	0	0
5-year-old reclaimed agroecosystem	0	0	143 ± 12.7 e	114.4 ± 5.8 c
10-year-old reclaimed agroecosystem	0	0	282 ± 24.7 d	160.6 ± 15.3 b
Acacia plantation	$_{\alpha}$44 ± 5.3 a	$_{\alpha}$132 ± 5.9 a	$_{\beta}$133 ± 9.6 a	$_{\beta}$279.3 ± 21.5 e

Values followed by different Roman letters are significantly different ($P < 0.05$) between different sampling sites.
Values followed by different Greek subscripts are significantly different ($P < 0.05$) between same sampling sites.
± SE, n =10

geic species had significantly higher density (U = 25, P < 0.05) and biomass (U = 27, P < 0.05) than anecic species in PF and AAFP (density U = 35, P < 0.05, biomass U = 38, P < 0.05). Anecics were significantly dominant with higher density and biomass values in PAE and LPAE (density U = 25, P < 0.05, biomass U = 27, P < 0.05) than endogeic species. SE was deprived of any ecological category. Both endogeic and anecics recolonized AP with endogeic species having significantly higher density (U = 35, P < 0.05) and biomass (U = 33, P < 0.05) values. Only endogeic species recolonized both 5 and 10 Yr RA.

Functional guild changes between different sites

Density (F = 12.56, P < 0.05) and biomass (F = 11.25, P < 0.05) values of anecic species varied significantly between different sites. Density (F = 15, P < 0.05) and biomass (F = 9, P < 0.05) values of anecic species improved significantly in PAE than PF with subsequent decline in AAFP and AP. The biomass values of these species did not vary significantly between PAE and LPAE. Density and biomass values of endogeic species declined with the conversion of PF to agro ecosystems, but their abundance (F = 11.25, P < 0.05) and biomass values (F = 11, P < 0.05) improved significantly in AAFP. Density (F = 8.98, P < 0.05) and biomass (F = 14, P < 0.05) values of endogeic species were significantly higher in 10 Yr RA than 5 Yr RA, but based on their biomass values (F = 8.20, P < 0.05) alone, they were the dominant functional group in AP than both 5 Yr RA and 10 Yr RA (**Table 6**).

Seasonal variation

Population density of all the earthworm species varied seasonally in response to the seasonal changes in soil moisture and temperature. *E. nicholsoni* was present through out the year in the PF, AP and in AAFP, and had significantly higher population density values in PF (H = 7.35, P < 0.05), AP (H = 7.95, P < 0.05) and in AAFP (H = 6.41, P < 0.05) during rainy season than winter and summer (**Table 7**).

Table 7 Correlation coefficient for soil parameters and earthworm species across different sampling sites in the Indogangetic plains.

	Moisture (%)	Temperature (ºC)	Organic matter (%)
E. incommodes	0.88 *	0.91 *	0.84 *
E. orientalis	0.95 **	0.88 *	0.91 **
E. nicholsoni	0.92 **	0.91*	0.93 **
Glyphidrilus sp.	0.96 **	0.85 *	0.85 *

*: P < 0.05, **: P < 0.01

Population density values of *E. orientalis* were significantly higher during rainy season in PF and in AAFP than the winter months, but it was absent during the summer months. *E. incommodes* showed similar seasonal pattern as *E. orientalis* with significantly higher population density values in PF (H = 6.21, P < 0.05), AP (H = 6.41, P < 0.05) and in the AAFP during the rainy season, and was absent during the summer months in AP and PF (**Fig. 4A-C; Fig. 5A-C**). In the PAE population density values of *E. incommodes* (F = 10.25, P < 0.05) and *E. nicholsoni* (F = 9.45, P < 0.05) improved significantly in October subsequent to the harvest of rice crop with a decline in the wheat crop, both the species were absent in the intervening fallow period. In LPAE both *E. incommodes* and *E. nicholsoni* showed significant increase in the population density values (F = 8.84, P < 0.05) during July, with subsequent decline in the abundance thereafter, the latter species showed a small peak of increased density values during October, as in PAE here also both the species were absent in the intervening fallow period. Population density values of *Glyphidrilus* sp. increased significantly (F = 7.95, P < 0.05) in September and October corresponding to harvest of rice crop in 5 Yr RA, where as in 10 Yr RA *Glyphidrilus* sp showed a minor

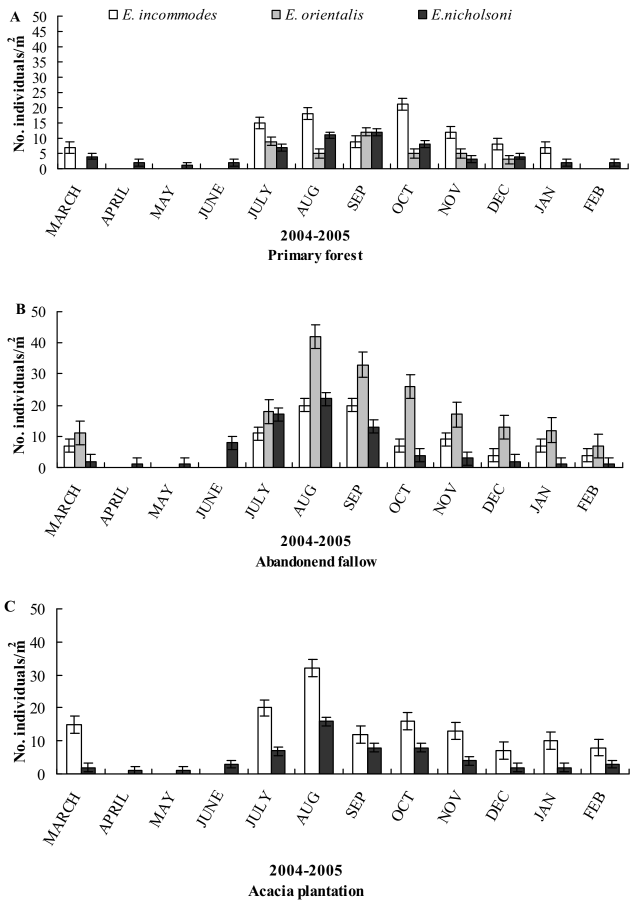

Fig. 4 Monthly changes in density (No./m^2) of earthworm species. (**A**) PF, (**B**) AAFP, (**C**) AP on reclaimed soil in the Indogangetic plains.

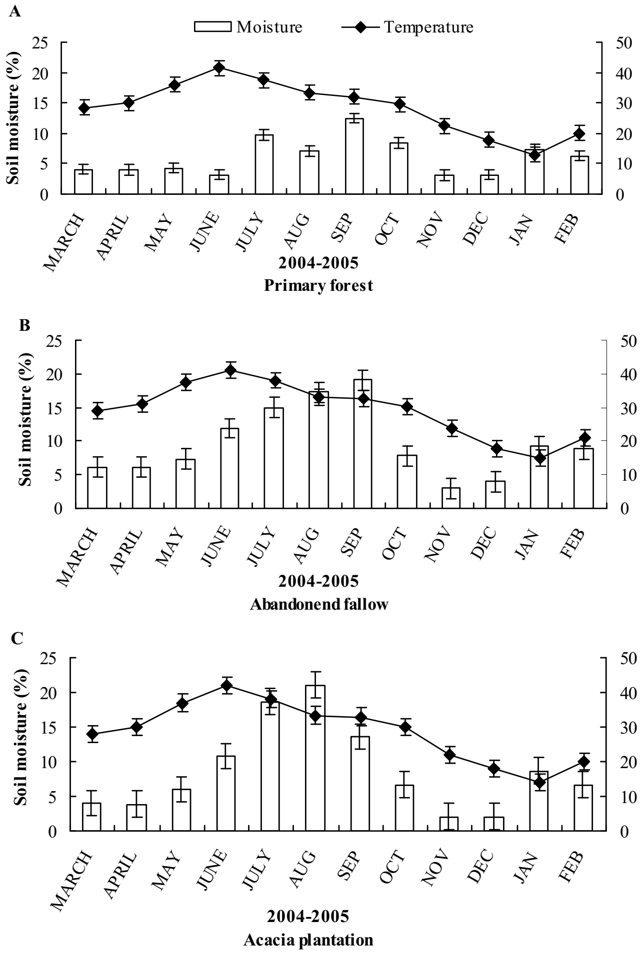

Fig. 5 Monthly fluctuations in soil moisture (%) and temperature (ºC). (**A**) PF, (**B**) AAFP, (**C**) AP on reclaimed soil in the Indogangetic plains.

increase in the density values during July and then a major peak of increased population density values (F = 8.73, P < 0.05) during September-October. This species was absent during the fallow period in 5 Yr RA but was present in the wheat crop under 10 Yr RA (**Fig. 6A-D; Fig. 7 A-D**).

DISCUSSION

Community structure

Conversion of natural PF to other land use types altered the habitat, which caused a shift in species composition and loss in species richness in the agro ecosystems, AP and the AAFP as has also been shown through the studies of Myers and Knoll (2001) and Delamini and Haynes (2004). The absence of original species composition in AP, as compared to PF even after a period of 15-20 years suggest that this is probably still the secondary successional stage over a time scale of 15 years (Folgarail *et al.* 2003). Higher species diversity in the PF could be explained to availability of diverse niches here.

Endemic versus exotics

The dominance of endemic earthworm species at all the sites could probably be explained as due to their better adaptation to local soil and climate condition (Callahan *et al.* 2006). This contradicts the report that native species dominate the undisturbed sites and disturbance and degradations leads to invasion by the exotic species (Callahan and Brail 1999). Resistance to invasion by exotic species here could be a function of physical and chemical characteristics of the site (Hendrix *et al.* 2006), and the unsuitability of the habitat probably impeded the invasion by the exotic species in the ecosystems under study (Hendrix and Bohlen 2002). Extreme degradation of agriculture ecosystems due to faulty land management practices probably led to the loss of earthworms in SE, as has also been shown through the studies of Delamini and Haynes (2004). Reclamation of degraded agro ecosystems over a period of 5 years led to recolonisation by another endemic species.

Density and biomass variations

Earthworms thrive best in moist soils and for this reason the earthworm fauna is depauperate in semi arid region of the Indogangetic plains (Julka and Paliwal 2005). The mean earthworm density in the AAFP, AP and in the PF was lower than that reported for similar ecosystems in Argentina by Thomas *et al.* (2004) and for the agro ecosystems in Bardsey Island by Edwards (1983). However the species richness observed in the present study falls with in the range of 1 to 7 as reported for cultivated soils (Haynes *et al.* 2003). Land use land cover change and management practices influence abundance and distribution of earthworm species (Bhadauria and Ramakrishnan 2005); land use intensification resulted in decline in the population density and biomass of earthworms probably due to alteration of habitat heterogeneity (Myers and Knoll 2001). Higher density and biomass of earthworms in the AAFP as compared to other experimental sites was probably due to large input of easily decomposable litter layer in form of root turnover which conserves moisture and improves the soil nutrient status thus supporting higher abundance of earthworms here, this pattern has been well documented by Haynes *et al.* (2003) and Frouze *et al.* (2006). Low resource diversity with high pH and low nitrogen and organic matter could probably account for lower density and biomass in 5 Yr RA and 10 Yr RA (Delamini and Haynes 2004). The improvement in

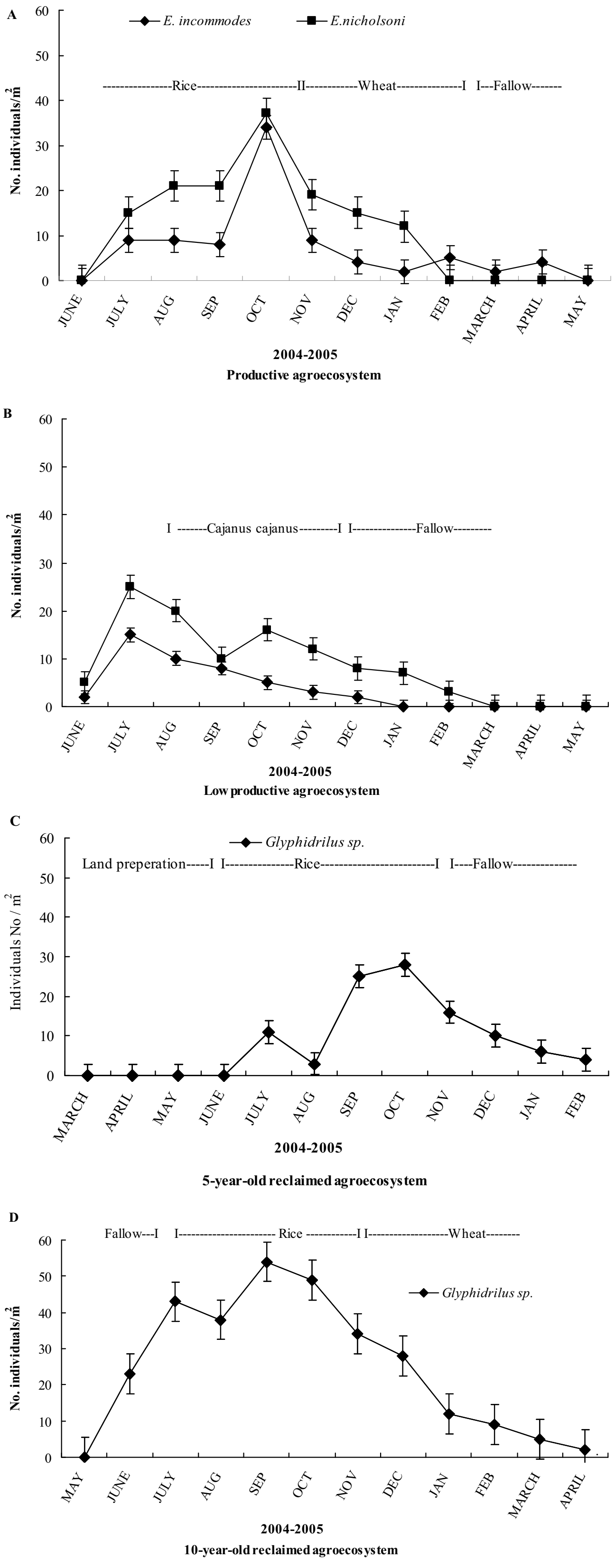

Fig. 6 Changes in density of earthworm species (No./m^2). (**A**) PAE, (**B**) LPAE, (**C**) 5 Yr RA, (**D**) 10 Yr RA during crop cycle in Indogangetic plains.

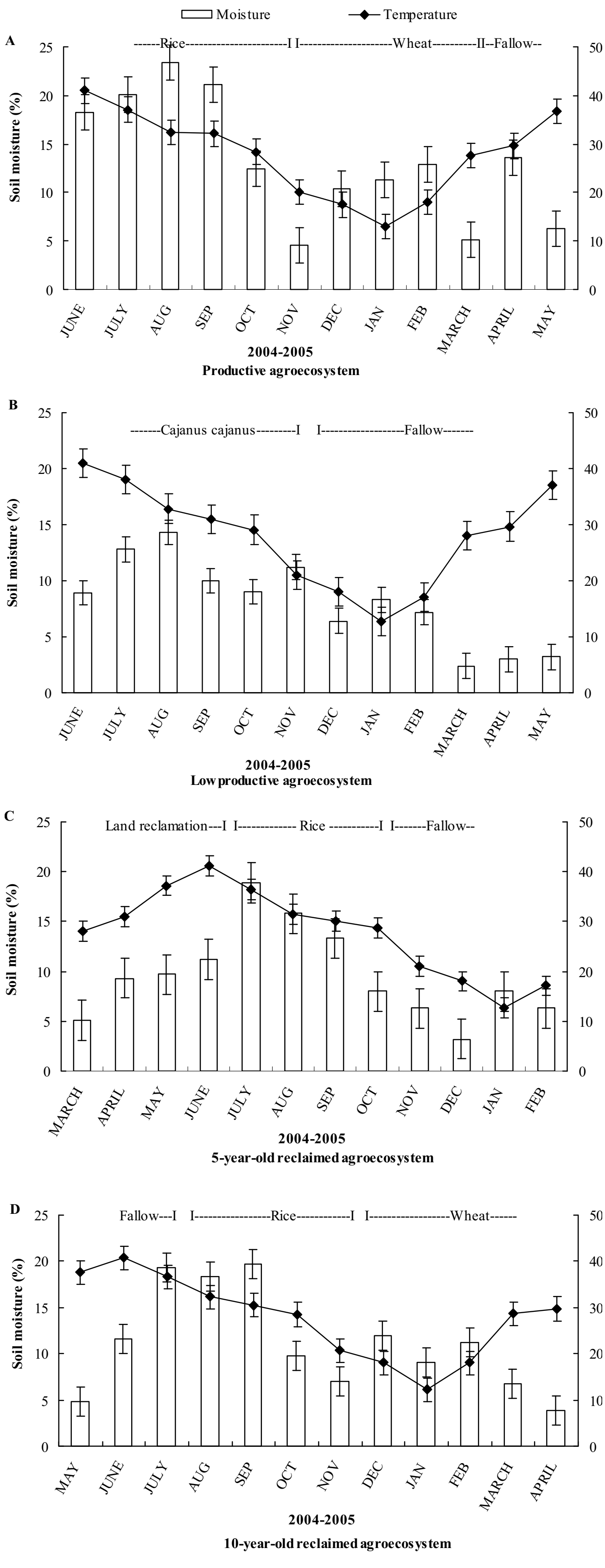

Fig. 7 Monthly fluctuations in soil moisture (%) and temperature (ºC). (**A**) PAE, (**B**) LPAE, (**C**) 5 Yr RA, (**D**) 10 Yr RA during crop cycle in Indogangetic plains.

the soil condition with organic matter input into the soil through the litter fall under AP could account for improved density and biomass of earthworms as compared to 5 Yr RA and 10 Yr RA (Kimbatsa *et al.* 2007). The overlap of *E. incommodes* in the PF, PAE and LPAE could be due to wider ecological amplitude of this species, but conversion of PF to PAE and LPAE resulted in the lower density and biomass of this species and elimination of *E. orientalis*, this could probably be linked to canopy cover differences and type of agriculture practices as earthworms are known to be more sensitive to vegetation cover changes (Haynes *et al.* 2003; Frouz *et al.* 2006). This alters the soil microclimatic condition related to disturbance regime and tillage activity and thus to decline in number or loss of some species (Altieri

1999). Relatively nutrient rich soils along with low perturbation pressure, low pH value and high soil moisture percentage favored the dominance of *E. orientalis* in the AAFP (Haynes and Hamilton 1999). The preference of *E. nicholsoni* for higher soil moisture percentage as well as quality of organic matter and soil nitrogen status (Julka 1988) resulted in the increased density and biomass of this species in PAE. The variation in the crop cycle in the agro ecosystems in same year resulted in lower earthworm population in LPAE as compared to PAE though the species composition remained the same. This difference could be attributed to the effect of crop rotation and agricultural management practices (addition of fertilizer, high moisture content, and mulch to the soil) during the cropping period under PAE that differs distinctly from LPAE (single legume crop taken over a period of one year along with low soil moisture and soil compaction and no fertilizer added) (Bhadauria *et al.* 1997; Fragoso *et al.* 1997). The hatching of juveniles of both the species *E. incommodes* and *E. nicholsoni* subsequent to harvest of paddy crop probably favored the increased density of these species in October in PAE. Addition of organic matter and fertilizer at the beginning of the cropping period in LPAE was correlated with increased population density of *E. incommodes* and *E. nicholsoni* species, subsequent tilling and ploughing operation and low soil moisture resulted in physical damage to the juveniles of these species causing the decline in population. Such population density changes due to perturbations have also been observed by Fraser (1994) and Bhadauria *et al.* (1997). The increased population density of *Glyphidrilus* species during the late rainy season could be associated with the higher soil moisture preference of this species (Julka 1988). Removal of the most of crop residues from the fields after rice crop harvest along with low soil moisture and temperature probably resulted in the decline of earthworm species number in the wheat crop mixture and following intervening short fallow period. Presence of completely different *Glyphidrilus* sp. in the 5 Yr RA and 10 Yr RA as compared to other sites could be associated with high soil pH and land management practices leading to microclimatic variation of the soil favoring this species, as has also been observed by Eggleton *et al.* (2005) through their studies in Scottish landscape. Further relatively stable soil environmental conditions probably resulted in increased density and biomass of *Glyphidrilus* sp. under 10 Yr RA. Increased plant density and undergrowth development in AP was probably responsible for improved density and biomass of *E. incommodes* and *E. nicholsoni* here as compared to 5 Yr RA and 10 Yr RA.

Functional guild

The conversion of PF to agro ecosystems led to a shift in functional categories from endogiec to anecic dominated composition; use of organic manure and higher soil moisture percentage prior to rice crop plantation probably favored the dominance of anecic species in the LPAE and PAE (Pizl 2001). Experimental studies (Butt *et al.* 2004) in the reclaimed plots have shown anecics to be slow colonizers of the reclaimed sites and this could probably explain their absence from the 5 Yr RA and 10 Yr RA. Endogeics being geophagus, their predominance in the AAFP and in AP could be because probably these habitats offered favorable base resource to the species which migrated from the surrounding plots to colonize and establish themselves in the new habitats (Pizl 2001; Winsome *et al.* 2006). The successful colonization of endogiec *Glyphidrilus* species in the 5 Yr RA and 10 Yr RA could also be associated with the preference of the species for submerged habitats rich in the moisture and organic matter (Julka 1988). Dominance of endogeics in the disturbed habitats has also been shown through the studies of Blanchart and Julka (1997) and Bhadauria and Ramakrishnan (2005).

Seasonal variation

Seasonal variation has been shown for macro faunal assemblages for temperate (Berg *et al.* 1998), for tropical (Rossi and Blanchart 2005) and for semiarid region (Miranda *et al.* 2007), similar seasonal rhythm for all the species was also observed in our studies. The increase in the population density and the biomass of all earthworm species during the rainy season could be attributed to better soil moisture and temperature condition, with subsequent decline in the population associated with declining soil moisture and temperature conditions in winters (Delamini and Haynes 2004; Rossi and Blanchart 2005).

CONCLUSIONS

From the results so obtained it can be concluded that land use intensification strongly influences species composition according to the land management practices, thereby leading to shift in the range of species and/or local extinction. Due to wider ecological amplitude, some species show overlap between the natural and degraded ecosystems. Resistance to invasion by exotic species could be a function of physical and chemical characteristics of the site and the unsuitability of the habitat probably impeded the invasion by the exotic species in the ecosystems under study. Functional guild changes with the change in land management practices, and endogeics dominated the disturbed and degraded ecosystems. Extreme degradation of agriculture ecosystems led to the loss of earthworms however reclamation of degraded ecosystems can lead to recolonization by some earthworm species having good adaptation to low soil nutrient condition and disturbances which in turn can further enhance soil reclamation process through their activity. From these conclusions it can be inferred that by manipulating the existing earthworm fauna through suitable management techniques under disturbed and degraded ecosystems, the soil fertility can be sustained over longer period of time.

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