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Impact of *Tithonia diversifolia* (Hemsly) A. Gray on the soil, species diversity and composition of vegetation in Ile-Ife (Southwestern Nigeria), Nigeria

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In Nigeria, most especially in the southwestern region, *Tithonia diversifolia* (Hemsly) A. Gray had been identified to be invasive following their introduction and fast spread, displacing the native species and affecting the soil nutrient status. Hence, we decided to evaluate the impact of *T. diversifolia* on the diversity and floristic compositions of native species and soil nutrient status of the invaded vegetation. Sample plots, 5 x 5 m each were established on invaded and uninvaded area in 10 sites in area invaded by *T. diversifolia*. In each plot, plant species enumeration was done to the species level and species diversity, evenness and index of similarity were evaluated. Soil samples were randomly collected at depth 0-15 cm and analyzed for chemical properties (pH, organic carbon, exchangeable cations (Ca, Mg, K and Na), nitrogen and phosphorus). One way ANOVA was used to determine significant difference in soil properties on invaded and uninvaded plots. The result showed that as compared to the control, in the *Tithonia* invaded area, the average number of plant species reduced by 25.4%; the Shannon-Wiener diversity reduced by 27% while the evenness reduced by 24.9% and the Sorensen index of similarity between the invaded and uninvaded plots for *Tithonia* was 32.6%. The invaded plots had higher pH, organic carbon, N, P and exchangeable cations than the uninvaded plot ($p=0.05$). We concluded that invasion of *T. diversifolia* is drastically affecting the diversity of the invaded areas and had significantly improved the soil fertility of the invaded sites.

Key words: Invasive species, biological diversity, Shannon-Winner.

INTRODUCTION

The biota of the world is being homogenized as a result of the decline of native species and their replacement by a relatively small number of alien species that either deliberately or accidentally moves beyond their natural ranges (McKinney and Lockwood, 1999). These invasive alien species have encroached into many ecosystems and communities throughout the world, disrupting ecosystem structure and function and, thus, reducing native biodiversity (Borgmann and Rodewald, 2005). These outcompete native species or occupy the available niches in

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alien environment (Cowie, 1998) and cause major economic loss in countries around the world, by decreasing growth and productivity of useful species (Pimentel et al., 2000). The increasing rate of invasion and deliberate introduction of aliens into an area by man is the by-product of the globalization of regional economics. Large parts of the world are presently dominated by human modified ecosystems that often comprise a greater biomass of introduced than native organisms (Vitousek et al., 1997). Besides human actions, several other factors contribute to successful invasion by alien plants. The climatic and edaphic similarities between the original and new habitats are very important factors for the establishment of such species (Holdgate, 1986). Biological invasion are clearly a potential force of change, operating on a global scale and affecting many dimensions of society (Wilcove et al., 1998; Ohlemuller et al., 2006).

Tithonia diversifolia (Hemsly) A. Gray (Asteraceae), commonly called Mexican sunflower, is a common shrub (weed) native to Central America but has become naturalized in many tropical countries, including Nigeria. It is now widely distributed throughout the humid and sub-humid tropics in Central and South America, Asia and Africa (Sonke, 1997), and it is common in indigenous fallow systems in Southeast Asia. *Tithonia* was probably introduced into Africa as an ornamental (Akobundu and Agyakwa, 1987). It has been reported to be present in Kenya (Niang et al., 1996), Malawi (Ganunga et al., 1998), Nigeria (Ayeni et al., 1997), Rwanda (Drechsel and Reck, 1998), Zimbabwe (Jiri and Waddington, 1998) and Zambia (Muoghalu and Chuba, 2005).

T. diversifolia is now prominent and fast-growing in Nigeria, inhabiting the rainbelt of the southern part of Nigeria, especially the southwestern and the coastal regions. It also inhabits the wet part of the Guinea savanna, especially along the fringes of the rain belt (latitude 6-9°N). States with infestation include Lagos, Ogun, Osun, Ekiti, Ondo, Edo, Imo, Anambra, Delta, Bayelsa, Rivers, Abia, Enugu, Ebonyi, Cross River, Benue, Kogi, Oyo, Kwara, Taraba (Agboola et al., 2005) and Plateau State.

T. diversifolia is an invasive, annual weed, growing aggressively along road path, abandoned farmlands and hedges all over Nigeria (Shokalu, 1997). It has been used successfully to improve soil fertility and crop yields in Kenya (Jama et al., 2000), Malawi (Ganunga et al., 1998), Nigeria (Ayeni et al., 1997), Rwanda (Drechsel and Reck, 1998) and Zimbabwe (Jiri and Waddington, 1998). It has also been found in Cameroon, Uganda and Zambia (Shokalu, 1997). It has different uses, such as ornamental plant, animal feed (Farinu et al., 1999; Olayemi, 2006), insecticide (Akanbi et al., 2007), nematicide and soil fertility improvement (Jama et al., 2000). Other reported uses of *Tithonia* include fodder (Anette, 1996; Roothaert and Patterson, 1997; Roothaert et al., 1997), poultry feed (Odunsi et al., 1996), fuelwood (Ng'inja et al., 1998), compost (Drechsel and Reck, 1998; Ng'inja et al., 1998), land demarcation (Ng'inja et al., 1998), soil erosion control (Ng'inja et al., 1998), building materials and shelter for poultry (Otuma et al., 1998). In addition, extracts from *Tithonia* plant parts reportedly protect crops from termites (Adoyo et al., 1997) and contain chemicals that inhibit plant growth (Baruah et al., 1994; Tongma et al., 1997), control insects (Carino and Rejestes, 1982; Dutta et al., 1993) and possess medicinal value for treatment of hepatitis (Lin et al., 1993; Kuo and Chen, 1997) and control of amoebic dysentery (Tona et al., 1998).

T. diversifolia propagates from seeds and vegetative growth (Muoghalu and Chuba, 2005). Seeds frequently germinate naturally under the tithonia canopy, and the seedlings can be dug up and transplanted elsewhere. When established from seeds in the field, germination can be poor if the seeds are sown deep or covered with clayey soil and covering the seeds with a thin layer of sandy soil and grass mulch can enhance germination (King'ara, 1998).

In Nigeria, most especially in the southwestern region, *T. diversifolia* had been identified to be invasive following its introduction and is fast spreading, displacing the native species and affecting the soil nutrient status. There has been paucity of studies on the impact of *T. diversifolia* on the species diversity, composition and soil nutrient status of the invaded vegetation. This study therefore investigated the impact of *T. diversifolia* on the soil, species diversity and composition of vegetation.

METHODOLOGY

Study area

This study was carried out in Ile-Ife in southwestern Nigeria. Ile-Ife lies within latitudes 07°30' N to 07°35' N and longitudes 04°30' E to 04°35' E. The original vegetation of Ile-Ife has been described as lowland forest zone (Keay, 1959), semi deciduous moist forests (Charter, 1969) and Guineo-Congolian forest drier type (White, 1983). Hall (1969) also described the vegetation as the dry forest sub-group Figure 1.

There are two prominent seasons in Ile-Ife area: a rainy and a dry season. The dry season is short, usually four months from November to March, and longer rainy season prevails during the remaining months. The weather report from the meteorological stations located within OAU Teaching and Research farm showed the annual rainfall at Ile-Ife averaged 1400 mm year^{-1} in a 5-year survey (Oke and Isichei, 1997) and mean annual temperature ranges from 22.5 to 31.4°C (Odiwe et al., 2012). The relative humidity in the early morning is generally high, usually over 90% throughout the year. At midday it is rather lower, around 80% in the wet season, as low as 50-60% in the dry season (Hall, 1969).

The geology of the area is underlain by the Precambrian basement complex of the southwestern Nigeria. The rock consists of banded gneisis and migmatite quartzites, quartz, mica, schists and related rocks (Smyth and Montgomery, 1962).

The soils of the area are moderately to strongly leached and have low to medium humus contents, weakly acidic to neutral surface layers and moderately to strongly acidic sub soils (Smyth and Montgomery, 1962). It is derived from materials of old basement complex which is made up of granitic, metamorphosed

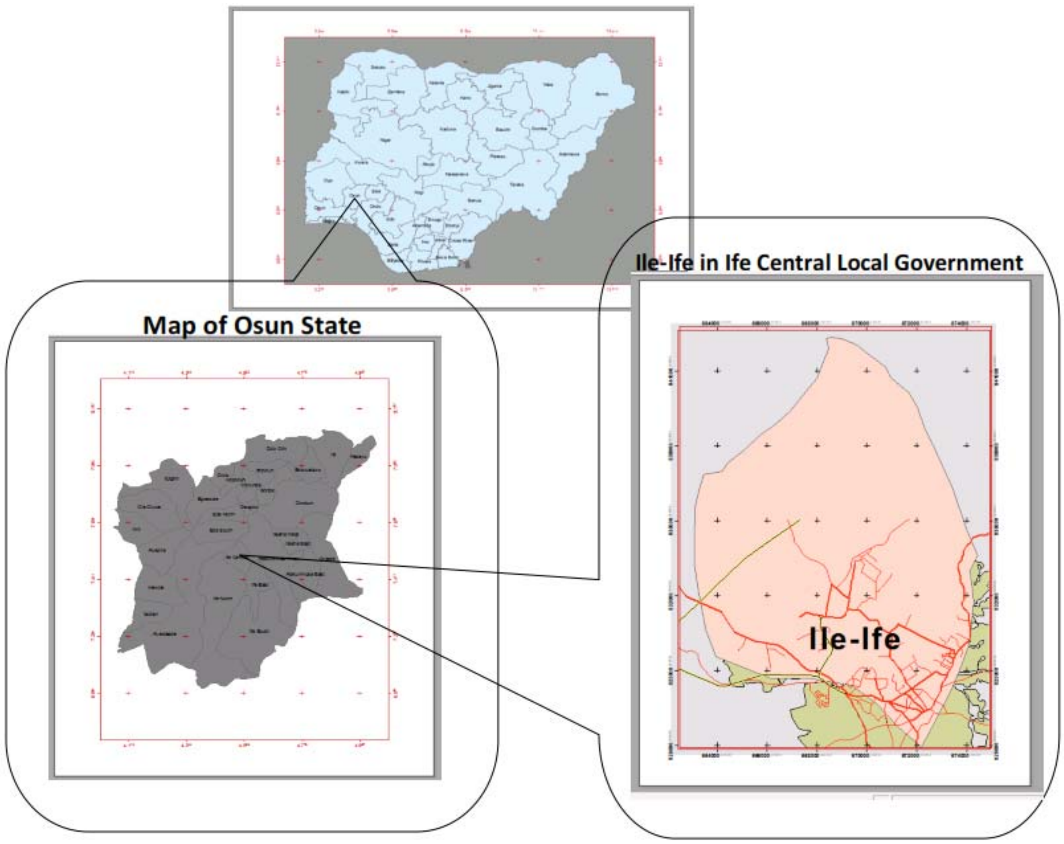

Figure 1. Location of Ile-Ife in Osun State, Nigeria.

sedimentary rock (Hall, 1969).

Vegetational analysis

An extensive search of sites heavily invaded by *T. diversifolia* in different locations at Ile-Ife was carried out. Ten of such sites were selected and sample plots established in them. In each location, a pair of 5 x 5 m adjacent sample plots was established. One plot of the pair was placed at *T. diversifolia* invaded vegetation (invaded plot) where *T. diversifolia* was dominant and has a high cover, and the second plot was allocated at neighboring vegetation, where the *T. diversifolia* has no cover (uninvaded plot). The uninvaded plot was chosen so as to have similar site conditions as possible to the invaded plot. The geographic locations of sample plots as determined by Geographic Positioning System (GPS) are shown in Table 1.

In each plot, all species of vascular plants were identified to the species level. Specimens of plant species that could not be identified in the field were collected, pressed and identified in the IFE Herbarium (IH). The species composition of the plots was established by listing the plant species encountered in each plot, summing up to get the total number of plant species for the plot. Authorities of botanical nomenclature follow the Flora of West Tropical Africa (Hutchinson and Dalziel, 1954-72).

Three 5-m line transects were randomly established in each plot. At every metre point along each transect, the cover of the plant species in the plot was taken. The number of 'hits' on each species was used to calculate the percentage cover of the species in the plot. Species cover was used as importance values for calculating the Shannon-Wiener diversity index (H') and evenness (J'). Evenness was calculated as H'/lnS, where S is the species richness expressed as the number of species. Differences in species richness, Shannon-Wiener index (H') and evenness (J') between invaded and uninvaded plots were used to measure the effect of invasion on these community characteristics.

The Shannon diversity index (H') was used to characterize species diversity in each plot using the formula.

To assess the impact of invasion on species composition of resident species, Sorensen index of similarity (ISs) between each plot pair was calculated based on species presence.

In addition, for each invasive species studied, the total number of species recorded in all plots with invaded and uninvaded vegetation (Stotal) was used as a measure of the impact of the invasion on species richness S. This was expressed as the percentage reduction of the total number of species recorded in invaded (S_{tot} inv) plots as compared to that recorded in uninvaded plots (S_{tot} uninv = 100%). Positive and negative values indicate a higher species number in uninvaded and invaded vegetation, respectively.

Soil analysis

Five soil samples each were randomly collected to a depth of 0-15 cm from invaded and uninvaded plots using a soil auger. The five samples were bulked for each plot, air-dried and sieved through <2 mm mesh size for chemical analysis. The soil samples were analysed for soil pH, exchangeable cations (Ca, Mg, K and Na), total nitrogen, available phosphorus and organic matter. Soil pH was determined in 0.01 M $CaCl_2$ (1:2 soil solution ratio) using a glass

Table 1. GPS locations of invaded and uninvaded sites for *T. diversifolia*.

Site	*Tithonia diversifolia*	
	Invaded	Uninvaded
1	N07° 30.380, E004° 32.706	N07° 30.391, E004° 32.704
2	N07° 30.156, E004° 33.265	N07° 30.164, E004° 33.718
3	N07° 31.889, E004° 34.966	N07° 31.895, E004° 34.962
4	N07° 30.725, E004° 31.062	N07° 30.707, E004° 31.045
5	N07° 32.153, E004° 32.217	N07° 32.141, E004° 32.200
6	N07° 32.131, E004° 32.210	N07° 32.139, E004° 32.216
7	N07° 31.308, E004° 33.295	N07° 31.322, E004° 33.278
8	N07° 31.088, E004° 32.553	N07° 31.101, E004° 32.545
9	N07° 32.147, E004° 32.381	N07° 32.138, E004° 32.375
10	N07° 33.421, E004° 31.805	N07° 33.417, E004° 31.796

Table 2. Impact of *T. diversifolia* on community characteristics of invaded sites.

Parameter	Uninvaded	Invaded	decrease over uninvaded (Impact) (%)
Total species	59	44	(-)25.4
Total number of families	25	24	(-)4.0
Shannon's index of diversity (H')	2.9836	2.1787	(-)27.0
Index of evenness (J’)	0.8036	0.6035	(-)24.9
Similarity index		32.6%	
Dissimilarity index		67.4%	

electrode pH meter (Pye model 292). Total nitrogen, available phosphorus and exchangeable cations (Ca, Mg, K, Na) analyses were done according to the method of International Institute of Tropical Agriculture (IITA) Manual Series No 7 (Tel and Rao, 1982). The soil organic matter was determined using Walkey–Black method (Black, 1965). The plant samples collected from both inva-ded and uninvaded plots were analysed for nitrogen, phos-phorus, potassium, calcium, magnesium and sulphur according to the method of International Institute of Tropical Agriculture (IITA) Manual Series No 7 (Tel and Rao, 1982).

Statistical analysis

For each experiment, statistical analysis was done using software programmes like SPSS ver. 10.0. For determining the significance of a single treatment with control (paired treatment), ANOVA was applied. Significance of difference between soil characteristics of control and weed invaded sites was determined using one way ANOVA at $P \leq 0.05$.

RESULTS

Impact of *T. diversifolia* invasion on the structure of invaded communities

The invasion of *Tithonia diversifolia* drastically reduced the species composition of the invaded communities by 25.4%, from 59 species in the uninvaded area to 44 species in the invaded area (Table 1). The similarity index of the communities in the invaded and uninvaded areas was only 32.6% (Table 1), which shows a clear indication of loss of species due to the invasion of *T. diversifolia*. The Shannon-Wiener diversity of the *T. diversifolia* for uninvaded sites was 2.984 while it was 2.179 in the invaded sites. This is a reduction of 27.0% in species diversity as a result of invasion (Table 2).

Species evenness (J’) was significantly decreased from 0.8036 in uninvaded to 0.6035 in invaded communities (24.9% reduction) due to the invasion of *T. diversifolia* (Table 2).

Impact of *T. diversifolia* invasion on species composition of invaded communities

Tithonia invasion heavily disturbs the composition and structure of species in the invaded habitats. In the pre-sent study, floristic composition between *Tithonia* invaded and uninvaded areas was compared. There were 34 families observed in *T. diversifolia* invaded and uninva-ded sites with Fabaceae having the highest number (9) of species. Twenty-five of these families were present in uninvaded plots and 24 in invaded plots. Fifteen families were common to the plots while 19 families were present in only one plot.

The list of families encountered in both invaded and uninvaded plots for *Ti. diversifolia* are Malvaceae, Araceae, Amaranthaceae, Fabaceae, Euphorbiaceae, Sapindaceae, Poaceae, Acanthaceae, Combretaceae, Cucurbitaceae, Apocynaceae, Icacinaceae, Piperaceae, Celastraceae and Sterculiaceae Table 3.

Impact on soil nutrients

The soil pH of invaded sites was significantly higher than that of uninvaded sites (F = 39.421, P≤0.05) (Table 4). It was slightly alkaline in the invaded sites (Table 4).

The soil nitrogen concentrations of the *T. diversifolia* invaded sites were significantly higher than that of the uninvaded sites (F=53.513, P≤0.05) (Table 4). The concentrations of all the other soil properties (organic carbon, calcium, magnesium, potassium, sodium and phosphorus) in the invaded sites by the invasive species were significantly higher than those of the uninvaded sites (*T. diversifolia* invaded sites: organic carbon, F= 51.60, P≤0.05; Ca, F= 56.85, P≤0.05; Mg, F= 39.451, P≤0.05; K, F= 16.91, P≤0.05; Na, F= 26.47, P≤0.05; P, F= 13.82, P≤0.05). There were no significant differences in the soil concentrations of these elements in *T. diversifolia* invaded sites (Table 4). However, while the soil pH and the concentrations of nitrogen, magnesium, potassium and sodium in invaded sites were not significantly different, their carbon (F= 60.615, P≤0.05), calcium (F= 53.682, P≤0.05) and phosphorus (F= 9.515, P≤0.05) were significantly different (Table 4).

Percent organic carbon in the invaded sites was increased bt nearly 27.1% by *T. diversifolia* and the increase in the available nitrogen content by *T. diversifolia* invasion (39.45%) was highest among all other nutrients. The soil available phosphorus, potassium and sodium concentrations were increased by 18.54, 37.05 and 35.25% by *T. diversifolia* invasion when compared with those of uninvaded sites. Similarly, the soil concentrations of available calcium and magnesium were increased by 38.11 and 25.6% respectively in the *T. diversifolia* invaded soil.

DISCUSSION

Being primary producers, the plants are the major components of the ecosystem. So, it is very important to save the plant kingdom from various threats to sustain all other living beings. The higher loss in the case of the plants growing in invaded areas shows that they become less productive in comparison with the plants in the control area. The pressure created by the invasive species in the invaded habitats disturbs the functions of biological communities and reduce the diversity of species and dependent fauna (Kinzig et al., 2001). To respond effectively to the invasive species problems, quantitative measurements of the impact of invasion on diversity are required (Schooler et al., 2006).

T. diversifolia has become a very strong invader in south western part of Nigeria and it has increased its density and abundance in the invaded habitats as a result posing a threat to the extinction of native species. An increasing abundance of the invaders can decrease the diversity of species (Kercher and Zedler, 2004). Much effort has been put into identifying determinants constraining broad-scale variability in species richness (Francis and Currie, 2003; Rahbek, 2005). It is apparent that the factors influencing patterns of species richness vary with the geographical extent and sample resolution (Willis and Whittaker, 2002). Therefore, only by multiple analyses scales for different locations and at various spatial scales, general explanations of broadscale species richness, diversity and distribution patterns can be derived (Zhao and Fang, 2006).

It is concluded from the studies that *T. diversifolia* is a strong invader in these areas and its increased abundance, cover and density poses a threat to the native species which also include medicinally important species. The decrease in ecological indices (Shannon Weinner diversity, abundant species, index of evenness etc.) in the *T. diversifolia* invaded habitats clearly signifies that these become less productive and stable as compared to non-invaded habitats. There were some species which were totally lost in the invaded areas while some other species preferred to grow there. The absence of seedlings of tree species like *Vigna gracilis*, *Euphorbia hirta, Indigofera trifoliate*, *Icacinea trichanta* and *Milletia thonningi* in the invaded areas showed that it inhibited their seedling growth. Thus, *T. diversifolia* directly alters the growth of other plant species by forming its own monocultures.

The invasion of *T. diversifolia* also alters the physico-chemical properties of soils in the invaded areas. The soils in the invaded areas become nutrient rich which generally help in the growth of invasive species. It was clear from the results that the values of all soil nutrients were found to be higher in the *Tithonia* invaded areas as compared to the control. Minimum change was observed in the case of pH as compared to other parameters. Likewise, the phenolics well known groups of allelochemical were found to be more in weed-invaded soil as compared to the control soil. These phenolics are released from the plant part through various mechanisms such as leachation from above ground parts, root exudation, volatilization or microbial degradation. These allelochemicals besides imparting the plant allelopathic property also regulate the biotic communities of soil and alter the phy-sical and chemical properties of soil (Nardi et al., 2000). Many studies suggest that allelopathy may contribute to the ability of particular alien species to become dominant in the native plant communities (Abdul-Wahab and Rice, 1967; Vaughn and Berhow, 1999; Ridenour and Callaway, 2001). Several aggressive weeds exhibit the phenomenon of allelopathy as a mechanism of interference which provides them competitive advantage over other plants. El-Ghareeb (1991) studied the allelopathic effect of the invasive plant *Tribulus terrestris* on surrounding vegetation in an abandoned field of Kuwait. His study demonstrated that besides the growth inhibitory effect of plant on other plants, the soil moisture and concentration

Table 3. Species composition of *T. diversifolia* invaded and uninvaded plant communities in Ile-Ife, Southwest Nigeria.

Plant species	Family	Uninvaded	Invaded
Abutilon sp.	Malvaceae	-	+
Anchomanes difformis	Araceae	-	+
Achyranthes aspera	Amaranthaceae	+	-
Aeschynomene indica	Fabaceae	+	+
Albizia angertifolia	Fabaceae	+	-
Albizia zygia	Fabaceae	+	+
Alchornea laxiflora	Euphorbiaceae	+	+
Allophylus africanus	Sapindaceae	+	-
Alternanthera sessilis	Amaranthaceae	+	-
Andropogon gayanus	Poaceae	+	-
Aneileme beninse	Commelinaceae	-	+
Aspilia africana	Asteraceae	-	+
Asystasia gangentica	Acanthaceae	-	+
Blighia unijugata	Sapindaceae	+	-
Bridelia micrantha	Euphorbiaceae	+	-
Calopogonium mucunoides	Fabaceae	+	+
Chasmanthera dependens	Menispermaceae	+	-
Chassalia kolly	Rubiaceae	-	+
Chromolaena odorata	Asteraceae	-	+
Cissus argueta Hook. f.	Vitaceae	-	+
Combretum nigerica	Combretaceae	+	+
Cnestis ferruginea	Connaraceae	-	+
Croton bonplandianum	Euphorbiaceae	+	+
Croton zambesicus Muell. Arg.	Euphorbiaceae	-	+
Cucurbita sp	Cucurbitaceae	+	-
Culcasia scandens	Araceae	+	-
Cynodon dactylon (L.) Pers	Poaceae	+	+
Cyathula prostate	Amaranthaceae	+	+
Deinbolia pinnata	Sapindaceae	-	+
Desmodium gangeticum	Fabaceae	+	+
Digitaria sp.	Poaceae	+	-
Dioscorea dumetorum (Kunth) Pax	Dioscoreaceae	+	-
Euphorbia heterophylla	Euphorbiaceae	+	+
Euphorbia hirta	Euphorbiaceae	+	-
Ficus exasperate	Moraceae	-	+
Gloriosa superb	Liliaceae	+	-
Glyphaea brevis	Tiliaceae	+	-
Holarrhena floribunda	Apocynaceae	-	+
Icacina trichantha	Icacinaceae	+	-
Indigofera trifoliate	Fabaceae	+	-
Ipomoea carnea	Convolvulaceae	+	-
Jateorhiza macrantha	Menispermaceae	+	-
Justicia insularis	Acanthaceae	+	-
Luffa cylindrical	Cucurbitaceae	-	+
Mallothus oppositifolius	Euphorbiaceae	-	+
Margaritaria discoidea (Baill.)	Euphorbiaceae	+	-
Mariscus alternifolius Vahl	Cyperaceae	+	-
Merremia sp.	Convolvulaceae	+	-
Mezoneuron benthamianum	Leguminosae	+	-
Millettia thonningii	Fabaceae	+	-

Table 3. Contd.

Mimosa pudica	Fabaceae	+	+
Mondia whitei	Apocynaceae	+	-
Mormodica charantia	Cucurbitaceae	-	+
Mucana pruriens	Fabaceae	+	-
Newbouldea laevis	Apocynaceae	+	-
Panicum maximum	Poaceae	+	-
Paulina pinnata	Sapindaceae	-	+
Pouzolzia guineensis	Urticaceae	+	-
Pennisetum purpureum	Poaceae	+	+
Pepperonea pellucida	Piperaceae	+	+
Phyalopsis sp.	Acanthaceae	+	-
Pleiuserae barterii	Apocynaceae	+	-
Pyrennicantra stanthia	Icacinaceae	-	+
Rottboellia exaltata	Poaceae	-	+
Rotbollia cochinchinensis	Poaceae	+	-
Salacia chinensis	Celastraceae	+	-
Salacia pallens	Celastraceae	+	+
Securinega virosa	Euphorbiaceae	+	+
Senna hirsute	Fabaceae	+	-
Sida acuta	Malvaceae	+	+
Sida corymbosa	Malvaceae	-	+
Sida veronicifolia	Malvaceae	-	+
Smilax kraussiana	Smilacaceae	-	+
Spigelia althelmia	Loganiaceae	-	+
Spondias mombin	Anacardiaceae	+	-
Sporobolus pyramidalis	Poaceae	+	-
Stachytapheta angustifolia	Verbenaceae	+	-
Sterculia tragacantha	Sterculiaceae	+	-
Synedrella nodiflora	Asteraceae	+	+
Talinum triangulare	Portulacaceae	-	+
Tithonia diversifolia	Asteraceae	-	+
Tridax procumbens	Asteraceae	+	+
Urena lobata	Malvaceae	+	-
Vigna gracilis	Fabaceae	+	-
Voacanga africana	Apocynaceae	-	+
Total		**59**	**44**

of N, P and K were significantly higher in *T. terrestris* site. In the pre-sent study too, the amounts of available nutrients were significantly more in weed-invaded soils as compared to the weed free soils. Abundant evidences support the idea that higher resource availability increases the suscepti-bility to invasion of plant communities (Burke and Grim, 1996; Maron and Connor, 1996).

Further, the absorption of phenolics, the allelopathic compounds, by soil particles and their microbial break-down may account for the outcome of the present obser-vations (Dalton, 1999; Huang et al., 1999; Wardle et al., 1998) which are further affected by various soil factors such as soil texture, organic carbon and organic matter etc. (Kobayashi, 2004).

The reason why some invasive plants are so success-ful in new environments may be that they bring novel mechanisms of interactions with the recipient community. However, Dietz et al. (1996) concluded that factors other than allelopathy might be operating in nature that favours

Table 4. Soil pH and nutrient elements concentrations in the invaded and uninvaded sites of *T. diversifolia*.

Soil properties	*Tithonia diversifolia*	
	Invaded site	Uninvaded site
pH	7.44±0.22[b]	5.4233±0.1197[a]
Nitrogen	2.999±0.866[b]	1.816±0.080[a]
Organic Carbon	0.70253±0.023[c]	0.4759±0.02054[b]
Calcium	2.9994±0.1033[c]	1.8564±0.1109[b]
Magnesium	0.834±0.0274[b]	0.6205±0.0201[a]
Potassium	0.2556±0.0169[b]	0.1609±0.0155[a]
Sodium	0.4059±0.0212[b]	0.2628±0.0179[a]
Phosphorus	64.0621±2.5112[c]	52.1855±2.0577[a]

*Values are mean ± 95% confidence interval; ** Values with the same superscript along the same row are not significant different .

rapid establishment and persistence of dense stands of alien species.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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