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Soil erosion under teak (*Tectona grandis* L.f.) plantations: General patterns, assumptions and controversies

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ABSTRACT

High rates of soil loss are usually assumed under teak (*Tectona grandis* L.f.) plantations and some debate has been created about this during recent years. We analyzed the processes of soil loss and accumulation in a case study and performed a critical review of literature from other studies, due to the shortage of field experimental data from around the world to sustain this theory. The case study was established in Alfisols and slopes ranging from 30 to 60% in Guanacaste, Costa Rica, and compares secondary forests with mature teak plantations and young teak plantations under different management regimes. Over a period of 14 months with higher rainfall than the regional average, very little soil loss was registered in the teak plantations of Guanacaste, although there were slight differences between treatments (1–4 mm), while soil accumulation was measured in secondary forests (4 mm). A number of other authors also report low levels of soil loss in teak plantations and those studies in which high erosion rates have been identified tend to be associated with teak plantations where fires are a common phenomenon. Hence, we conclude that poor forest management (prescribed fires, machinery, extremely steep slopes, previous land use, etc.) rather than the nature of the teak itself causes the high rates of erosion.

1. Introduction

Forest cover controls soil erosion by protecting the surface of the soil from raindrop impact and by reducing the speed of run-off water in the hydrological cycle (Brauman et al., 2007; Durán and Rodríguez, 2008; Evans, 2009). Afforestation can protect and even restore degraded soils and their hydrological functions in the water cycle (e.g. Bruijnzeel, 1997, 2004; Brauman et al., 2007; van Dijk and Keenan, 2007), as it is considered to improve infiltration, porosity and hydraulic conductivity, affecting groundwater recharge, surface run-off and soil erosion (e.g. Bonell et al., 2010; Ilstedt et al., 2007; Mapa, 1995). However, some forestry activities, particularly the use of certain machinery, timber extraction and the creation of forest roads, could cause soil degradation and compaction and therefore increase erosion (e.g. Worrel and Hampson, 1997; Ziegler et al., 2004a, 2004b). In addition to these negative issues associated with forest management, the relationship between forest cover and soil erosion is not simple as it is influenced by the forest species composition, the progress of the forest community in the ecological succession, soil type and other environmental variables (Jost et al., 2012; Ziegler et al., 2004b). Even though managed forests (especially plantations) present greater levels of erosion than natural forests, Durán and Rodríguez (2008) highlighted the fact that the rates of erosion in these forest plantation ecosystems are much lower than those for deforested land or areas of other agricultural crop production.

Teak (*Tectona grandis* L.f.) plantations have been widely established in Central America, initially in Costa Rica and Panama (De Camino et al., 2002) and more recently in Guatemala, El Salvador and Nicaragua. Teak has become an important species in the quality tropical hardwood sector (e.g. Pandey and Brown, 2000), with a total planted area of $4.3 \cdot 10^6$ ha (not including the natural areas), of which 132,780 ha is in Central America (3%) and 31,500 in Costa Rica (Kollert and Cherubini, 2012). Soil erosion under teak plantations has generated some debate (e.g. Bell, 1973; Pandey and Brown, 2000; Ramnarine, 2001) because a number of authors consider that these systems do not provide the abovementioned hydrological benefits associated with forests (Carle et al., 2009). Based on the presumption of high erosion rates under teak plantations, in some countries such as Costa Rica, such plantations cannot be legally established on slopes steeper than 30%, while slopes with a steeper gradient (>30%) are considered adequate for forest plantations of other species or even other perennial crops such as coffee or

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fruit trees (MAG-MINENEM, 1994). Unfortunately no data is presented to support this presumption and in many instances, soil erosion which occurred prior to planting teak is also attributed to the new plantation.

Due to the limited amount of objective, impartial research (based on observations and experiments) into the soil erosion process under teak plantations, there is very little reliable data available (Arce and Alvarado, 2003; Bell, 1973; Jirasuktaveekul, 1998; Santamaría, 1992; Tangtham, 1992; Wolterson, 1979). This shortage of data has inspired the present paper, which has the following objective: to analyze soil erosion under a teak plantation, considering the effect of plantation management at different stages and contrasting the results with those from secondary forests with similar soil and climatic conditions. We pursue this objective through an experiment conducted at Guanacaste (North Pacific Coast of Costa Rica) and also present a critical summary of literature from other studies undertaken around the world.

2. Material and methods

2.1. Study area

The study area is located in Guanacaste on the North Pacific Coast of Costa Rica, in a property of 1500 ha belonging to PanAmerican Woods Ltd. (PAW), of which 1100 ha is occupied by a teak (*T. grandis* L. f.) plantation (9902° N, 85,478° E). The region is bioclimatically classified as tropical moist forest according to Holdridge's life zones (Holdridge, 1967); with a climate characterized by an average annual precipitation of 2500 mm and 4 to 6 dry months. The area has fertile, reddish clayey soils described as Typic Rhodustalfs, mixed with Typic Dystrustepts (Soil Survey Staff, 2010) and inclusions of other soils derived from sedimentary limestones and basaltic parent materials.

The plantation was established over the period 1985–1991 on previously grazed land. Today, the area is a mosaic of teak plantations of different ages, cultivated under varied management practices on soils surrounded by small grazed patches, small villages and secondary forests close to the streams. Young tree plantations (1–5 years) were re-planted over previously harvested areas after the first rotation (approx. 20 years) and were established using different methods depending on the site quality: a) clones were planted at the most productive sites and are managed intensively using herbicide for weed control; and b) the coppice method was used at less productive sites where weed control is carried out manually and only around trees that will remain until the final cut (low intensity management).

2.2. Experimental design and methodology

The experimental design included four treatments: 1) secondary forests, 2) mature plantation (approximately 20 years), 3) young plantation (two years) from clones, and 4) young plantation (two years) from coppicing. Three replicates for each treatment were established (accounting for a total of 12 plots) in the same steeply sloped range (30–60%) with the same soil (Typic Rhodustalfs). Plots (20 × 10 m, 200 m^2) were established in the same slope position, following the maximum slope gradient and with no borders around them so as to allow overland flow through the plots, thus recreating the natural condition of the slopes.

Soil micro-pits (60 cm) were dug near each study plot and three undisturbed topsoil samples (0–10 cm) were collected using metallic cylinders (7.5 cm height × 4.5 cm diameter). The resulting 36 soil samples were taken during the rainy season (28–30 July 2010), assuming water content as field capacity, and analyzed in the soil laboratory at the Centro de Investigaciones Agronómicas, University of Costa Rica (CIA-UCR) for saturated hydraulic conductivity, bulk density, particle density and porosity. Once the undisturbed samples had been analyzed, they were mixed and analyzed for texture in the same laboratory following the modified Bouyoucos method (Forsythe, 1975). The results of these analyses are shown in Table 1.

Erosion pins were established in each plot according to a modification of the FAO guidelines (FAO, 1997). A hundred metal pins (40 cm length, 5 mm diameter) were installed with a 2 × 1 m rectangular spacing (200 m^2). The erosion pin has been shown to be a cost-effective technique, recommended to measure only the magnitude of the erosion processes when precise quantification is not required (FAO, 1997). Hence, this technique was considered appropriate for the objectives of the present study and was also chosen because of budgetary limitations which precluded the use of other possible alternatives. The erosion pins were installed between July 22nd and 30th 2010. The height of the pins above the topsoil, to be used as a reference for subsequent measurements, was recorded at the time of establishment. Measurements were taken from the top of the pin to the topsoil, removing leaf litter; hence, litter was not taken into account in height measurements. Soil erosion was estimated through periodic measurements of the height of the pins. Seven sets of measurements were carried out: in July (on establishment), October and November 2010, and January, March, June and September 2011. Hence, we were able to estimate the erosion process as the variation in topsoil height for the periods between pin measurements and for the study period as a whole, from July 2010 to September 2011.

Additional pin measurements were made during November 2010 and January and June 2011 to estimate the method precision. In each of these periods, one plot was randomly selected and the measurement was repeated three times; hence, 300 pins were measured three times during all the study period, a total of 900 measurements. A variation coefficient of 2% was observed between the repeated measurements of the erosion pins, while the mean standard deviation was 4 mm, which is considered a conservative estimation of the precision of the method. Hence, differences between periodic measurements lower than 4 mm

Table 1
Physiography and topsoil (0–10 cm) physical properties of erosion plots in secondary forests (B-1, B-2 and B-3), teak (*Tectona grandis* L.f.) plantations of approx. 20 years (M-1, M-2 and M-3), young (2 years) teak plantations of clones (Cl-1, Cl-2 and Cl-3), and young (2 years) teak plantations of coppice (Co-1, Co-2 and Co-3), established in Puerto Carrillo (Guanacaste, Costa Rica).

	Slope (%)	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g cm^{-3})	Porosity (%)	Hydraulic conductivity (cm h^{-1})
B-1	51	18	29	53	Clay	0.77	68.12	2.78
B-2	58	28	26	46	Clay	0.66	71.88	4.30
B-3	45	22	32	46	Clay	0.76	68.10	4.19
M-1	35	21	36	44	Clay	0.91	60.15	0.07
M-2	37.5	26	36	38	Clay loam	0.88	62.82	1.43
M-3	35	13	36	51	Clay	1.07	59.05	0.10
Cl-1	47.5	6	44	51	Silty clay	1.03	60.06	1.51
Cl-2	45	3	29	68	Clay	1.17	55.70	0.54
Cl-3	45	21	46	33	Clay loam	1.04	57.28	0.04
Co-1	37.5	15	29	56	Clay	0.86	66.26	11.78
Co-2	37.5	18	29	53	Clay	0.73	70.73	11.23
Co-3	40	3	29	68	Clay	0.99	59.88	0.14

(absolute value) should be taken carefully as they are within the precision margin of the method.

2.3. Data analysis and statistical analysis

The difference between the measured values using the erosion pin method was calculated and used as an estimate of soil volume loss or accumulation (mm). These values were transformed to estimate loss or accumulation of soil mass (t ha^{-1}) using the topsoil bulk density values (Table 1). Analysis of variance (ANOVA) and Tukey tests were performed to analyze the effect of treatments on soil loss or accumulation during a) the period October–November 2010 (hurricane Tomas), and b) the total study period July 2010–September 2011.

3. Results

Between July and October 2010, soil accumulation was registered in all the studied forest covers (Fig. 1). However, between October and November 2010 high rates of soil loss were measured in the teak treatments, while rates were low for the same period in the secondary

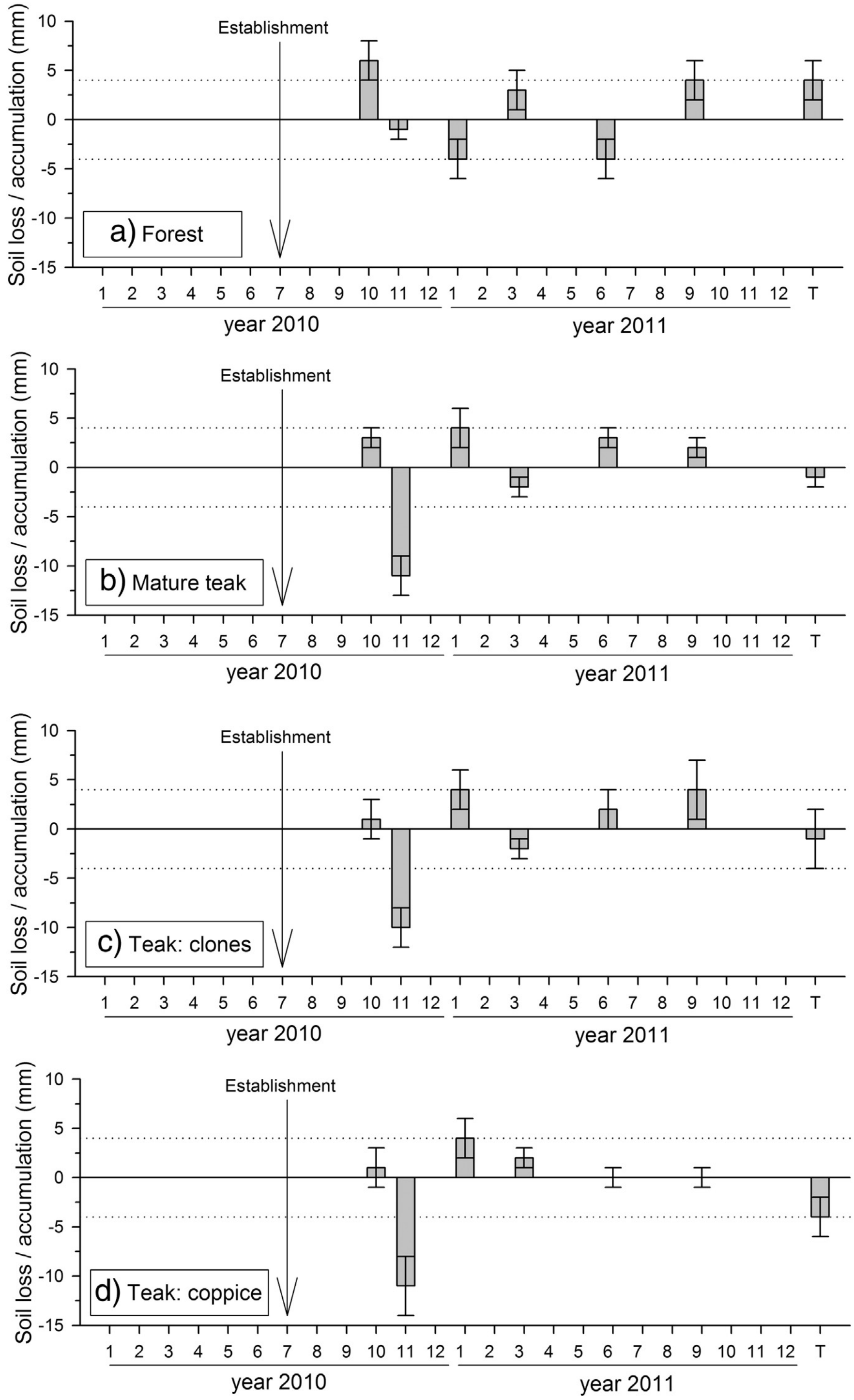

Fig. 1. Soil loss or accumulation (mm) under different forest covers (a, secondary forests, b, mature teak approx. 20 years, c, young teak — 2 years, clones, d, young teak — 2 years, coppice) in the study area in Puerto Carrillo (North Pacific Coast of Costa Rica). The dotted line represents the estimated precision of the erosion pin method used. The average and confidence intervals (95%) are reported for the erosion measured at different times and the total from July 2010 to September 2011 ("T").

forests (Fig. 1). From November 2010 to September 2011, the processes of soil loss and accumulation were irregular; most of the observed values being below the range of precision of the methodology (Fig. 1).

Both 2010 and 2011 were rainy years with annual precipitation values above the average as well as more frequent extreme meteorological events (i.e. tropical storms, cyclones, hurricanes…). We only registered one actual erosion episode during the period October–November 2010 (Fig. 1), due to the high intensity storms caused by hurricane Tomas, when up to 495 mm day^{-1} were registered at nearby locations and several landslides occurred inside the study area (Fig. 2e). The response of the forest covers studied to this extraordinary rain event was significantly different ($F_{3,\,1191} = 26.041$; $p < 0.001$): the three teak plantation treatments showed 10 times higher soil loss compared with the secondary forests (Fig. 1).

The soil erosion processes (loss and accumulation) registered over the whole study period (July 2010–September 2011) varied between the analyzed treatments ($F_{3,\,1131} = 7.7486$; $p < 0.001$). According to the FAO (1980) classification of soil erosion rates, moderate soil and litter accumulation was observed under secondary forests, while low rates of soil loss were recorded in plantations of mature teak and young teak clones, and moderate rates of soil loss in coppiced young teak plantations (Table 2).

4. Discussion

4.1. Soil erosion under teak plantations: case study

The reported results (Fig. 1) agree with the theory which states that annual erosion rates are mainly originated by a few individual storms of higher intensity than normal (e.g. Lal, 1976; Zimmermann et al., 2012). In these extreme rain events, rain intensity largely exceeds soil infiltration and hydraulic conductivity, generating overland flow and runoff

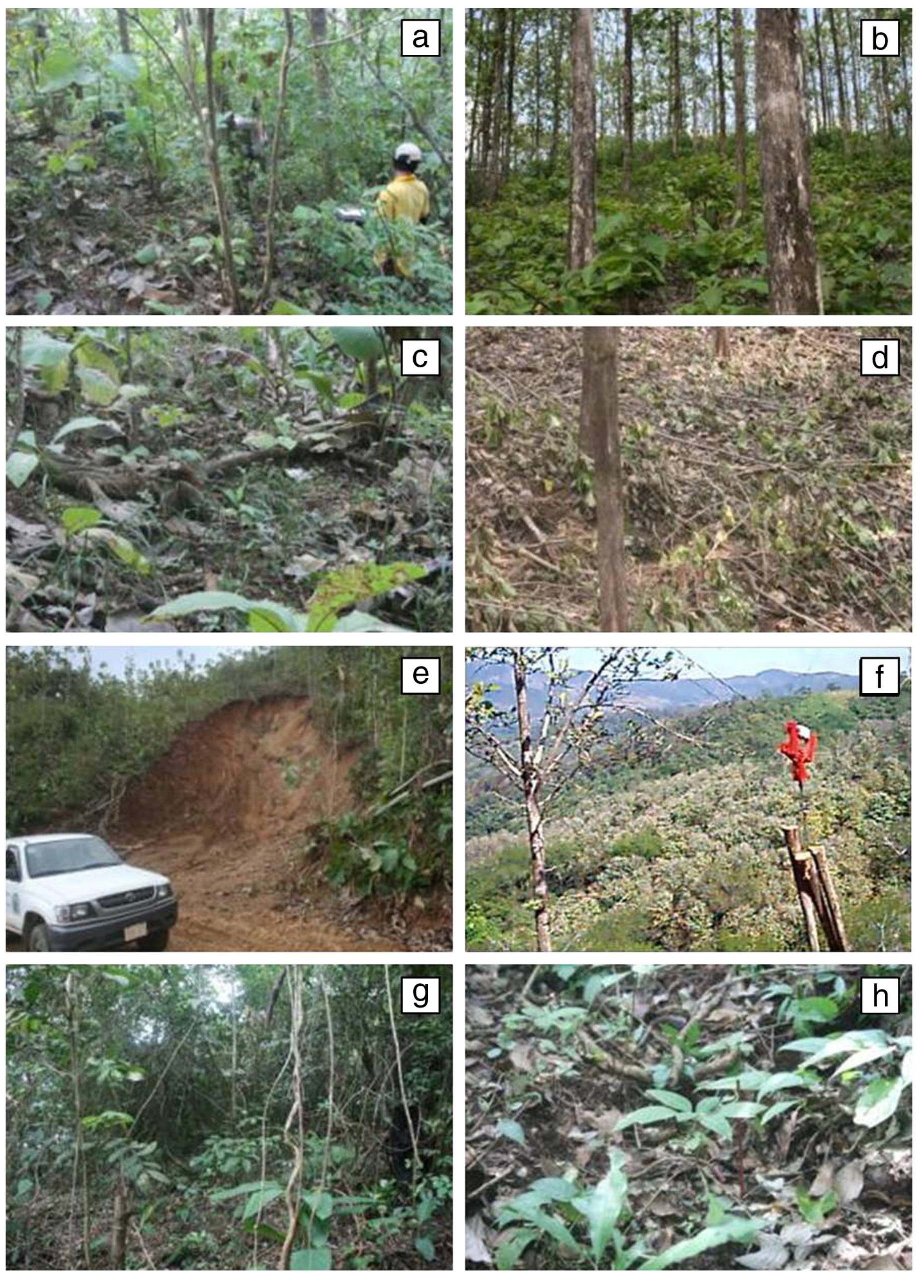

Fig. 2. Details of the forest ecosystems at the study area in Puerto Carrillo (North Pacific Coast of Costa Rica): a) and b) understory vegetation under mature (approx. 20 years) teak (*Tectona grandis* L.f.) plantations; c) litter and soil cover under mature teak plantations; d) vegetation residues after pruning and understory vegetation clearance in teak plantations; e) landslides after hurricane Tomas (November 2010); f) teak timber extraction by wire method; g) understory vegetation under secondary forests; h) litter and soil cover under secondary forests.

Table 2
Mean and standard error (in brackets) of the soil loss or soil accumulation under different forest covers in the study area (North Pacific Coast of Costa Rica).

	Erosion classes (FAO, 1980)	Soil loss rates[a] ($t\ ha^{-1}$)	Soil accumulation rates[a] ($t\ ha^{-1}$)
Secondary forests			28.6 (6.7)
Teak (approx. 20 years)	Null–low [<10 $t\ ha^{-1}\ year^{-1}$]	6.7 (5.5)	
Teak clones (2 years)	Null–low [<10 $t\ ha^{-1}\ year^{-1}$]	7.2 (17.1)	
Teak coppice (2 years)	Moderate [10–50 $t\ ha^{-1}\ year^{-1}$]	35.1 (7.8)	

[a] These values do not correspond to exactly one year but are for a period from July 2010 to September 2011 (14 months).

(eg. Hassler et al., 2011; Zimmermann et al., 2012). Accordingly, the plots under secondary forests, where higher hydraulic conductivity has been observed (Table 1) (Fernández-Moya et al., 2013), showed much lower erosion rates under the extreme weather event recorded in this study.

Despite the abovementioned presumption of high erosion rates in teak plantations, low to moderate rates were found in the present case study (Table 2), a finding which is supported by those of other authors such as Jirasuktaveekul (1998) (6.9–12.3 $t\ ha^{-1}\ year^{-1}$) for plantations on a 20–40% slope, and Tangtham (1992) (3–12.5 $t\ ha^{-1}\ year^{-1}$).

The estimated soil erosion rates under the studied teak plantations (Table 2) are lower than those reported by Arce and Alvarado (2003), using the same methodology and with similar environmental characteristics (geographically proximate and 30–60% slopes), for intermediate age teak (105.81 $t\ ha^{-1}\ year^{-1}$), *Bombacopsis quinata* (80.79 $t\ ha^{-1}\ year^{-1}$), *Astronium graveolens* (50.79 $t\ ha^{-1}\ year^{-1}$) and secondary forests (44.15 $t\ ha^{-1}\ year^{-1}$). The only notable difference between the present study and that of Arce and Alvarado (2003) is the plantation management, which could therefore be the main factor explaining the higher erosion rates in one plantation compared to the other.

Santamaría (1992) also reported higher erosion rates (162–190 $t\ ha^{-1}\ year^{-1}$) than those found in the present study, even though the same plantation was used in both studies. However, the first of these two studies was conducted almost 20 years ago, when the plantation management was completely different. Bearing in mind that prior to the establishment of the teak plantation the land had been dedicated to grazing, which affects the hydraulic properties of the soil, it is likely that when Santamaría (1992) conducted the study (only 5 years after establishment of the plantation), the soil had not had enough time to recover its properties. However, 20 years later, the hydraulic properties of the soil under the teak plantation have improved to the point where conditions are much like those in the nearby secondary forests (Fernández-Moya et al., 2013) and soil erosion rates have drastically reduced.

4.2. Soil erosion under teak plantations: general patterns

Teak plantations have been reported to increase soil hydraulic conductivity and macroporosity in comparison to grazed land (Mapa, 1995). However, teak plantations are thought to induce high erosion rates, which is usually attributed to: 1) reduction in understory vegetation due to excessive light reduction and/or allelopathy; 2) low organic matter accumulation due to low litter production; and 3) increase in raindrop erosivity because the large leaves of the teak induce an increase in raindrop size (Bell, 1973; Boley et al., 2009; Carle et al., 2009; Pandey and Brown, 2000; Ramnarine, 2001; Wolterson, 1979). However, none of these explanations are completely satisfactory. Some authors assert this presumption despite the absence of any experimental basis. For example, Healey and Gara (2003) highlight "the high level of erosion commonly observed in teak plantations (Champion, 1932 in White, 1991; Keogh, 1987; Lamprecht, 1989; Evans, 1992)" but provide no experimental data which would allow the scientific community to make this assumption. In addition, some authors (e.g. Bell, 1973) report high erosion rates under teak plantations when in fact their observations (0.01–0.15 $t\ ha^{-1}\ year^{-1}$) are considered null or low by the FAO (1980).

The suppression of undergrowth and tree regeneration in teak plantations is also commonly referred to (e.g. Boley et al., 2009; Carle et al., 2009; Healey and Gara, 2003) although this assertion is not supported by the field data from the present case study (Fig. 2) or by the data presented by Arce and Alvarado (2003), who found greater understory development and more litter biomass accumulation in teak plantations than in secondary forests. Moreover, some studies are contradictory on the matter of undergrowth reduction, such as Boley et al. (2009), who comment on the lack of understory in the teak plantation they studied, while their methods section mentions a periodic (at least yearly) clearing of understory vegetation. In fact, weed control constitutes one of the major costs in many teak plantations in Central America. Hence, the supposed lack of understory and recruitment observed by some authors could be due to this management practice rather than to the shading effect of teak trees. Allelopathy has also been reported as one of the causes of understory suppression by teak trees. Laboratory tests conducted in a number of studies have revealed that teak leaf and root exudates in high concentrations have an allelopathic effect on the germination of some crops. However, this effect is not observed when the hypothesis is tested in field trials (Abugre et al., 2011; Gyamfi, 2009). Healey and Gara (2003) pointed to the existence of circumstantial evidence supporting the allelopathic effect of teak on the understory seeds and Murugan and Kumar (1996), cited by Healey and Gara(2003), reported considerable concentrations of phenolic acids in teak foliage. However, this allelopathic effect has not been proven, as the same authors recognize, and remains a questionable factor (Healey and Gara, 2003).

Low levels of litter production have also been linked to high rates of erosion under teak plantations (Boley et al., 2009). However, since teak is a deciduous tree, a large amount of leaf biomass is deposited every year. Evidence of litter production and soil cover by teak residues in the studied plantations are shown in Fig. 2. Arce and Alvarado (2003) reported similar litter biomass production under teak plantations, *B. quinata* plantations and secondary forests.

The large leaves of teak trees are associated with an increase in raindrop erosivity, as drops falling from teak vegetation will have several times greater kinetic energy than those falling from other species such as *Pinus* sp. (Calder, 2001). The high erosivity of these drops was also observed by Calder (2001) during a storm in India, after a forest fire had destroyed most of the understory vegetation. The post-fire recovery of vegetation brought about a reduction in the erosive energy, as the multilayered understory vegetation serves to protect the soil from the kinetic energy of the raindrops, thus reducing rainfall erosivity (e.g. Brandt, 1988). Hence, the mistaken assumption discussed above that the understory vegetation is suppressed in teak plantations, also has an important bearing on the question of raindrop erosivity. Although the large raindrops associated with large teak leaves are highly erosive, properly conserved multilayered understory vegetation (accompanied by a litter layer) would reduce erosivity (Fig. 2).

The few field experiments reported by previous authors generally indicate low or moderate erosion rates in teak plantations; although some discrepancies are found between different studies, probably due to the use of different methodologies but also to differences in soils, climates and particularly, to plantation management. However, a general trend can be observed as many of the studies reporting high erosion rates were conducted in places where prescription fires are a common management practice (Calder, 2001; Maeght et al., 2011; Tangtham, 1992; Wolterson, 1979). A number of studies have highlighted the drastic increase in erosion rates as a result of prescribed fires in forest plantations (Hamilton, 1991; Maeght et al., 2011; Tangtham, 1992), so the generalized belief that teak plantations are prone to high rates of soil erosion probably originated in certain specific plantations where prescription fires are a common management tool.

Although prescription fires are common in some teak plantations (Bell, 1973; Maeght et al., 2011; Pandey and Brown, 2000), they are not so common in the plantations observed in Central America. The absence of recurrent fires in the plantations analyzed in the present case study would favor the presence of understory vegetation along with a well-developed litter layer (Fig. 2), which contributes to lowering soil erosion rates. Hence, plantation management would appear to be the main factor affecting soil erosion in teak forest plantations, rather than the teak itself. However, intensive weed control using herbicides is common in most of the productive teak plantations (Pandey and Brown, 2000), including those observed in Central America, and is considered another cause of soil remaining unprotected, thereby leading to erosion and diminishing the hydraulic properties of the soil (Boley et al., 2009; Bonell et al., 2010; Bruijnzeel, 2004; Fernández-Moya et al., 2013; van Dijk and Keenan, 2007). Both prescribed fires and herbicides result in weed and understory reduction, hence a reduction in organic matter (Balagopalan et al., 1992; Boley et al., 2009). This is considered a soil degradation process, which has been identified as a cause of the deterioration of soil hydraulic properties in teak plantations (Fernández-Moya et al., 2013; Mapa, 1995).

5. Conclusions

Low to moderate erosion rates were registered at the teak plantations studied (slope gradient 30–60%): 6.7 t ha^{-1} in mature plantations, 7.2 t ha^{-1} in young clones, and 35.1 t ha^{-1} in young coppices. Storms associated with hurricane Tomas (November 2010) were the main agents of the overall erosion process, as soil losses of approx. 100 t ha^{-1} were registered in just one month. These rates of erosion, measured over a period in which the levels of rainfall were higher than the average for the region, combined with the information gleaned from a critical review of existing literature (Table 3) on the subject, suggest that the notion of high rates of erosion under teak plantations is speculative. This mistaken belief probably stems from the fact that some of the previous studies in this area were conducted in plantations where either inappropriate management techniques were employed or where fire was a common phenomenon.

Conflict of interest

None of the authors have any kind of conflict of interests.

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Table 3
Literature review of soil erosion measurements in tropical areas under different forest covers and soil conditions.

Land cover	Erosion classes (FAO, 1980)	Erosion: Land cover (t ha^{-1} $year^{-1}$)	Erosion: Secondary forest (t ha^{-1} $year^{-1}$)	Region	Slope (%)	Soil	Plot dimensions	Method	Reference
Bare fallow	Very high	230		Western Nigeria	15	Alfisols	25 × 4 = 100 m^2	Runoff plots	Lal (1976)
Natural forests	Null–low		0.03–6.16	Tropical global				Literature review	Wiersum (1984) in Hamilton (1991)
Forest plantations (undisturbed)	Null–low	0.02–6.20		Tropical global				Literature review	Wiersum (1984) in Hamilton (1991)
Forest plantations (burned or litter removed)	Low–high	5.92–104.80		Tropical global				Literature review	Wiersum (1984) in Hamilton (1991)
Teak unburned (16–31 years)	Low	3			23		2 × 10 = 20 m^2	Runoff plots	Tangtham (1992)
Teak burned (16–31 years)	Moderate	12.5			23		2 × 10 = 20 m^2	Runoff plots	Tangtham (1992)
Teak	Low–moderate	6.86–12.25			20–40				Jirasuktaveekul (1998)
Teak (10–11 years)	Null–low	0.01–0.15	<0.01–0.02	Trinidad			0.87–1.27 ha	Runoff plots	Bell (1973)
Teak (approx. 10 years)	High	105.81	44.15	North Pacific Coast of Costa Rica	30–60		7 × 22 = 154 m^2	Pins	Arce and Alvarado (2003)
Bombacopsis quinata	High	80.79	44.15	North Pacific Coast of Costa Rica	30–60		7 × 22 = 154 m^2	Pins	Arce and Alvarado (2003)
Astronium graveolens	High	50.79	44.15	North Pacific Coast of Costa Rica	30–60		7 × 22 = 154 m^2	Pins	Arce and Alvarado (2003)
Teak (approx. 5 years)	High	160–190		North Pacific Coast of Costa Rica	20–60				Santamaría (1992)
Teak (approx. 20 years)	Null–low	6.7[a]	28.6 (accumulation)	North Pacific Coast of Costa Rica	30–60	Typic Rhodustalfs	10 × 20 = 200 m^2	Pins	Present study
Teak clones (2 years)	Null–low	7.2[a]	28.6 (accumulation)	North Pacific Coast of Costa Rica	30–60	Typic Rhodustalfs	10 × 20 = 200 m^2	Pins	Present study
Teak coppice (2 years)	Moderate	35.1[a]	28.6 (accumulation)	North Pacific Coast of Costa Rica	30–60	Typic Rhodustalfs	10 × 20 = 200 m^2	Pins	Present study

[a] These values do not correspond to exactly one year but are for a period from July 2010 to September 2011 (14 months).

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