Mass Loss and Nutrient Release through Leaching in *Tectona grandis* and *Theobroma cacao* leaf litter in Ile-Ife, Nigeria

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Abstract

Tectona grandis and *Theobroma cacao* are common plantation tree crops planted to replace natural forest in Nigeria because of their faster growth rate and economic values. The changes in land use have marked effects on the soil nutrients and organic matter stock, thereby affecting physical, chemical properties and soil microbial activity. This study looked at the mass loss and rate of leaching of nutrients in the two tree species. Bulk of fallen senescent leaf litters were collected from the plantations, air-dried and thoroughly mixed. Two grammes of each species was weighed into a 500 ml beaker and 250 ml of distilled water added and were retrieved at interval of 0, 24, 48, 72, 96, 120 and 144 hrs, this was replicated six times. The *p*H, mass loss (%), rate of mass loss (% hr^{-1}), conductivity (µs), total dissolve solid (mg l^{-1}), nutrients in leached water were measured. Results showed higher mass loss rate of 0.37 % hr^{-1} in *Tectona grandis* compared to 0.29 % hr^{-1} in *Theobroma cacao* after 24 hrs. At the end of the study, 1.20%, 5.23%, 6.64% and 8.25% of the initial amount of Ca, Mg, K, and Na in the *Theobroma cacao* leaf litter; and 2.23%, 1.38%, 7.99%, and 13.077% in *Tectona grandis* leaf litter were retained. It was observed that 9.27% and 3.71% of the initial amount of N and P were lost from *Theobroma cacao* leaf litter while, 9.23%, and 8.10% were released in *Tectona grandis* at the end of the study. The release of P, Ca, K and Na with respect to leaching at the end of the study was better in *Tectona grandis* and the information of nutrients release will be helpful in selecting the best tree species for plantation establishment in terms of nutrients return for improved productivity.

Introduction

Nutrients leaching is the downward movement of dissolved nutrients in the soil profile with percolating water. Nutrients that are leached below the rooting zone of the vegetation are the least temporarily lost from the system, although they may be recycled if roots grow deeper. Leached nutrients may contribute to ground water contamination in regions with intensive agriculture. Nitrate leaching is also a significant source of soil acidification. When nitrate, which is negatively charged, is taken up by plants, a hydroxide ion, also negatively charged, is released from the plant to maintain electrical balance. If nitrate is not taken up by plants, it can leach away from the root zone, meaning that no hydroxide ion is released from the plant to bind with a hydrogen ion (Lin *et al*., 2001,

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Haynes, 1983; Helyar & Porter 1989; Porter *et al*., 1995).

The cations that leach are usually sodium, potassium or calcium rather than hydrogen, because hydrogen ions are more strongly held by the soil. If the nitrate is from ammonium fertiliser, the result is a net increase in hydrogen ions. Soil acidification occurs because the concentration of hydrogen ions in the soil increases. In humid climates, some nutrient leaching occurs even under natural vegetation, but agricultural activities can greatly increase leaching loses (Havlin *et al.*, 1999).

Litter decomposition proceeds by several mechanisms including heterotrophic utilization of organic compounds in litter, and also leaching during rain events and combinations by small insects which do not lead directly to CO_2 release to the atmosphere. The balance between litter inputs and heterotrophic litter decomposition influences the amount of C stored in the forest floor; this is important because forest floor C can respond to disturbance over short time scales (Gaudinski *et al.* 2000). Other nutrients like N, P and C are released from plant litter during decomposition where they can become available for plant and microbial uptake.

Litter produced by deciduous and evergreen trees is the primary mechanism by which nutrients are returned to the soil (Swift *et al.* 1979). Leaf litter is the main and fastest source of organic matter and nutrient to the soil compared to other litter types (Hossain *et al*., 2011; Park and Cho, 2003). The nutrients in litter were added to the soil through microbial decomposition and physical leaching of soluble components followed by microbial oxidation of refractory components (Hasanuzzaman and Mahmood, 2014).

This pool of litter represents a relatively large, labile reservoir of organic matter to soil decomposer communities (Gosselink & Kirby, 1974; Benner *et al*., 1986). Although resorption prior to leaf abscission can be an effective means of conserving vital elements in many plant species, there is still a substantial outflow of organic and inorganic nutrients from trees and macrophytes via leaf senescence and decomposition (Tukey, 1970; Gosz*et al*., 1973; Aerts, 1996; Killingbeck, 1996; Maie *et al.* 2005).

It has been reported that the initial leaching phase of wood and leaf litter decomposition typically lasts from a few days to a few weeks, yet it is responsible for substantial loss of mass and release of materials such as carbon, nitrogen and phosphorus to the environment (Ibrahima *et al.* 1995; Taylor & Ba¨rlocher, 1996; Davis *et al.* 2003; Romero *et al.*, 2005: Stephen *et al*., 2006). Given that standing water or saturated soil conditions expedite this abiotic process (Stephen *et al*., 2006; Tukey, 1970) the coupled process of litter production and leaching may be an especially important autochthonous source of nutrients and fixed carbon in oligotrophic nutrient-limited wetland systems.

Nutrient losses through leaching have been reported to be generally higher in humid than in dry climates because water transport below the rooting zone requires that the soil water content exceeds field capacity and water balance is positive. This means that water inputs with rainfall (and irrigation) exceed evapotranspiration (Havlin *et al.* 1999; Lehmann & Schroth, 2003). In certain soils, however, water can infiltrate into the subsoil through continuous vertical macrospores. This is especially important in cracking clay soils (vertisols) at the onset of the rainy season (Smailing and Bouma, 1992). Macropores are also created by faunal activity and root growth. They only conduct water under conditions of heavy rainfall or irrigation, under other conditions they are filled with air. Macropore or bypass flow may increase nutrient leaching following the surface application of fertilizers, because a solution with high nutrient concentration then infiltrates rapidly into the soil with little contact with the soil matrix. On the other hand, macropore flow may also protect nutrients present in smaller soil pores from being leached by rapidly channeling away surplus water (Cameron and Haynes, 1986; Noordwijk *et al.* 1991).

Over the years, natural forests have been destroyed and they are still being destroyed and disturbed all over the globe. This destruction has altered the ecosystem functions both in terms of species composition, richness and more importantly, nutrient availability. Most of these destroyed forest ecosystems in Nigeria have been replaced by tree crop plantations such as *Tectona grandis*, *Theobroma cacao*, *Cola nitida* among others. The tree crop plantations abound all over Nigeria, especially in Southwestern Nigeria because of the economic importance (timber and wood) and their faster growth rate. Following the widespread of these plantations in Ile-Ife, the pattern and amount of nutrients that will be available for plant growth is expected to have been altered as a result of change in land use (Awotoye *et al.*, 2011; Ogunkunle and Awotoye, 2011; Ekanade *et al.*, 1991; Shittu & Amusan, 2015).

Several questions remained unanswered from different plantations in Ile-Ife following the change in land use: Some of these questions are, how does the nutrient uptake and release differ in the plantations, and to what extent has change in land use impacted on nutrient availability across the plantations? This study was carried out as an attempt to provide information on some of these questions, specifically to look at the pattern of nutrients leaching (N and P) and cations (Ca, Mg, K and Na) from the leaf litter of *Tectona grandis* and *Theobroma cacao.* The study investigated (1) the rate at which nutrients are leached from the two species (2) the species that released more nutrients into the system and how much of the nutrients are available in the system (leaf litter) for plant use?

Materials and methods

Study area

The leaf litter of *Theobroma cacao* and *Tectona grandis* plantation that was used in this study were collected from the Obafemi Awolowo University Teaching and Research Farms, Ile-Ife, Nigeria. Ile-Ife lies between latitude 07 32' N and longitude 04 31' E. The elevation of Ile-Ife ranges from 215 m to 457 m above sea level (Hall, 1969). The plantation sites from where the leaves were collected for this study is located on Latitude 07 31.311' N and Longitude 04 30.983' E in within Obafemi Awolowo University, Ile- Ife. The climate of the area is a tropical type with two prominent seasons, the rainy and dry seasons.

The dry season is short, usually lasting 4 months from November to March and the longer rainy season prevails during the remaining months. The most recent climatic survey conducted in 2014 by the

Atmospheric Physics Research Group, Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile-Ife, showed that the annual rainfall at Ile-Ife averaged 1302 mm per year, with relative humidity of 82.80%, average temperature of 25.5 °C, Solar radiation of 164.30 Wm^{-2} and average wind speed of 2.06 km per hour.

The soil of the area is derived from material of old basement complex which is made up of granitic metamorphosised sedimentary rock (Hall, 1969). The soils are moderately to strongly leached and have low to medium humus content, weakly acid to neutral surface layers and moderately to strongly acid sub-soils (Smyth and Montgomery, 1962). The soils which are usually acidic contain less than 10% clay which is mainly kaolinite and hence are characterized by low cation exchange and low water holding capacity (Ayodele, 1986). The soil has been classified as lixisols, FAO/ UNESCO (1974) and utisols (USDA, 1975).

The original vegetation of Ile-Ife is lowland rainforest as climax vegetation (Keay, 1959). The forest sub-type is dry deciduous forest (Onochie, 1979). The vegetation of the areas has been described as the Guineo-Congolian drier forest type (White, 1983). Most of the original lowland rain forests are however, been massively destroyed leaving remnants of re-growth secondary forest scattered around. Tree crop plantations like *Tectona grandis, Theobroma cacao, Cola nitida* and *Elaeis guineensis* are now common around the area.

Sampling procedure

Bulk of fallen senescent leaves were collected from the plantations using a litter bag, leaf litter were collected in January, 2014 as this period correspond to dry season when it is believed there was no leaching or the rate of leaching from the leaf litter was very minimal. The leaf litters that were collected were air-dried at room temperature for a week. The air-dried leaf litter was thoroughly mixed, two grammes of the air-dried sample were weighed into a 500 ml beaker and 250 ml of distilled water added to determine the rate of leaching from the leaf litter (Mahmood *et al.*, 2009). Few drops of thymol crystal ($C_{10}H_{14}O$) were added to prevent fungal growth.

Altogether, a total of 72 samples were prepared for both species, 36 for each species and were monitored during the leaching experiment. Samples of air dried leaf litter of *Theobroma cacao* and *Tectona grandis* were oven dried at 70 °C to obtain the oven-dried weight for conversion and for initial nutrients determination. The leached water were collected after the leaf litter had been removed, stored in a refrigerator at 4 °C and analyzed almost immediately.

Six replicates of litter samples in the 500 ml beaker were collected at interval of 0, 24, 48, 72, 96, 120 and 144 hours and the collected samples were rinsed in distilled water and oven dried at 70 °C to a constant weight. The pH of the leached water was determined using Mettler Toledo pH Meter. The mass loss (%) due to leaching process was calculated from the differences between the initial and final oven-dried weights and expressed as a percentage of initial loss. The rate of mass loss (% hr^{-1}) was obtained by dividing mass loss (%) with the leaching time. Conductivity (µs), total dissolve solid (TDS mgl^{-1}) of leaching water samples were measured by a conductivity and TDS meter in the Central Science Laboratory, Obafemi Awolowo University, Ile Ife , Osun state.

Nutrient Measurement in Leaf Litter

The nutrients in the leached water and in the leaf litter after leaching in each of the species were determined using atomic absorption spectrophotometer and the analysis was done at International Institute of Tropical Agriculture (IITA) Laboratory. The analysis was done following the method described by Tel and Rao (1982). The amounts of nutrients left in the leaf litter and in the leached water were calculated as differences between initial and final amounts and this was expressed as percentage of initial amounts.

Statistical analysis

Mass loss, the rate of mass loss and nutrients (N, P, K, Ca, Mg, and Na) concentration in leached water and leaf litter of each of the species at different time interval was compared using one way analysis of variance. Rate of mass loss, conductivity, TDS and nutrients (N, P, K, Ca, Mg and Na) concentration in leaf litter between two species were also compared using a t-test.

Results

The pH of leached water in *Theobroma cacao* and *Tectona grandis* showed that there was no significant difference ($p > 0.05$) between the two species at each of the time intervals. Highest pH was recorded in both species at 48 hours and the lowest at 72 h. The pH value at the end of the study period was found to be higher in *Theobroma cacao* (6.82) compared to *Tectona grandis* (6.56) (Fig. 1).

The results of the mass loss of nutrients indicated that there was no significant difference ($P > 0.05$) between the two species across the time intervals. The details are shown in Fig 2. There was an initial rapid loss of mass of leaf litter of *Theobroma cacao* and *Tectona grandis* increased from 0% at 0 h to 6.9% and 8.2% at 24 hrs respectively. At the end of the study (144 hrs), it was found to have increased to 9.1% in *Theobroma cacao* and *Tectona grandis* (Fig. 2).

The results of the rate of mass loss of nutrients indicated that there was generally no significant difference ($P > 0.05$) between the two species at each of the time intervals (Fig 3.). Higher mass loss rate of 0.37% hr^{-1} was recorded in *Tectona grandis* compared with 0.29% hr^{-1} in *Theobroma cacao* after 24 hrs. The mass loss rates in *Theobroma cacao* was (0.0628% hr^{-1}) and (0.0635% hr^{-1}) in *Tectona grandis* at the end of the study (Fig. 3). The average mass loss rate in *Tectona grandis* was 0.15% hr^{-1} and that of *Theobroma cacao* was 0.13 % hr^{-1}.

There was loss in leaf weight with increasing leaching time in both species. The leaf weights of *Theobroma cacao* and *Tectona grandis* decreased from 1.88g to 1.86g (6.92%) in *Theobroma cacao*, and from 1.75 and 1.71 (8.07%) in *Tectona grandis* after 24 hours. At the end of the experiment, the litter weight has further decreased by 9.04% (1.71 g) in *Tectona grandis* and 9.14% (1.69g) in *Theobroma cacao* (Fig. 4).

After 24 hours, the total dissolve solid of the leaching water from *Theobroma cacao* and *Tectona grandis* leaf litter increased from 0 to 110 mg l^{-1} and 114 mg l^{-1} respectively (Fig. 5). At the end of the experiment, TDS further increased to 231.67 mg l^{-1} in *Theobroma cacao* (52.5 %) and 187.33 mg l^{-1} in *Tectona grandis* (39.2%). However, the amount of TDS was found not to be significantly

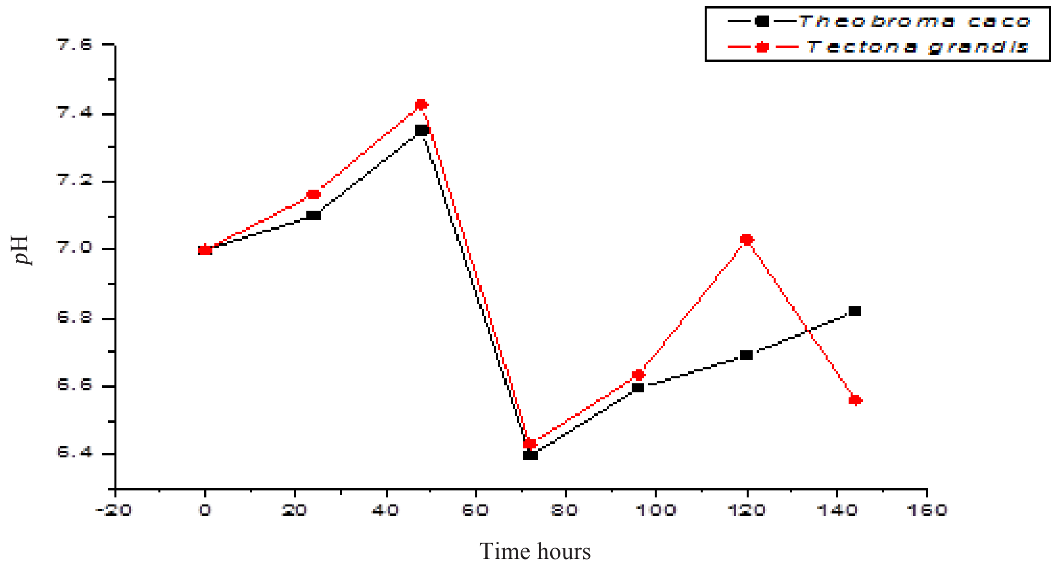

Fig. 1. The pH of leached water samples of *Theobroma cacao* and *Tectona grandis* at different time intervals.

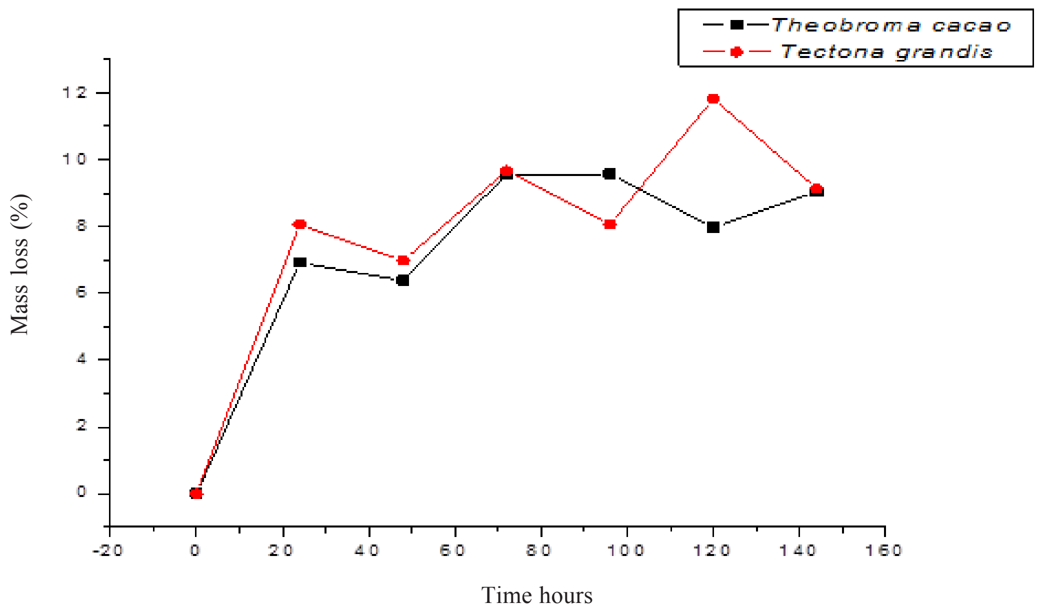

Fig. 2. Mass loss (%) of leaf litter of *Theobroma cacao* and *Tectona grandis* at different time intervals.

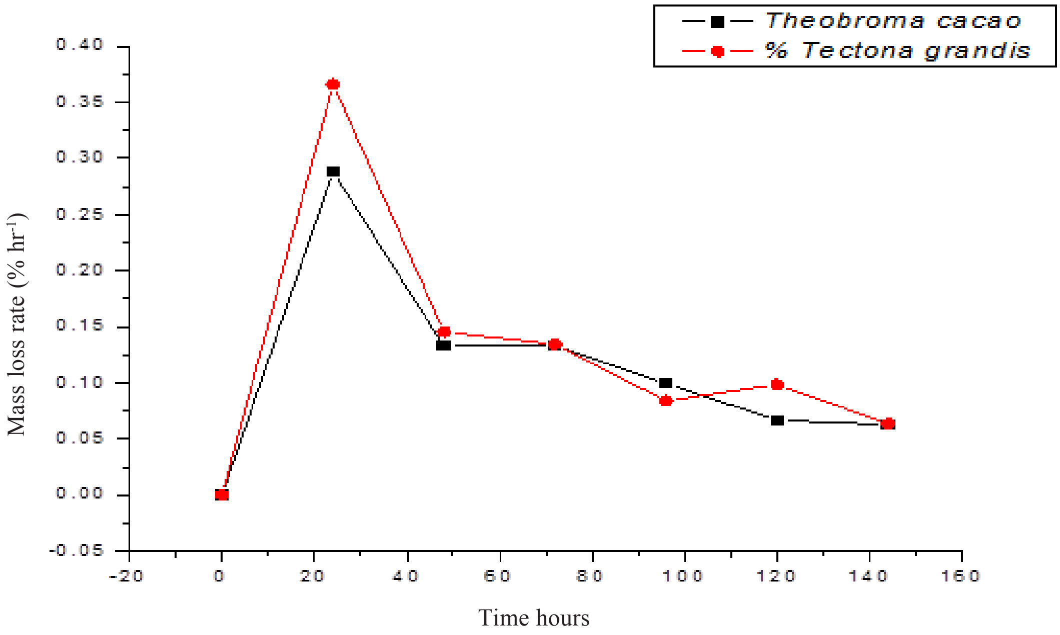

Fig. 3: Mass loss rate (% hr^{-1}) of leaf litter of *Theobroma cacao* and *Tectona grandis* at different time intervals.

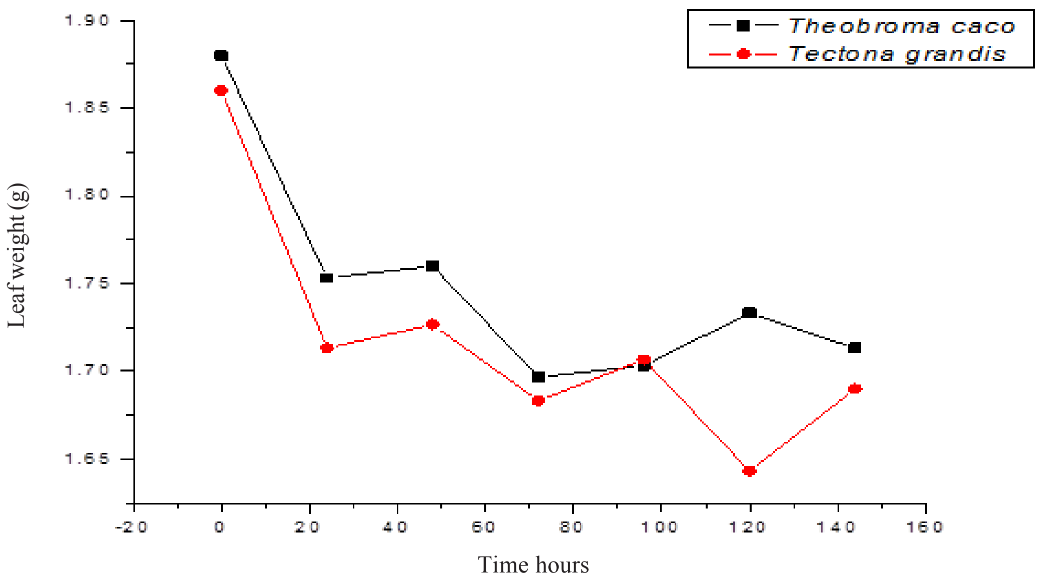

Fig. 4: Weight of leaf litter of *Theobroma cacao* and *Tectona grandis* at different time intervals**.**

different (P < 0.05) between the leached water from the leaf litter of the two species.

The conductivity of the leached water of both species significantly (P < 0.05) increased at the end of the experiment (Fig. 6). The conductivity increased from initial value of 0.16 µS in both species to 114 µS in *Theobroma cacao* and 189.45 µS in *Tectona grandis* after 24 hours. The values further increased from what they were after 24 hours to 384.29 µS (73.5 %) in *Theobroma cacao* and 355.24 µS (61.7 %) in *Tectona grandis* at the end of the study (Fig. 6). However, there was no significant difference (P > 0.05) between the two species at the end of the study.

Nutrients in leached water

After 24 hours, the initial concentration of the exchangeable cations: Ca, Mg, K and Na in the leached water of *Theobroma cacao* significantly (P < 0.05) decreased from 47.65 ppm, 16.54 ppm, 10.19 ppm, 0.52 ppm, to 45.65 ppm, 16.47 ppm, 7.64 ppm, 0.42 ppm respectively (Fig. 7a). Similarly in *Tectona grandis,* the concentration of Ca, Mg, K and Na significantly (P < 0.05) decreased from 56.77 ppm, 15.012 ppm, 8.65 ppm, 0.79 ppm, to 55.62 ppm, 14.74 ppm, 7.43 ppm, 0.76 ppm respectively after 24 hours (Fig.7a). At the end of the study, 9.6%, 7.6%, 33.3% and 30% of the initial amount of Ca, Mg, K and Na were released from the leaf litter of *Theobroma cacao* and 16.76%, 2.83%, 39.3%, 8.39% of Ca, Mg, K, Na were released in *Tectona grandis* leaf litter (Fig. 7a).

After 24 hours, the concentration of nitrogen significantly (P < 0.05) increased from 0.15 ppm to 0.20 ppmin in leached water from *Theobroma cacao leaf litter* and from 0.17 to 0.20 ppm in *Tectona grandis* (Fig. 7b) However, the concentration of phosphorus in leached water decreased significantly (P < 0.05) from 5.57 ppm to 5.13 ppm in *Theobroma cacao* and 6.99 ppm to 6. 6 ppm in *Tectona grandis* respectively. At the end of the study, 35% of N and 10% of P were released in *Theobroma cacao,* while 28% and 29% of N and P were released in *Tectona grandis* leaf litter (Fig. 7b).

Concentrations of cations (Ca, Mg, K and Na) retained in leaf litter after leaching

After 24 hours, the concentration of exchangeable cations Ca, Mg, K and Na found in the leaf litter significantly (P > 0.05) decreased from 0.48%, 0.21%, 0.19%, 0.001% to 0.42%, 0.19%, 0.16%, 0.002% in the leaf of *Theobroma cacao* (Table. 1). Similarly, the amount of cations remaining in *Tectona grandis* leaf litter, (Ca, Mg, K and Na) also significantly (P < 0.05) decreased from 0.53% and 0.20% to 0.40% and 0.18% in Ca and Mg while there was no difference in K and Na respectively (Table 1). At the end of the study, 1.20%, 5.23%, 6.64% and 8.25% of the initial amount of Ca, Mg, K, and Na was retained in the *Theobroma cacao* leaf litter while 2.23%, 1.38%, 7.99%, and 13.077% was found in *Tectona grandis* leaf litter.

Nitrogen and Phosphorus concentrations in leaf litter over study period

After 24 hours, there was no significant (P > 0.05) difference in the concentration of N and P left in the leaf litter in both species (Table 1). It should however, be noted that at the end of the study, 9.27% and 3.71% of the initial amount of N and P were lost from *Theobroma cacao* leaf litter while, 9.23%, and 8.10% were released in *Tectona*

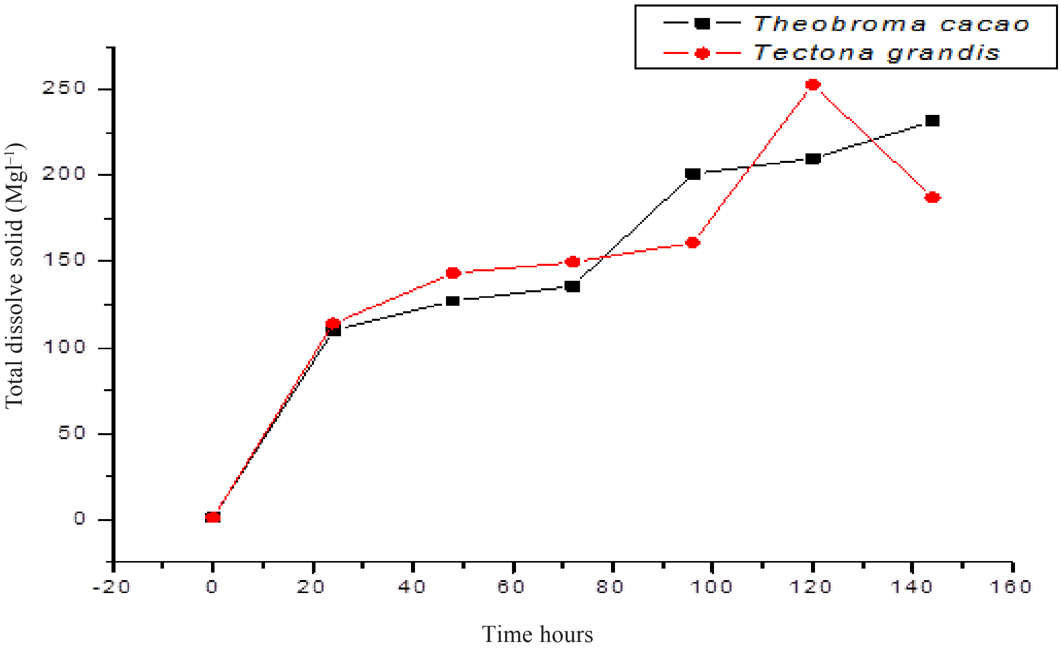

Fig. 5. Total dissolve solid (Mg l^{-1}) in leaching water samples of *Theobroma cacao* and *Tectona grandis* at different time intervals.

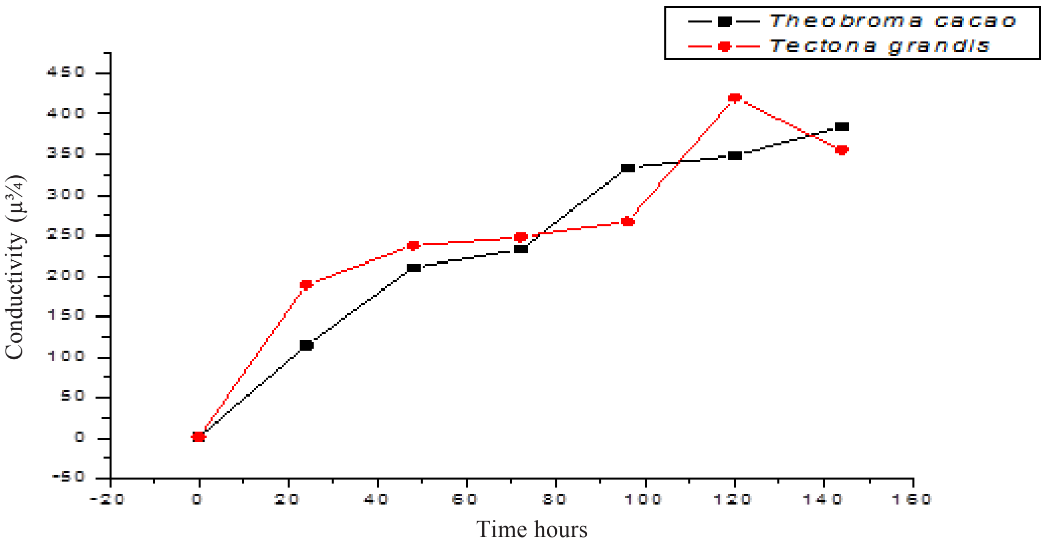

Fig. 6. Conductivity (µS) of leaching water samples from leaf litters of *Theobroma cacao* and *Tectona grandis* at different time intervals.

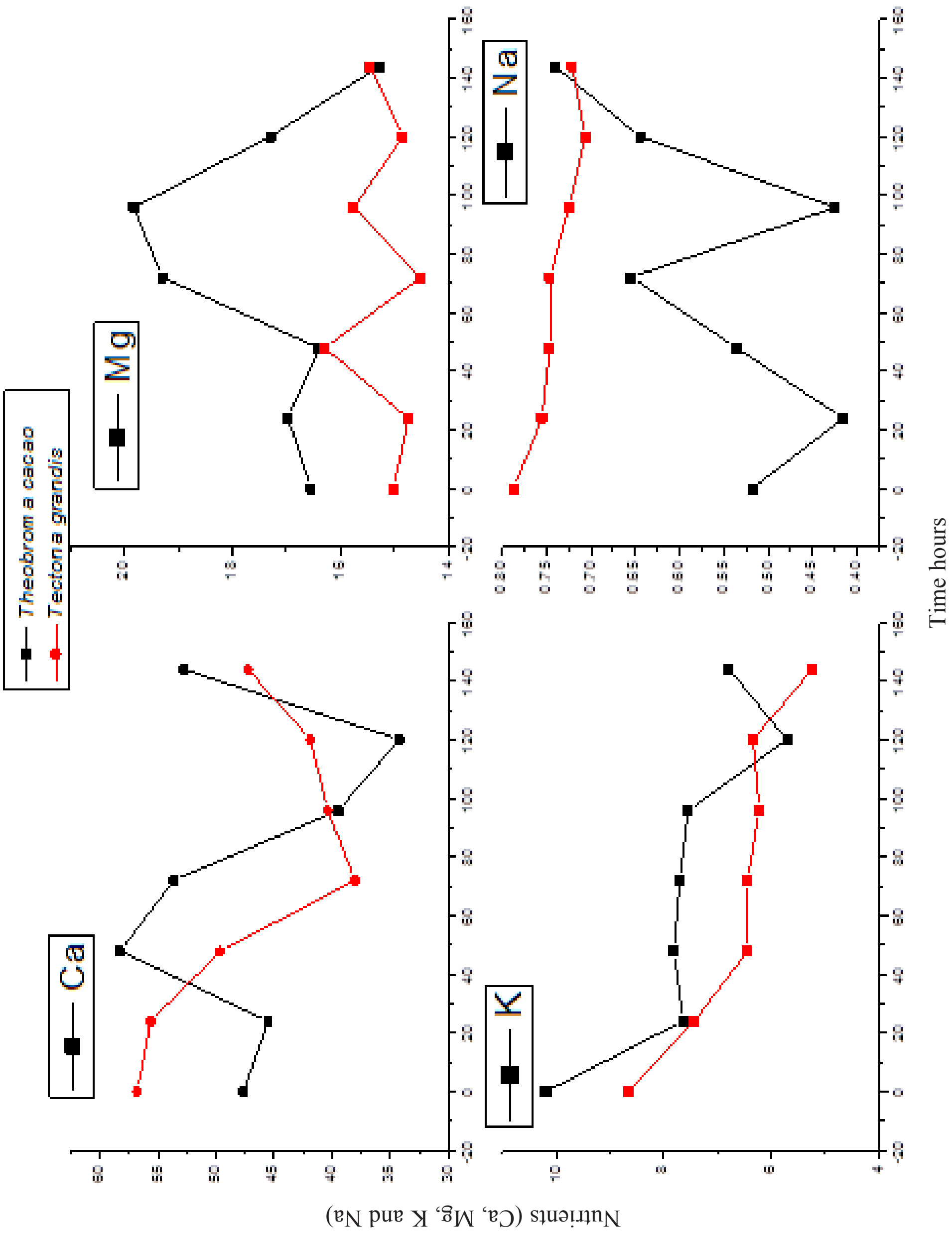

Fig. 7a. Nutrients (Ca, Mg, K and Na) concentration (ppm) in the leached water samples of *Theobroma cacao* and *Tectona grandis* at different time intervals.

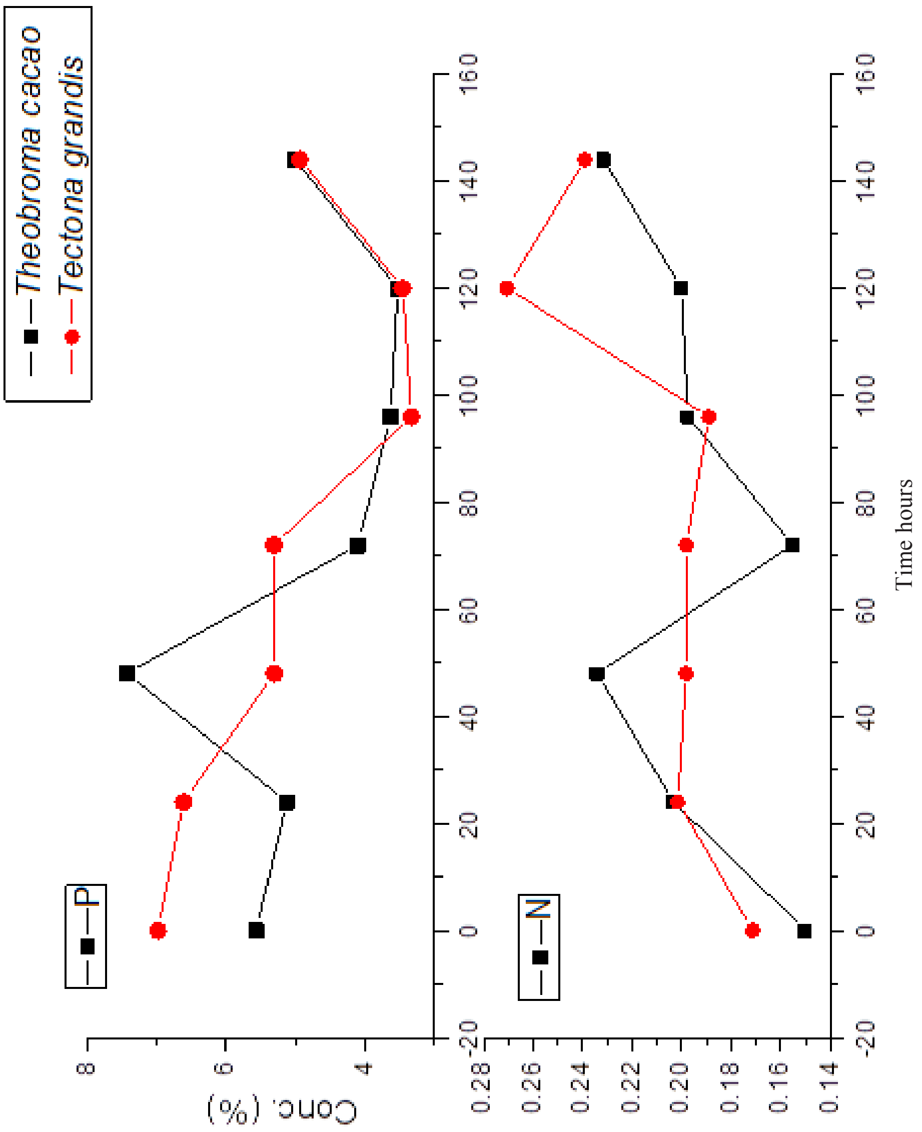

Fig. 7b. Nutrients concentration (ppm) in leaching water samples of *Theobroma cacao* and *Tectona grandis* at different time intervals.

TABLE 1

Nutrients concentration (%) in leaf litter of Tectona grandis and Theobroma cacao at different time intervals

	Time (hrs)	*N(%)*	*P (%)*	*Ca (%)*	*Mg (%)*	*K (%)*	*Na (%)*
	0	0.556 ± 0.04	0.007 ± 0.003	0.439 ± 0.03	0.200±0.02	0.150 ± 0.02	0.002 ± 0.002
	24	0.552 ± 0.06	0.007 ± 0.002	0.395 ± 0.04	0.183±0.02	0.147 ± 0.02	0.002 ± 0.002
	48	0.529 ± 0.09	0.007 ± 0.003	0.378 ± 0.06	0.175±0.03	0.141 ± 0.02	0.002 ± 0.03
T. grandis	72	0.533 ± 0.14	0.007 ± 0.004	0.381 ± 0.09	0.177±0.04	0.142 ± 0.04	0.002 ± 0.004
	96	0.648 ± 0.07	0.008 ± 0.005	0.463 ± 0.05	0.214±0.02	0.172 ± 0.02	0.002 ± 0.002
	120	0.648 ± 0.12	0.008 ± 0.002	0.463 ± 0.09	0.214±0.04	0.172 ± 0.03	0.002 ± 0.001
	144	0.613 ± 0.06	0.008 ± 0.002	0.448 ± 0.040	0.203±0.02	0.163 ± 0.01	0.002 ± 0.002
% nutrients released		9.23	8.10	2.23	1.38	7.99	13.07
	0	0.598 ± 0.03	0.008 ± 0.002	0.471 ± 0.02	0.207 ±0 .01	0.175 ± 0.01	0.002 ± 0.004
	24	0.583 ± 0.06	0.007 ± 0.006	0.417 ± 0.04	0.193 ±0 .02	0.155 ± 0.02	0.002 ±0 .002
	48	0.627± 0.09	0.008 ± 0.004	0.448 ± 0.07	0.207 ± 0.03	0.166 ± 0.02	0.002 ± 0.002
T. cacao	72	0.580 ± 0.08	0.007 ± 0.003	0.415 ± 0.06	0.192 ±0 .02	0.154 ± 0.02	0.002 ± 0.003
	96	0.608 ± 0.04	0.008 ± 0.001	0.435 ± 0.02	0.201 ± 0.01	0.162 ± 0.01	0.002 ± 0.003
	120	0.675 ± 0.06	0.008 ± 0.002	0.482 ±0 .039	0.223 ± 0.02	0.179 ± 0.01	0.0021 ± 0.001
	144	0.659 ± 0.11	0.008 ± 0.002	0.477 ± 0.067	0.218 ± 0.04	0.187 ± 0.03	0.002± 0 .002
% nutrients released		9.27	3.71	1.20	5.23	6.64	8.25

grandis (Table 1). Generally, it was found that the amount of P, K and Na retained in the leaf litter were higher in *Tectona grandis* while the amount of Mg retained in *Theobroma cacao* leaf litter was higher.

Discussion

The pH of leached water samples significantly varied with leaching time and tends to vary from neutral at 0 hr to slightly alkaline after 24 hrs. It tends towards acidity, showing that with increasing leaching time, the leaf of both species becomes acidic. This might indicate that more cations were released into the water from both species. The initial rapid loss of mass of leaf litter of *Theobroma cacao* and *Tectona grandis* might be as a result of loss of soluble nutrients from the leaf. This result is consistent with the findings of Tukey (1970) and Mahmood *et al.* (2009) where it was reported that rapid loss of soluble organic and inorganic substance occurred at the initial stage of leaching.

The average mass loss rate recorded in this study (0.13–0.15% hr^{-1}) is lower compared to the value of 0. 92% hr^{-1} in *E. camaldulensis* and 0.4 1% hr^{-1} in *S. macrophylla* leaf litter (Mahmood *et al.* 2009); *Acacia auriculiformis* (0.25% hr^{-1}), *Vitex madiensis* (0.25% hr^{-1}), *Syzygium guineese* var. *guineese* (0.03% hr^{-1}) (Kongkon *et al.* 2007; Ibrahima *et al.* 2008; *Melia azedarach*; 1.15% hr^{-1} (Hasan *et al.* 2006). The observed differences in the mass loss rate among different species may be due to the variation in the concentration of different soluble inorganic and organic substances, the physical, chemical and morphological characteristics of leaf litter

(Nykvist, 1963; Taylor & Parkinson, 1988; Ibrahima *et al.* 1995 and Park & Cho, 2003). Moreover, the different rate of mass loss might emphasize the potentiality of different species to provide readily available organic and inorganic compounds for microbiota (Wetzel, 1995).

The increase in the values of both the TDS and conductivity recorded at the end of the study in both species simply indicate that more of the nutrients, both organic and inorganic substances were released during the leaching process. This is consistent with the findings of Allen (1974) who pointed out that the conductivity and TDS values of a solution are the rough estimation of cations and dissolved organic substances.

The general lack of no significant difference in the amount of P that was released in both species at the end of the study might be related to the low amount that is generally present in the leaf litter. Phosphorus has been pointed out to be most abundant in meristematic tissue and accumulated in the reproductive plant component (seeds and fruits) (Meyer *et al.* 1973) and the leaf contained lower amount of P, therefore only a little amount of phosphorus is available in the leaf during leaching. It has also been reported that the concentration of available phosphorus in the soils compared to other elements is very low, so the cycles of P in soils mainly depend on the microbial activities (Gosz *et al.* 1973) which will ultimately influence the amount that is available in the plants including the leaf litter.

The lowest amount of Ca released in the leached leaf litter in this study in the two species might be related to the fact that Ca is a structural component of leaf litter and is not mobile. This finding is consistent with the report of Blair (1988), who reported that initial loss of Ca compared to K and Mg was less because of the nature of Ca as a structural component of plant litter. Lousier and Parkinson (1978). Wang *et al.* (2003) have also suggested that the release of calcium from the leaf litter was mainly caused by both decomposition and leaching and not just leaching.

The rapid release of K at the initial period in both species might be as a result of the fact that K is highly mobile in plants and accumulated in physiologically active tissues (leaves, buds, and roots) (Marschner, 1995). The significant variation in concentration of N and K concentration in the leaf litter of *Theobroma cacao* and *Tectona grandis* during the leaching process might be a function of their initial concentration (Tukey, 1970), characteristics, mobility and involvement in structural properties of the respective plant cell (Meyer *et al.* 1973). Potassium is highly mobile compound compared to N and P, in addition to the fact that K is not structurally bounded (Marshner, 1995). This could be the reason for observing higher amount of K release from leaf litter especially at the initial stage of the leaching. Our findings are consistent with the results of Bockheim & Leide (1986); Enright & Ogolen (1987) and Wang *et al.* (2003), where quick decrease of K concentration and percentage at the beginning has been attributed to significant effects of leaching during decomposition.

The fact that Mg concentration and the amount (percentage) that was released at the end of the study did not differ much in the two species might indicate that the reduction of Mg is not entirely affected by leaching process. Blair (1988) found out that leaching contributed to Mg release in early periods while microbial effect was more significant in the latter periods. Some ecologists reported that Mg release was mostly affected by microbial effects during the process of organic matter decomposition, which was reported to be characterized by linear relationship between Mg release and litter mass loss (Staaf & Berg, 1982; Rapp and Leonardi, 1988). The findings from our study tend to incline with the position that Mg release was more likely to be affected by microbial effect since the pattern of the release observed is very low and the rate was more or less stable. Generally, it has been reported that different nutrients showed different rate of leaching, which depends on the characteristics of individual nutrient, environmental factors, initial concentration in litter (Tukey, 1970; Marschner, 1995) and nutrients involvement in structural properties of respective plant cell (Meyer *et al.* 1973).

Conclusion

From the study, it can be deduced that leaf litter releases nutrients to the soil through leaching and the amounts released may contribute substantially to increase soil fertility through nutrients availability. *Tectona grandis* was found to perform better in terms of P, Ca, K and Na returns with respect to leaching. The knowledge of nutrients released from this study will thus assist in selecting the best tree species for plantation establishment in terms of nutrient returns and availability in order to improve site productivity.

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