Single-tree influence of *Tectona grandis* Linn. f. on plant distribution and soil characteristics in a planted forest

Beckley Ikhajiagbe¹, Matthew Chidozie Ogwu¹,²* and Adebayo Emmanuel Lawrence¹,³

**Abstract**

**Background:** Little is known about the single-tree influence of *Tectona grandis* Linn. f. on plant distribution and soil characteristics in Benin City, Nigeria. We investigated the possible single-tree effect of *T. grandis* on understory plants in an 8-year-old teak plantation at the Moist Forest Research Station. An area of 36.57 m by 60.96 m was marked out and divided into 15 equal-sized subplots containing 10 trees per subplot. Marked distances from the base of a randomly selected tree per subplot were made (0–0.5 m, 0.5–1.0 m and 1.0–1.5 m).

**Results:** Single-tree influence of *T. grandis* was observed in the soil total organic carbon, total nitrogen and soluble phosphorus, where concentrations were higher with 1.5-m radius from the tree than beyond. Moreover, the pH of the topsoil within 1.5 m from the base of the tree was lower (pH 4.4) than beyond 1.5 m from the base of the tree (pH 5.4). Species-specific single-tree effect was also observed on the understory plant distribution likely due to diverse ecophysiological interactions. Within 1.5 m from the tree, plant species abundance, especially of *Sida garckeana*, *Reisantia indica*, *Momordica charantia* and *Tridax procumbens* were negatively affected. However, the distribution of *Eleusine indica* around the tree was not negatively influenced. Plant abundance was generally suppressed in *Cynodon dactylon*, *Axonopus compressus*, *Andropogon gayanus*, *Commelina diffusa* and *Euphorbia hirta*. Generally, there were more plant species beyond the canopy fringes than within the canopy, indicating inhibitory single-tree effects.

**Conclusion:** Not all plant species in close proximity to *T. grandis* are affected. This is important considering that plant-plant associations affect the quality of forest soils. Generally, more plant species were recorded outside the 1.5-m demarcation than within, an increase in soil organic matter may further enhance such plant species abundance. The impact of *T. grandis* in forest soil quality is possibly a factor of the outcome of its association with neighbouring plant species. Diverse mechanisms at play may be responsible for the observed effects on soil chemistry. However, a reduction in the soil organic matter and variations in other environmental factors also contributed to observed single-tree effect.

**Keywords:** Plant diversity, Tropical forest, Single-tree effect, *Tectona grandis* Plantation, Understory, Forest weeds

**Background**

The importance of trees is underscored by their economic and environmental roles. Some tree populations have been known to control the overall plant community likely because of their biomass (Thakur and Eisenhauer, 2015; Jia et al., 2018). By so doing, they create a micro-environment through the diminished air and soil temperatures and reduce wind speeds enabling the formation of smaller niches within the forest ecosystem. Jose et al. (2008); Rao et al. (1998) posited that these events culminate in ecophysiological changes such as decreased evaporation with enhanced humidity in forest areas. Moreover, the availability of water in the forest to plants, particularly those within close proximity to tree roots has been reported (Burgess et al., 1998; Ong et al.,...
Through the processes of hydraulic lift, these trees help to transport water from deep soil layers, which were hitherto impossible for most of the understory herbaceous plants, to drier surfaces, which were bedevilled with competition for water and other nutrients. In turn, plant abundance within tree canopies may be attributed to protection from extreme irradiation and heat effects, which invariably increases the rate of water loss by these plants (Lopez-Pintor et al. 2000). From the foregoing, it is evident that the understory regions of trees are possible microhabitats for these sets of plants.

Another consideration is many plant populations never exist in isolation of other plants. Rather, as outlined in Riginos (2009), their coexistence and interaction ultimately give rise to codominance. However, such associations may become hampered in the event that the associated tree exhibits some level of allelopathy, or the capacity to alter the availability of soil nutrients, light and other limiting resources. On the other hand, the growth performance of any tree may be affected by a number of factors including cultural practices, planting density, as well as the tree’s interaction with understory plants that also significant from an ecological viewpoint (Cantarelli et al. 2006, Leopold and Salazar 2008, Silva et al. 2010).

The ability of natural forests to meet the demand for timber requirements was evidently in doubt in Nigeria; hence, the intensification in afforestation programmes in Nigeria has been performed by the Department of Forestry and the Federal Ministry of Environment. One of the tree species adopted for afforestation programme was teak (Tectona grandis Linn. f. Verbenaceae). Actually, the usefulness and popularity of teak have been known for many centuries, which contributed to the relatively widespread distribution and cultivation throughout the tropics. Generally, the agroforestry deliberately combines tree cultivation with crops and pasture production. Accordingly, the success of the agroforestry system depends on the choice of both tree and associated crop or pasture. In either case, guaranteeing the total development of the tree is paramount; hence, the distribution of the understory plants cannot be overlooked. The question, therefore, is whether the single-tree influence on the distribution of the associated weeds counts one way or the other.

Inderjit and Callaway (2003) reported that it is important to study spatial patterns of the weeds in the field as it relates to silviculture as well as growth inhibition zones as this point to the allelopathic disposition of the trees in question. Consequently, the deliberate investigation of plant species beneath the canopy of the tree would help to pinpoint possible beneficial plant species that may be useful in weed control via allelopathy. In a bid to guarantee sustainable practice in agricultural development, allelochemicals are being viewed as possible alternatives to synthetic agrochemicals (Scrivanti et al. 2003, Maraschin-Silva and Aquila 2006). Some of these allelochemicals, otherwise known as functional allelochemicals (Aldrich, 1984) are transformed by soil microorganisms, and as such has influence in the activity and distribution of soil microorganisms.

The capacity, however, for T. grandis to exhibit a negative influence on plant development has been previously reported (Kole et al. 2011, Manimegalai 2013). Kole et al. (2011) investigated allelopathic effects of teak leaf extract on junglerice (Echinochloa colona) and sedge (Cyperus difformis) in a rice farm. They reported no significant effects on rice germination, but inhibitory activity on the germination of the two weeds. Similarly, Evangeline et al. (2012) and Manimegalai (2013) reported allelopathic effects of Tectona grandis on the germination and seedling growth of Vigna mungo and Vigna radiata respectively.

Given the huge economic benefits of T. grandis, which has made it a largely sought after species of wood across the world including Nigeria, the possibility, therefore, exists for overexploitation of this forest resource. As such, many timber farmers may popularize their plantations with Teak. One of the major advantages of relying on the tree for agroforestry interventions over a wide area or climate is because T. grandis will survive and grow under a wide range of climatic and edaphic conditions. The question, therefore, is whether teak plantations would impact negatively on the distribution and diversity of other plants as well as the soil characteristics of the area. Although studies related to T. grandis have been carried out across other countries of the world including Nigeria (Akindele, 1989, Aborisade and Aweto 1990, Izekor and Fuwape 2011, Oyebade and Anaba 2018), not much is known about the single-tree influence of teak on plant diversity. The aim of this study, therefore, was to investigate the effects of teak plantation on plant species diversity within and around the tree, as well as the impacts on soil physicochemical characteristics.

**Methods**

**Study area**

The study was carried out at the Moist Forest Research Station, Benin City located along Utagban road, Off Ekehuan Road (6° 34’ 0” N, 5° 34’ 34” E). It is a reserve measuring 1 mi² (about 258.999 ha) jutting towards the Ogba river behind Airport road. The landmass is a reserve that was endowed with various exotic and indigenous forest tree species such as Khaya sp., Lovoa trichilioides, Nauclea diderrichii, Allanblackia floribunda, just to mention a few, as well as a wide array of animals, including reptiles, birds and mammals species.
before the forest was clear-felled; which lead to rigorous replanting/reforestation by successive administrations of which a *Tectona grandis* plantation was established measuring about 45.72 m by 91.44 m from which our study was carried. The forest was planted in the year 2011. Routine clearing of undergrowth in the forest occurs annually, usually during the dry season in other to forestall any outbreak of fire.

**Sampling method and procedure**

For the purpose of this study, 36.57 m by 60.96 m was marked out of the teak plantation using a measuring tape. The marked out area was divided into three columns with five rows making 15 equal sized subplots measuring 12.19 m by 12.19 m each. From the 15 subplots, five subplots were randomly selected from each of the rows. Each subplot contained an average of ten trees per plot. In each of the randomly selected subplot, only one of the trees within each of the subplot was used for the experiment. The five selected plots were pegged using small pegs not more than 0.91 m, labelled with Mon Ami black permanent markers and demarcated into 0–0.5 m, 0.5–1.0 m and 1.0–1.5 m, respectively from the base of the tree using white twines. The trees used in this study were thereafter measured. The subplots were demarcated using ranging poles, pegs, and twines. Soil samples were taken using a soil auger.

**Data collection**

Measurements of heights, girths and canopy heights were taken. The height of the tree and the canopy height were measured using Haga altimeter, while the girth was measured using a metre tape. A 1 m by 1 m quadrat was thrown on the subplots to identify species diversity and population count. A stem count of the flora available within the study area was used in identifying and counting the species. Soil samples were collected using soil auger within and within and beyond the canopy fringes of the trees in the study area at a depth of 10 cm from the soil surface and taken to the laboratory in a clean black polythene bag for analysis.

**Laboratory analysis and identification of flora species**

The soil physicochemical parameters were analysed at a laboratory following standard procedures (Bray and Kurtz 1945a,b, SSSA 1971, Haluschak 2006, ICARDA 2013, Nasir et al. 2015). The flora species collected were identified with the assistance of the Plant Taxonomists of Plant Biology and Biotechnology, University of Forestry Research Institute of Nigeria, and the Department of Plant Biology and Biotechnology, University of Benin, Nigeria. A plant identification text was also used where necessary (Akobundu and Agyakwa, 1998).

**Data analysis**

Plant abundance within and outside canopy demarcations was analysed using the IBM Statistical Package for Social Sciences version 20.0 for Windows (SPSS v.20). Correlation, mean, standard deviation and variances were the analytical parameters considered. SPSS was also used to compare species abundance within and around the tree canopy. To analyse the flora species collected, diversity indices (Taxa, Dominance, Simpson, Shannon-Winner, Evenness, Brillouin, Menhinick, Margalef, Equitability, Beger-Parker and Chao-1) were used. These were analysed using the statistical software called PAST® version 2.17c. Mean, range and standard deviation were the descriptive tools considered.

**Results**

The morphological characteristics of *T. grandis* have been presented in Table 1. Plant height averaged 11.8 m whereas canopy length averaged 2.41 m. The highest level of variability amongst the trees sampled occurred with stem girth (CV = 11.99) compared to the other tree parameters measured.

The soil physicochemical parameter was determined around the region covered by the canopy as well as beyond its fringes (Table 2). The pH was significantly lower under tree canopy (pH 4.4) compared to outside the canopy demarcation (pH 5.4). However, in spite of the minimal differences in electric conductivity (EC) between the two soil areas, no significant differences were observed (p < 0.05). Similarly, no difference between soil composition of calcium (15.2–17.3 meq/100 g), potassium (1.1–1.4 meq/100 g), magnesium (13.4–18.2 meq/100 g) and Sulphate (14.9–18.6 mg/kg) were reported in the soil samples collected with the subplot, whether close or far from the tree base. Total organic carbon and total nitrogen within 1.5 m from the tree base were significantly higher than beyond (Table 2). As reported earlier, 5 subplots (Q1–Q5) within the forest were randomly selected. Each subplot contained at least 20 plants out of the 36 identified in the forest; including *Eleusine indica*, *Cynodon dactylon*, *Axonopus compressus* and *Oplismenus burnianii*. However, *Aneilema beninensi*, *Sida garckeana*, *Reisantia indica*, *Mallotus oppositifolius*,

**Table 1** Measurement of the *Tectona grandis* stands

| Plant parameters (m) | Subplots Mean SD CV |
|----------------------|----------------------|
|                      | Q1 | Q2 | Q3 | Q4 | Q5 |              |
| Height               | 12 | 11 | 11.5 | 12.5 | 12 | 11.80 | 0.57 | 4.83 |
| Girth                | 0.5 | 0.4 | 0.47 | 0.55 | 0.53 | 0.49 | 0.06 | 11.99 |
| Canopy height        | 2.45 | 2.14 | 2.46 | 2.56 | 2.43 | 2.41 | 0.16 | 6.56 |

Q1–Q5 represent each of the five subplots
SD standard deviation, CV coefficient of variation
| Test variable                        | Condition | Mean   | SD    | t value | p value | 95% CI Lower | 95% CI Upper |
|-------------------------------------|-----------|--------|-------|---------|---------|--------------|--------------|
| pH                                  | W1.5m     | 4.4    | 0.3   | -4.348  | 0.003*  | -1.41        | -0.42        |
|                                     | Out1.5m   | 5.4    | 0.4   |         |         |              |              |
| Electric conduct (μs/cm)            | W1.5m     | 324.8  | 40.4  | 1.185   | 0.270   | -22.13       | 68.93        |
|                                     | Out1.5m   | 301.4  | 17.9  |         |         |              |              |
| Total organic carbon (%)            | W1.5m     | 0.8    | 0.3   | 3.164   | 0.013*  | 0.11         | 0.69         |
|                                     | Out1.5m   | 0.4    | 0.1   |         |         |              |              |
| Total nitrogen (%)                  | W1.5m     | 0.3    | 0.1   | 2.753   | 0.025*  | 0.02         | 0.18         |
|                                     | Out1.5m   | 0.2    | 0.0   |         |         |              |              |
| Potassium (meq/100 g soil)          | W1.5m     | 1.1    | 0.2   | -1.715  | 0.125   | -0.83        | 0.12         |
|                                     | Out1.5m   | 1.4    | 0.4   |         |         |              |              |
| Calcium (meq/100 g soil)            | W1.5m     | 15.2   | 2.7   | -1.010  | 0.342   | -6.84        | 2.67         |
|                                     | Out1.5m   | 17.3   | 3.7   |         |         |              |              |
| Magnesium (meq/100 g soil)          | W1.5m     | 18.2   | 6.2   | 1.645   | 0.139   | -1.94        | 11.62        |
|                                     | Out1.5m   | 13.4   | 2.3   |         |         |              |              |
| Soluble phosphorus (mg/kg)          | W1.5m     | 187.6  | 27.9  | 2.689   | 0.028*  | 5.11         | 66.61        |
|                                     | Out1.5m   | 151.7  | 10.6  |         |         |              |              |
| Sulphate (mg/kg)                    | W1.5m     | 18.6   | 4.7   | 1.687   | 0.130   | -1.34        | 8.68         |
|                                     | Out1.5m   | 14.9   | 1.2   |         |         |              |              |

W1.5m within 1.5 m from base, Out1.5 m outside canopy demarcation, SD standard deviation, CI confidence interval

**Euphorbia hirta**, *Alchornea laxiflora*, *Tridax procumbens*, *Chromolaena odorata*, *Ageratum conyzoides*, *Panicum laxum*, *Ludwigia abyssinica*, *Setaria barbata* and *Sorghum arandinaeum* were absent within 0.5 m from the tree base (Table 3).

Within the distance of 0.5–1.0 m from the base of the tree, there were a total of 26 plants identified of different species totaling 179 (Table 4). As with the previous demarcations (0–0.5 m), *Reisantia indica*, *Euphorbia hirta*, *Tridax procumbens*, *Chromolaena odorata* were also absent (Table 4). Plant distribution under the canopy from within the 1.0–1.5 m radial demarcation included a total of 762 individual plants species comprising of 28 taxa (Table 5); these included *Elesine indica*, *Cynodon dactylon*, *Axonopus compressus*, *Commelina diffusa*, *Anelilema aequinoctialae*, *Sida garckeana*, *Schrankia leptocarpa*, *Anthonotha macrophylla*, *Reisantia indica*, *Brachiaria deflexa*, *Mallotus oppositifolius*, *Euphorbia hirta*, *Alchornea laxiflora*, *Alchonea cordifolia*, *Combretum hispidum*, *Newbouldia laevis*, *Tridax procumbens*, *Snydrella nodiflora*, *Chromolaena odorata*, *Gomphrena celosiodes*, *Panicum laxum*, *Ludwigia abyssinica*, *Icacina trichantha*, *Oplismenus burmannii*, *Paspalum conjugatum*, *Setaria barbata*, *Phylanthus amarus*, *Sorghum arandinaeum* and *Smilax ances* were represented in at least 4 of 5 subplots.

As shown in Table 6, *Triumfetta cordifolia* was the fewest plant species within the subplots and was only found in 1 of 5 subplots. However, *Elesine indica*, *Cynodon dactylon*, *Axonopus compressus*, *Commelina diffusa*, *Anelilema aequinoctialae*, *Sida garckeana*, *Schrankia leptocarpa*, *Anthonotha macrophylla*, *Reisantia indica*, *Brachiaria deflexa*, *Mallotus oppositifolius*, *Euphorbia hirta*, *Alchornea laxiflora*, *Alchonea cordifolia*, *Combretum hispidum*, *Newbouldia laevis*, *Tridax procumbens*, *Snydrella nodiflora*, *Chromolaena odorata*, *Gomphrena celosiodes*, *Panicum laxum*, *Ludwigia abyssinica*, *Icacina trichantha*, *Oplismenus burmannii*, *Paspalum conjugatum*, *Setaria barbata*, *Phylanthus amarus*, *Sorghum arandinaeum* and *Smilax ances* were represented in at least 4 of 5 subplots.

The percentage of plants abundance within specified distances from the tree base and under the canopy was compared with the totals obtained within the respective subplots and expressed on a percentage (Table 7). *E. indica* had a 7.03% relative abundance at 0.5 m from the tree base, and 9.83% further away from the base of the tree. Within the 1.0–1.5 m space, *Commelina diffusa*, *Anelilema beninense* and *Aspilia Africana* had the highest coefficient of variability amongst the plants discovered. The totality of plant species counted within the entire subplots showed an average of 398 *Cynodon dactylon* plant species per plot and 215 *Panicum maximum* species per plot (Table 5).
when the plants were closer to the tree base than further away; thereby suggesting possible rhizospheric influence of T. grandis. Anieilema beniniense, Sida garckeana, Reissantia indica, Mallotus oppositifolius, Euphorbia hirta, Alchornea laxiflora, Momoedceae chrantia, Tridax procumbens, Chromolaena odorata, Ageratum conyzoides, Panicum laxum, Ludwigia abyssinica, Stetera barbata and Sorghum arundinaceum were all absent within 0.5 m from the tree base; perhaps suggesting inhibitory rhizospheric influence.

Statistical differences between plant abundance within and outside canopy demarcations have been presented (Table 8). For Eleusine indica, plant abundance under the canopy and outside canopy demarcations were statistically
similar; implying that the tree may not have significantly affected plant distribution. Species abundance of *Cynodon dactylon*, *Axonopus compressus*, *Anthropogon gayanus*, *Commelina diffusa*, *Aneilema beniniense*, *Aneilema aequinoctiale*, *Commelina diffusa*, *Aneilema beniniense*, *Aneilema aequinoctiale*, *Sida garckeana*, *Anthonotha macrophylla*, *Reissantia indica* and *Euphorbia hirta* were generally suppressed.

Diversity indices of plant species within and outside canopy demarcations were compared (Table 9). Generally, there were fewer species within 1.5 m from the tree than beyond this radial demarcation, thus indicating inhibitory effects of tree presence. The implication of this suppressed species abundance within close proximity to the tree is the possibility for a number of dominant species to spring up

### Table 4

| S/N | Plant identity            | Within selected tree (0.5–1.0 m) | Q.1 | Q.2 | Q.3 | Q.4 | Q.5 | Sum | Mean | SD  | CV  |
|-----|---------------------------|----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | *Eleusine indica*         | 2      | 6    | 0    | 2   | 2   | 12  | 2.4 | 2.2 | 91.3|     |
| 2   | *Cynodon dactylon*        | 17     | 50   | 27   | 11  | 21  | 126 | 25.2| 15.0| 59.7|     |
| 3   | *Axonopus compressus*     | 2      | 2    | 2    | 3   | 2   | 11  | 2.2 | 0.4 | 20.3|     |
| 4   | *Anthropogon gayanus*     | 3      | 4    | 3    | 4   | 3   | 17  | 3.4 | 0.5 | 16.1|     |
| 5   | *Commelina diffusa*       | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 6   | *Aneilema beniniense*     | 2      | 0    | 0    | 6   | 0   | 8   | 1.6 | 0.4 | 223.6| 223.6|
| 7   | *Aneilema aequinoctiale*  | 0      | 1    | 0    | 9   | 0   | 10  | 2   | 3.9 | 196.9|     |
| 8   | *Triumfetta cordifolia*   | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 9   | *Sida garckeana*          | 0      | 0    | 0    | 1   | 0   | 1   | 0.2 | 0.4 | 223.6|     |
| 10  | *Schrankia leptocarpa*    | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 11  | *Daniella oliveri*        | 0      | 0    | 0    | 5   | 0   | 5   | 1   | 2.2 | 223.6|     |
| 12  | *Anthonotha macrophylla*  | 0      | 1    | 1    | 3   | 0   | 5   | 1   | 1.2 | 122.5|     |
| 13  | *Reissantia indica*       | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 14  | *Brachiaxia deflexa*      | 10     | 10   | 10   | 10  | 9   | 49  | 9.8 | 0.4 | 4.6 |     |
| 15  | *Mallotus oppositifolius* | 0      | 0    | 0    | 0   | 9   | 9   | 1.8 | 4.0 | 223.6|     |
| 16  | *Euphorbia hirta*         | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 17  | *Alchornea laxiflora*     | 3      | 3    | 3    | 3   | 0   | 12  | 2.4 | 1.3 | 55.9|     |
| 18  | *Alchornea cordifolia*    | 1      | 0    | 0    | 0   | 1   | 2   | 0.4 | 0.5 | 136.9|     |
| 19  | *Momordica charantia*     | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 20  | *Cambretum hispidum*      | 0      | 0    | 3    | 0   | 0   | 3   | 0.6 | 1.3 | 223.6|     |
| 21  | *Newbouldia laevis*       | 0      | 3    | 0    | 3   | 0   | 6   | 1.2 | 1.6 | 136.9|     |
| 22  | *Tridax procumbens*       | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 23  | *Synedrella nodiflora*    | 10     | 2    | 7    | 2   | 4   | 25  | 5   | 3.5 | 69.3|     |
| 24  | *Chromolaena odorata*     | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 25  | *Ageratum conyzoides*     | 0      | 0    | 0    | 0   | 4   | 4   | 0.8 | 1.8 | 223.6|     |
| 26  | *Gomphrena celosioides*   | 0      | 3    | 1    | 3   | 0   | 7   | 1.4 | 1.5 | 108.3|     |
| 27  | *Panicum laxum*           | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 28  | *Aspilia Africana*        | 0      | 1    | 1    | 2   | 0   | 4   | 0.8 | 0.8 | 104.6|     |
| 29  | *Ludwigia abyssinica*     | 1      | 1    | 0    | 3   | 4   | 9   | 1.8 | 1.6 | 91.3|     |
| 30  | *Icacinia trichantha*     | 0      | 0    | 2    | 0   | 0   | 2   | 0.4 | 0.9 | 223.6|     |
| 31  | *Opismenus burmannii*     | 12     | 17   | 30   | 11  | 16  | 86  | 17.2| 7.6 | 44.2|     |
| 32  | *Paspalum conjugatum*     | 3      | 5    | 5    | 2   | 0   | 15  | 3   | 2.1 | 70.7|     |
| 33  | *Setaria barbata*         | 1      | 0    | 0    | 2   | 3   | 6   | 1.2 | 1.3 | 108.7|     |
| 34  | *Phyllanthus amarus*      | 0      | 0    | 0    | 3   | 0   | 3   | 0.6 | 1.3 | 223.6|     |
| 35  | *Sorghum arundinaceum*    | 0      | 0    | 0    | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 36  | *Smilax anceps*           | 0      | 3    | 2    | 4   | 0   | 9   | 1.8 | 1.8 | 99.4|     |
around the tree canopy. With a Brillouin index of 2.941 beyond the canopy demarcation and 2.601 within the canopy, it was suggested that the group diversity of plant species outside the 1.5-m demarcation was slightly higher than within. However, going by the Berger-parker index value of 0.258 under tree canopy (UC) compared to 0.190 beyond the demarcation (BC), the dominant species within 1.5 m from the tree were more abundant than those in beyond (Table 9). There was a highly significant negative correlation between species abundance and total organic carbon of the soil outside the tree canopy ($R = -0.880, p < 0.05$) (Table 10). Similarly, species index also negatively correlated with soil sulphates ($R = -0.906$) at spaces beyond 1.5 m from the tree. Species abundance outside the 1.5-m

Table 5: Plant distribution at radial distance of 1.0–1.5 m from trunk of tree (under canopy)

| S/ N | Plant identity | Within selected tree (1.0–1.5 m) | Q.1 | Q.2 | Q.3 | Q.4 | Q.5 | Sum | Mean | SD | CV |
|------|----------------|----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|----|----|
| 1    | Eleusine indica | 2                               | 4   | 0   | 5   | 2   | 13  | 2.6 | 1.9 | 75.0 |
| 2    | Cynodon dactylon| 30                              | 50  | 36  | 34  | 14  | 164 | 32.8| 12.9| 39.4 |
| 3    | Axonopus compressus| 3                             | 0   | 0   | 0   | 3   | 6   | 1.2 | 1.6 | 136.9|
| 4    | Anthropogon gayanus| 6                            | 7   | 8   | 7   | 6   | 34  | 6.8 | 0.8 | 12.3 |
| 5    | Camemelina diffusa| 0                              | 0   | 4   | 0   | 4   | 8   | 0.8 | 1.8 | 223.6|
| 6    | Anelima beniniense| 0                             | 0   | 0   | 8   | 0   | 8   | 1.6 | 3.6 | 223.6|
| 7    | Anelima aequinoctiale| 1                          | 0   | 0   | 4   | 1   | 6   | 1.2 | 1.6 | 136.9|
| 8    | Triumfetta cordifolia| 0                        | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 9    | Sida garckeana     | 0                              | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 10   | Schrankia leptocarpa| 0                          | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 11   | Daniella oliveri   | 0                              | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 12   | Anthothona macrophyl|a| 3                            | 1   | 1   | 1   | 1   | 9   | 1.8 | 1.1 | 60.9 |
| 13   | Reissantia indica  | 0                              | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 14   | Brachiaia deflexa   | 10                             | 10  | 115 | 10  | 10  | 155 | 31  | 47.0| 151.5|
| 15   | Mallotus oppositifolius| 0                   | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 16   | Euphorbia hirta     | 0                              | 3   | 0   | 3   | 0   | 6   | 1.2 | 1.6 | 136.9|
| 17   | Alchornea laxiflora | 10                             | 10  | 10  | 10  | 10  | 50  | 10  | 0.0 | 0.0 |
| 18   | Alchornea cordifolia| 8                              | 5   | 5   | 5   | 4   | 27  | 5.4 | 1.5 | 28.1 |
| 19   | Momordica charantia | 0                              | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 20   | Cambretum hispidum  | 5                              | 2   | 2   | 2   | 5   | 16  | 3.2 | 1.6 | 51.3 |
| 21   | Newbouldia laevis   | 3                              | 0   | 0   | 0   | 5   | 9   | 1.8 | 2.2 | 120.4|
| 22   | Tridax procumbens   | 0                              | 1   | 0   | 1   | 0   | 2   | 0.4 | 0.5 | 136.9|
| 23   | Synedrella nodiflora| 3                             | 5   | 5   | 5   | 2   | 20  | 4   | 1.4 | 35.4 |
| 24   | Chromolaena odorata | 0                             | 1   | 0   | 1   | 5   | 7   | 1.4 | 2.1 | 148.1|
| 25   | Ageratum conyzoides | 3                             | 0   | 0   | 1   | 6   | 10  | 2   | 2.5 | 127.5|
| 26   | Gomphrena celosioides| 4                            | 5   | 2   | 5   | 0   | 16  | 3.2 | 2.2 | 67.7 |
| 27   | Panicum laxum       | 5                              | 6   | 6   | 12  | 0   | 29  | 5.8 | 4.3 | 73.6 |
| 28   | Aspilia Africana    | 0                              | 0   | 0   | 0   | 2   | 2   | 0.4 | 0.9 | 223.6|
| 29   | Ludwigia abyssinica | 2                             | 4   | 0   | 5   | 2   | 13  | 2.6 | 1.9 | 75.0 |
| 30   | Isocoma trichantha  | 0                              | 0   | 0   | 0   | 0   | 0   | 0.0 | 0.0 | 0.0 |
| 31   | Opilmensus burmannii| 15                             | 10  | 60  | 10  | 3   | 98  | 19.6| 23.0| 117.3|
| 32   | Paspalum conjugatum | 1                             | 8   | 8   | 8   | 9   | 34  | 6.8 | 3.3 | 48.1 |
| 33   | Setaria barbata     | 0                             | 1   | 5   | 1   | 3   | 10  | 2   | 2.0 | 100.0|
| 34   | Phyllanthus amarus   | 0                             | 0   | 3   | 2   | 0   | 5   | 1   | 1.4 | 141.4|
| 35   | Sorghum arundinaceum| 0                             | 0   | 0   | 3   | 0   | 3   | 0.6 | 1.3 | 223.6|
| 36   | Smilax anceps       | 3                             | 0   | 0   | 0   | 3   | 6   | 1.2 | 1.6 | 136.9|
radial demarcation may have been positively influenced by the soil’s organic carbon from soils in close proximity with the tree ($R = 0.916, p < 0.05$). The implication of the correlation is that species abundance outside the tree canopy could be enhanced by positively influencing total organic carbon within the canopy or reducing organic carbon outside canopy demarcation.

**Discussion**

The results of this study showed that some selected physiochemical characteristics of the soil were influenced by the proximity of the tree to the point of soil collection for analysis.

The pH of the topsoil (0 – 15 cm) obtained randomly within 1.5 m from the base of the tree was higher than

---

**Table 6** Plant distribution with each quadrant, inclusive of vegetative counts about the test tree

| S/N | Plant identity           | Within subplot abundance |
|-----|-------------------------|--------------------------|
|     |                         | Q.1 | Q.2 | Q.3 | Q.4 | Q.5 | Sum  | Mean | SD  | CV  |
| 1   | Eleusine indica         | 10  | 50  | 0   | 58  | 10  | 128  | 25.6 | 26.4| 103.1|
| 2   | Cynodon dactylon        | 300 | 600 | 150 | 518 | 421 | 1989 | 398  | 178.1| 44.8 |
| 3   | Axonopus compressus     | 20  | 20  | 20  | 20  | 43  | 123  | 24.6 | 10.3| 41.8 |
| 4   | Anthropogon gayanus     | 70  | 50  | 150 | 50  | 58  | 378  | 75.6 | 42.4| 56.1 |
| 5   | Commelina diffusa       | 13  | 10  | 40  | 11  | 44  | 118  | 23.6 | 16.9| 71.6 |
| 6   | Anelilema beniniense    | 38  | 54  | 123 | 43  | 37  | 295  | 59   | 36.4| 61.7 |
| 7   | Anelilema aequinoctiale | 45  | 56  | 0   | 56  | 54  | 211  | 42.2 | 24.0| 56.9 |
| 8   | Triumfetta cordifolia   | 0   | 0   | 0   | 2   | 2   | 2    | 0.4  | 0.9 | 223.6|
| 9   | Sida garkeana           | 10  | 4   | 4   | 14  | 36  | 72   | 7.2  | 4.6 | 63.9 |
| 10  | Schrankia leptocarpa    | 0   | 10  | 7   | 10  | 0   | 27   | 5.4  | 5.1 | 94.1 |
| 11  | Daniella oliveni        | 0   | 3   | 5   | 3   | 0   | 11   | 2.2  | 2.2 | 98.5 |
| 12  | Anthonotha macrophylla  | 12  | 50  | 50  | 50  | 34  | 196  | 39.2 | 16.7| 42.6 |
| 13  | Reissantia indica       | 12  | 13  | 12  | 0   | 50  | 10   | 5.6  | 5.6 | 56.1 |
| 14  | Brachiaria deflexa      | 150 | 150 | 150 | 150 | 150 | 750  | 150  | 0.0 | 0.0  |
| 15  | Mallotus oppositifolius | 100 | 15  | 25  | 15  | 100 | 255  | 51   | 44.9| 88.1 |
| 16  | Euphorbia hirta         | 30  | 15  | 50  | 15  | 30  | 140  | 28   | 14.4| 51.4 |
| 17  | Alchornea laxiflora     | 200 | 200 | 200 | 124 | 200 | 924  | 185  | 34.0| 18.4 |
| 18  | Alchornea cordifolia    | 70  | 60  | 60  | 60  | 70  | 320  | 64   | 5.5 | 8.6  |
| 19  | Momordica charantia     | 6   | 0   | 1   | 0   | 6   | 13   | 2.6  | 3.1 | 120.4|
| 20  | Combretum hispidum      | 14  | 15  | 40  | 32  | 14  | 115  | 23   | 12.2| 53.1 |
| 21  | Newbouldia laevis       | 13  | 23  | 13  | 21  | 13  | 83   | 16.6 | 5.0 | 30.0 |
| 22  | Tridax procumbens       | 0   | 5   | 14  | 5   | 11  | 35   | 7    | 5.5 | 78.9 |
| 23  | Synedrella nodiflora    | 0   | 50  | 70  | 47  | 13  | 180  | 36   | 28.7| 79.8 |
| 24  | Chromolaena odorata     | 25  | 15  | 0   | 22  | 25  | 87   | 17.4 | 10.5| 60.6 |
| 25  | Ageratum conyzoides     | 0   | 0   | 100 | 4   | 21  | 125  | 25   | 42.8| 171.3|
| 26  | Gomphrena celosioides   | 43  | 24  | 22  | 24  | 43  | 156  | 31.2 | 10.8| 34.6 |
| 27  | Panicum laxum           | 100 | 250 | 550 | 74  | 100 | 1074 | 215  | 199.9| 93.0 |
| 28  | Aspilia Africana        | 0   | 0   | 40  | 8   | 15  | 63   | 12.6 | 16.5| 131.3|
| 29  | Ludwigia abyssinica     | 8   | 50  | 14  | 64  | 8   | 144  | 28.8 | 26.3| 91.4 |
| 30  | Kacina trichantha       | 21  | 12  | 13  | 12  | 32  | 90   | 18   | 8.7 | 48.3 |
| 31  | Opismenus burmannii     | 100 | 150 | 300 | 84  | 93  | 727  | 145  | 90.1| 62.0 |
| 32  | Paspalum conjugatum     | 120 | 150 | 150 | 25  | 110 | 555  | 111  | 51.3| 46.2 |
| 33  | Setaria barbata         | 15  | 23  | 23  | 55  | 12  | 128  | 25.6 | 17.1| 67.0 |
| 34  | Phyllanthus amarus      | 28  | 22  | 50  | 26  | 32  | 158  | 31.6 | 10.9| 34.5 |
| 35  | Sorghum arundinaceum    | 70  | 56  | 46  | 43  | 54  | 269  | 53.8 | 10.5| 19.6 |
| 36  | Smilax aniceps          | 0   | 16  | 40  | 16  | 32  | 104  | 20.8 | 15.6| 75.0 |
somewhere within and beyond the canopy fringes. This supports the earlier findings of Rhoades (1997), who described that soil pH under the single-tree influence was lower under canopy than the outside. Another possible explanation for reduced pH may be in the exudation of organic acids which plants used most times as phytochelators to enhance absorption of nutrients or impede the accumulation of pollutants, as the case may be (Salt et al. 1999). In a similar study by Imoro et al. (2012) in the Afrensau Brohuma Forest Reserve in Ashanti region, Ghana, the authors reported that soil pH was directly influenced by T. grandis (pH = 7.04), when compared with the control plot (pH = 7.53). Watanabe et al. (2009) documented lower pH values (pH = 7.14).

Kanazawa et al. (1994), Pellet et al. (1995) reported that plants in most iron-contaminated soils usually have need of organic acids that enhance bio-availability of soil-bound iron. The survival of most of these plants in acidic soils also depends on their ability to exude citric and malic acids, amongst other organic acids to chelate the highly phytotoxic rhizospheric Al^{3+} to form a less toxic complex, a phenomenon which is also common in many oxisols and ultisols; particularly the most predominant soil type in Benin City, Nigeria. Apart from the fact that Al^{3+} enhances soil acidity (Merino-Gergichevich et al. 2010), the release of organic acids within root zones of the tree to chelate the metal further reduces the soil pH around this rejoin; perhaps the justification for the reduced pH reported compared to outside the canopy demarcation.

Although no single mechanism is responsible for changes in soil chemistry, we observed single-tree influence of T. grandis was also observed in the soil composition of total organic carbon, total nitrogen and soluble phosphorus. The concentrations of these soil characteristics under the canopy were higher than beyond; also confirming earlier reports (Rhoades 1997, Zinke 1962). The possibility exists therefore that the forest environment probably affect soil nutrients dynamics as earlier suggested by Lal (2005). Imoro et al. (2012) reported that soil nitrogen under the T. grandis plantation minimally surpassed that outside the tree plantation.

Enhanced accumulation of organic carbon and phosphorus is most likely attributed to the enormous organic materials, which are consequences of the decay of fallen litter that gathers around the tree. In a number of isolated cases, as observed in the study, some of the foresters, when carrying out routine slashing of the weeds around the planted forest, usually gather most of the weeds and place them around the trunk as mulch. Increasing the quantity of plant material incorporated into the soil usually would further advance soil nutrient standing. Increased organic matter has been reported by Dinakaran and Krishnayya (2010) in teak forested areas.

Table 7 Relative abundance of plant species within the radial distances within the tree canopy

| S/N | Plant identity       | Total (SP) | **Relative abundance (%)** |
|-----|----------------------|------------|---------------------------|
|     |                      | m          | 0.5 m  | 0.5–1.0 m | 1.0–1.5 m | 1.5–2.0 m |
| 1   | Eleusine indica      | 25.6       | 7.03   | 9.38      | 10.16     |
| 2   | cynodon dactylon     | 397.8      | 3.37   | 6.33      | 8.25      |
| 3   | Axonopus compressus  | 24.6       | 4.07   | 8.94      | 4.88      |
| 4   | Anthropogon gayanus  | 75.6       | 1.32   | 4.5       | 8.99      |
| 5   | Commelina diffusa    | 23.6       | 1.69   | 0         | 3.39      |
| 6   | Anthelia beninienne  | 59         | 0      | 2.71      | 2.71      |
| 7   | Anthelia equinocti   | 42.2       | 1.42   | 4.74      | 2.84      |
| 8   | Triumphlea cordifolia| 0.4        | 1.50   | 0         | 0         |
| 9   | Sida ganceana        | 7.2        | 0      | 2.78      | 0         |
| 10  | Schrankia leptocarpa | 5.4        | 22.22  | 0         | 0         |
| 11  | Daniella oliveri     | 2.2        | 9.09   | 45.45     | 0         |
| 12  | Antherotheca macrophylla | 39.2 | 5.1     | 2.55      | 4.59      |
| 13  | Reissania indica     | 10         | 0      | 0         | 0         |
| 14  | Bracharia deflexa    | 150        | 0.53   | 6.53      | 20.67     |
| 15  | Mallotus oppositifolius| 51        | 0      | 3.53      | 0         |
| 16  | Euphorbia hirta      | 28         | 0      | 0         | 4.29      |
| 17  | Alchornea laxiflora  | 184.8      | 0      | 1.3       | 5.41      |
| 18  | Alchornea cordifolia | 64         | 0.31   | 0.63      | 8.44      |
| 19  | Momordica charantia  | 2.6        | 0      | 0         | 0         |
| 20  | Combretum hispidum   | 23         | 4.35   | 2.61      | 13.91     |
| 21  | Newbouldia laevis    | 16.6       | 1.2    | 7.23      | 10.84     |
| 22  | Tridax procumbens    | 7.0        | 0      | 0         | 5.71      |
| 23  | Synechla nodiflora   | 36         | 7.22   | 13.89     | 11.11     |
| 24  | Chromolaena odorata  | 17.4       | 0      | 8.05      | 0         |
| 25  | Ageratum conyzoides  | 25         | 0      | 3.2       | 8         |
| 26  | Gompiera celosiodes  | 31.2       | 1.28   | 4.49      | 10.26     |
| 27  | Panicum laxum        | 214.8      | 0      | 0         | 2.7       |
| 28  | Aspilla Africana     | 12.6       | 1.59   | 6.35      | 3.17      |
| 29  | Ludwigia abyssinica  | 28.8       | 0      | 6.25      | 9.03      |
| 30  | Icacinia trichantha  | 18         | 5.56   | 2.22      | 0         |
| 31  | Opismenus burmannii  | 145.4      | 2.61   | 11.83     | 13.48     |
| 32  | Parapalan conjutum   | 111        | 0.72   | 2.7       | 6.13      |
| 33  | Setaria barbata      | 25.6       | 0      | 4.69      | 7.81      |
| 34  | Phylanthus amarus    | 31.6       | 0.63   | 1.9       | 3.16      |
| 35  | Sarghnum arundinaeum | 53.8       | 0      | 0         | 1.12      |
| 36  | Smilax aniceps       | 20.8       | 11.54  | 8.65      | 5.77      |

mTotal (SP) mean total of plant species within the subplot

*Distance from tree base

**Percentage of plant abundance at distance compared to totals within the subplot
systems (Rhoades, 1997). Some authors reveal that such influences may be necessitated by phytotoxins in the soil that may be plant-related (Harborne 1977, Rauha et al. 2000). Allelopathy is one of such plant-mediated influences that affect tree-plant interactions (Harborne 1977). Plants produce a large diversity of secondary metabolites including phenols and fatty acids which have an overall allelopathic effect on the growth and development of neighbouring plants species (Li et al., 2010). Other impeding factors may be poor availability of light necessitated by the tree canopy (Rauha et al. 2000). This means that those weeds or plants species that were located very close to the tree base would be sparsely abundant or distributed. This was the general observation about plant species abundance

| S/N | Plant identity                  | Under canopy (< 1.5 m) | Outside canopy demarcation (> 1.5 m) | t value | p value |
|-----|---------------------------------|------------------------|-------------------------------------|---------|---------|
| 1   | Eleusine indica                 | 6                      | 19                                  | -1.27   | 0.239   |
| 2   | cynodon dactylon                | 71                     | 326                                 | -3.37   | 0.01    |
| 3   | Axonopus compressus             | 4                      | 20                                  | -3.35   | 0.01    |
| 4   | Anthropogon gayanus             | 11                     | 64                                  | -2.8    | 0.023   |
| 5   | Commelina diffusa               | 1                      | 22                                  | -2.75   | 0.025   |
| 6   | Aneilema beniniense             | 3                      | 31                                  | -3.03   | 0.016   |
| 7   | Aneilema equinoctiale           | 4                      | 38                                  | -3.43   | 0.009   |
| 8   | Triumfetta cordifolia           | 1                      | 0                                   | -1      | 0.347   |
| 9   | Sida garckeana                  | 0                      | 7                                   | -3.16   | 0.013   |
| 10  | Schrankia leptocarpa            | 1                      | 4                                   | -1.31   | 0.228   |
| 11  | Daniella oliveri                | 1                      | 2                                   | -0.25   | 0.807   |
| 12  | Anthrohodra macrophylla         | 5                      | 34                                  | -3.79   | 0.005   |
| 13  | Reissantia indica               | 0                      | 10                                  | -3.98   | 0.004   |
| 14  | Brachinia deflexa               | 42                     | 108                                 | -2.16   | 0.063   |
| 15  | Mallotus oppositifolius         | 2                      | 49                                  | -2.48   | 0.038   |
| 16  | Euphorbia hirta                 | 1                      | 27                                  | -3.61   | 0.007   |
| 17  | Alchornea laxiflora             | 12                     | 172                                 | -10.4   | < 0.001 |
| 18  | Alchornea cordifolia            | 6                      | 58                                  | -25.4   | < 0.001 |
| 19  | Momordica charantia             | 0                      | 10                                  | -1.86   | 0.101   |
| 20  | Combretum hispidum              | 5                      | 18                                  | -2.5    | 0.037   |
| 21  | Newbouldia laevis               | 3                      | 13                                  | -3.97   | 0.004   |
| 22  | Tridax procumbens               | 0                      | 7                                   | -2.41   | 0.043   |
| 23  | Synedrella nodiflora            | 12                     | 27                                  | -1.49   | 0.175   |
| 24  | Chromolaena odorata             | 1                      | 16                                  | -3.27   | 0.011   |
| 25  | Ageratum conyzoides             | 3                      | 23                                  | -1.03   | 0.335   |
| 26  | Gomphrena celosioide            | 5                      | 26                                  | -3.62   | 0.007   |
| 27  | Panicum laxum                   | 6                      | 209                                 | -2.27   | 0.053   |
| 28  | Aspilia Africana                | 1                      | 11                                  | -1.38   | 0.206   |
| 29  | Ludwigia abyssinica             | 4                      | 24                                  | -1.81   | 0.108   |
| 30  | icacina trichanta               | 1                      | 17                                  | -3.36   | 0.011   |
| 31  | Opismenus burmannii             | 41                     | 105                                 | -2.13   | 0.066   |
| 32  | Passalum conjugatum             | 11                     | 100                                 | -3.96   | 0.004   |
| 33  | Setaria barbata                 | 3                      | 22                                  | -2.42   | 0.042   |
| 34  | Phylanthus amarus               | 2                      | 30                                  | -6.01   | < 0.001 |
| 35  | Sorghum arundinaceum            | 1                      | 53                                  | -10.3   | < 0.001 |
| 36  | Smilax anceps                   | 5                      | 16                                  | -1.88   | 0.096   |
within 1.5 m from the base of the tree base; thus implying a negative single-tree influence of *T. grandis* on neighbouring plant diversity. It is, however, important to note that close pointy of the tree also enhanced the development of those plant species that were hitherto not found beyond the canopy.

In another development, the species abundance of some plants increased away from the canopy cover, whereas, for some, it decreased outside the cover than within the cover. Specifically, the growth of *Sida garckeana*, *Reisantia indica*, *Momordica charantia* and *Tri-dax procumbens* was completely impeded within 1.5 m

| Parameters      | Under canopy | Outside canopy demarcation | Remarks                                      |
|-----------------|--------------|----------------------------|----------------------------------------------|
| Taxa_S          | 34           | 35                         | Comparable taxa                              |
| Individuals     | 1385         | 8577                       | More individuals outside canopy demarcation (OC) |
| Dominance_D     | 0.122        | 0.081                      | More dominant spp. under canopy (UC)         |
| Simpson_1-D     | 0.879        | 0.920                      | Comparable                                   |
| Shannon_H       | 2.656        | 2.954                      | OC slightly higher sample diversity          |
| Evenness_e^H/S  | 0.419        | 0.548                      | Species in OC more evenly distributed        |
| Brilouin        | 2.601        | 2.941                      | OC slightly higher group diversity           |
| Menhinick       | 0.914        | 0.378                      | UC with higher species richness than OC       |
| Margalef        | 4.562        | 3.754                      | UC with higher species richness than OC       |
| Equitability_J  | 0.753        | 0.831                      | Plants in OC probably more evenly distributed|
| Berger-Parker   | 0.258        | 0.190                      | The dominant spp. in UC is more abundant than that in OC |
| Chao-1          | 34           | 35                         | Comparable taxa                              |

*Calculation is based on the totality of weeds in all 5 quadrants
**The Chao-1 index is a measure of the abundance of individuals belonging to a certain class in a sample. In this case, we are looking at classes being individual species groups. The Berger-Parker index expresses the proportional abundance of the most abundant species

| Correlations (Pearson’s) | Spa-UC (0–0.5 m) | Spa-UC (0.5–1.0 m) | Spa-UC (1.0–1.5 m) | Spa-OC |
|--------------------------|------------------|--------------------|--------------------|-------|
| pH (OC)                  | – 0.496          | 0.315              | – 0.422            | – 0.176 |
| Electric conductivity (OC)| 0.466            | 0.325              | 0.807              | 0.402 |
| Total org. carbon (OC)   | 0.249            | – 0.379            | – 0.658            | – 0.880* |
| Total nitrogen (OC)      | – 0.134          | – 0.551            | 0.402              | 0.202 |
| Potassium (OC)           | – 0.431          | 0.088              | – 0.468            | 0.117 |
| Calcium (OC)             | – 0.043          | 0.416              | 0.790              | 0.933* |
| Magnesium (OC)           | – 0.254          | 0.549              | – 0.128            | 0.507 |
| Soluble phosphates (OC)  | – 0.015          | – 0.458            | – 0.591            | – 0.906* |
| Sulphates (OC)           | – 0.259          | 0.315              | 0.675              | 0.856 |
| pH (UC)                  | 0.454            | – 0.572            | – 0.330            | – 0.675 |
| Electric conductivity (UC)| – 0.405          | 0.640              | 0.047              | 0.393 |
| Total org. carbon (UC)   | – 0.174          | 0.482              | 0.710              | 0.916* |
| Total nitrogen (UC)      | 0.045            | – 0.404            | – 0.568            | – 0.400 |
| Potassium (UC)           | 0.534            | 0.154              | – 0.484            | – 0.391 |
| Calcium (UC)             | – 0.340          | 0.457              | 0.520              | 0.857 |
| Magnesium (UC)           | – 0.852          | 0.101              | – 0.49             | – 0.052 |
| Soluble phosphates (UC)  | – 0.557          | 0.188              | 0.236              | 0.262 |
| Sulphates (UC)           | – 0.078          | 0.521              | 0.800              | 0.884* |

*Correlation is significant at the 0.05 level (2-tailed)
A soil outside canopy demarcation, U soil under canopy, Spa-UC species abundance under tree canopy, Spa-OC species abundance outside canopy demarcation
from the tree. Being in close proximity to the base of the tree necessitated the development of \textit{Triumfetta cordifolia}, which was not found in any other location other than under canopy within the forest. This might be due to the allopathic influence of \textit{T. grandis}. Moreover, even though previous workers (Falk et al., 2008; Schnabel et al. 2017; Habashi and Waez-Mousavi, 2017) have reported a similar selective effect of single-tree on some plant species and soil microfauna, the mechanism is still unclear and may be short lived.

The possible association between soil physicochemical characteristics and plants species abundance under the single-tree influence suggested that increased sulphates in the soil might enhance plant species abundance under the influence of the tree canopy. Sulphates have been reported to enhance nutrient availability and acquisition by plants (Prade et al. 1993; Mitra et al. 2009). However, a negative association with phosphates was observed outside the tree canopy. Phosphorus is an essential macronutrient for plant growth, and it is limiting crop production in many regions of the world (Holford 1997). Increased phosphorus lead to increased plant development because phosphorus converts sunlight into usable energy, and essential to cellular growth and reproduction (Malhotra et al., 2018). The association statistics presented in Table 10 suggest both the negative and positive association between species abundance and total organic carbon under and outside canopies respectively. The negative association of this essential plant nutrient with plant species abundance within and beyond the canopy fringes calls for more scrutiny.

Species abundance outside the 1.5-m radial demarcation positively correlated with the total organic carbon of soils in close proximity with the tree ($R = 0.916$, $p < 0.05$); the implication being that enhancing soil organic carbon with the tree canopy may be an important factor in increasing species abundance beyond this demarcated area. As reported earlier, total organic carbon within the 1.5-m demarcated area to the tree was significantly higher than away from the area. Given the significant role organic carbon plays in plant species development, diversity and abundance through enhancing soil porosity, aggregate stability and water-holding capacity (Wehr et al. 2017), it is suggested that a reduction in organic matter of soil may have, amongst other biological and physicochemical factors, contributed to poor plant abundance of some plant species. Although there was generally more plant species outside the 1.5-m demarcation than within, an increase in soil organic matter may further enhance such plant species abundance.

**Conclusion**

The single-tree influence of \textit{T. grandis} on plant species abundance as well as characteristics of topsoil in an 8-year old planted forest has been investigated. Much as increased diversity of certain species was reported in close proximity to \textit{T. grandis}, most of the plant species identified were negatively impacted very close to the tree. Given the fact that plant-plant associations affect the quality of forest soils, the impact of \textit{T. grandis} in forest soil quality is possibly a factor of the outcome of its association with neighbouring plant species.

**Acknowledgements**

The researchers wish to thank the Management of the Moist Forest Research Station (Forestry Research Institute of Nigeria), Benin City, for providing space for the study.

**Funding**

Not applicable.

**Availability of data and materials**

Not applicable.

**Authors’ contributions**

BI conceived the project idea and developed the research strategy with AL. AL and BI collected the data while MO performed the statistical analysis. BI, AL and MO contributed to writing the manuscript. All authors read and approved the final version of the manuscript.

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interest**

The authors declare that they have no competing interests.

**Author details**

1Department of Plant Biology and Biotecnology, Faculty of Life Sciences, University of Benin, Ugbowo, Benin City PMB 1154, Nigeria. 2School of Bioscience and Veterinary Medicine, University of Camerino – Center for Floristic Research of the Apennine, Gran Sasso and Monti della Laga National Park, San Colombo, 67021 Barisciano, L’Aquila, Italy. 3Moist Forest Research Station, Forest Research Institute of Nigeria, Benin City, Edo State, Nigeria.

Received: 13 January 2020 Accepted: 10 February 2020

**Published online**: 19 February 2020

**References**

Aborinde AD, Aweto AO (1998) Effects of exotic tree plantations of teak (\textit{Tectona grandis}) and gmelina (\textit{Gmelina arborea}) on a forest soil in south-western Nigeria. Soil Use and Management 6(1):43–45

Akindele SO (1989) Teak yields in the dry lowland rainforest area of. \textit{Nigeria Journal of Tropical Forest Science} 21(1):32–36

Akobundu IO, Agyakwa CW. 1998. \textit{A Hand book of West African Weeds}.

Aldrich JD. 1984. \textit{Weed-Crop Ecology: Principles and Practices}, Breton Publishers, India, 1051-1060

Burgess SO, Adams MA, Turner NC, Ong CK (1998) The redistribution of soil water by tree roots systems. \textit{Ecologia} 115:306–311

Cantarelli EB, Machado SLO, Costa EC, Pezzutti R (2006) Efeito do manejo de plantas daninhas no desenvolvimento inicial de \textit{Pinus taeda} em várzeas na Argentina. \textit{Revista Árvore} 30(5):711–718

Dinakaran J, Krishnayya NSR (2010) Variations in soil organic carbon and litter decomposition across different tropical vegetation covers. \textit{Current Sci} 99(8):1051

Evangelene VR, Prakash EJJ, Samuel AS, Jayakumar M (2012) Allelopathic potential of \textit{Tectona grandis} I on the germination and seedling growth of \textit{Vigna mungo}. Pakistan Journal Weed Science Research 18(1):65–70

Falk K, Burke D, Elliott K, Holmes S (2008) Effects of single-tree and group selection harvesting on the diversity and abundance of spring forest herbs in deciduous forests in southwestern Ontario. \textit{Forest Ecology and Management} 255(7):2486–2494. https://doi.org/10.1016/j.foreco.2008.01.033
