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# Spatial and temporal variations of soil microbial respiration under native and exotic tree species

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## ABSTRACT

Different tree species can directly or indirectly affect soil conditions. They influence soil microbial diversity and abundance and hence soil respiration. Trees and soil respiration have a complex relationship that is poorly understood, as does the seasonal and spatial variation that naturally occurs in them. This study was therefore conducted to evaluate soil respiration processes under two native tree species, Msuku (*Uapaca kirkiana*) and Mtondo (*Julbernardia paniculata*), and one introduced tree species, Malaina (*Gmelina arborea*). In 2019 (March and October), soil samples were taken at 0.5m, 1.5m, 2.5 m, and 3.5m intervals from the trunks of the chosen tree species at depths of 0–10 cm and 10–20 cm. Using the alkali absorption method, soil respiration was assessed. The findings demonstrated that respiration decreased with the increase in horizontal distance from the trunk of both indigenous species. On the contrary, soil respiration increased with the increase in horizontal distances from the trunks of introduced tree species. The findings also demonstrated that respiration was higher at 0–10 cm than at 10–20 cm soil depths in both March and October under all three tree species. The higher microbial soil respiration in the surface layer could be attributed to better soil aeration, as opposed to the sub-surface soil. Furthermore, soil respiration was higher for soils collected in March than soils collected in October, probably because March is associated with the rainy season in which soil moisture content is higher than October. It can be concluded that different tree species strongly influence spatial and vertical soil respiration differently. This calls for proper selection of tree species to be utilised in agroforestry. Therefore, knowledge of nutrient uptake of various tree species and the influence of tree species on soil processes, but also microbial population effects on nutrient cycling linked to various tree species is essential.

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## INTRODUCTION

As a fundamental component of life and biodiversity, soil is a valuable natural resource whose quality affects the cycling of nutrients and human well-being (Bogunovic et al., 2017). According to Bogdanovic et al., (2017), soil spatial and temporal dimensions are characteristics that exist in both space and time, possessing both spatial extension and temporal duration. In addition to enhancing food security and quality, sustainable soil management with a thorough understanding of soil characteristics can assist minimize the loss of soil quality and value (Chen et al., 2020). The term "respiration of soil" describes the release of carbon dioxide during the respiration process of soil organisms (Moyano et al., 2012). This could include bacteria, animals, the rhizosphere, and plant roots breathing. One important ecosystem function that releases carbon from the soil as $CO_2$ is called soil respiration (Parkin et al., 1997). The primary terrestrial carbon dioxide flux sources are the respiration of heterotrophic soil organisms, autotrophic live root respiration, and the breakdown of soil organic matter (SOM) (Kuzyakov, 2006). Both biotic and abiotic factors have an impact on the intricate ecology of soil respiration. Lee and Jose (2003) have identified temperature and moisture content of the soil as significant environmental parameters that impact the rate of soil respiration. It is generally accepted that soil respiration rises with temperature (Kirschbaum, 1995) and falls with extreme dryness or wetness of the soil (Moyano et al., 2012; Orchard & Cook, 1983).

Soil respiration has emerged as a key concern in global change ecology because of its contentious contribution to the process of global warming (Kirschbaum, 1995). Soil respiration variations have the potential to either greatly exacerbate or ameliorate atmospheric $CO_2$ rises, which would have an impact on climate change feedbacks. These changes might equal or surpass the yearly amount of $CO_2$ released into the atmosphere as a result of changing land uses or the burning of fossil fuels. The carbon (C) cycle and soil respiration are tightly interwoven. Motivated by both autotrophic and heterotrophic mechanisms, soil respiration is in charge of transferring carbon from the ground to the atmosphere. Temperature, hydrology, land management, and the current biodiversity all interact intricately to regulate soil respiration (Kuzyakov, 2006). Soil respiration is an indicator of the soil's ability to support soil microorganisms and plant growth, according to McCurry et al., (2004) and Paul (2008). In terms of SOM and plant litter decomposition, soil respiration can be used to typically represent the degree of microbial activity.

A few biological factors, such as vegetation type (i.e., tree species, leaf area, litter quantity, and quality), canopy cover, nitrogen, and soil microbial population, can induce spatial and temporal variations in soil respiration (Walker, 1995; Sylvia et al., 2005; Metcalfe, 2011). Analysing changes and promptly modifying management methods are made easier with an understanding of the spatial and temporal characterisation of soil properties (Chen et al., 2020). Additionally, soil fertility evaluation within cultivated land is of high benefit for comprehending soil fertility levels and preventing soil degradation for high food crop productivity (Chen et al., 2020). Trees of different species can therefore directly or indirectly affect soil conditions such as soil respiration (Metcalfe, 2011). This may involve producing differing amounts and types of root exudates (Nguyen, 2003). Many tree species can encourage the growth of various microbial communities, while other tree species can inhibit soil microorganisms (Nguyen, 2003). Under various plants, microbial diversity and abundance can fundamentally modify soil processes that affect soil nutrient availability (Metcalfe, 2011).

The impact of tree species on soil respiration rate has been the subject of various investigations. For example, the study by Agusto et al., (2015), established the link between soil respiration and tree species-specific features. The authors found that through modifying the soil microbial habitat, soil physicochemical parameters, and carbon input and build-up, tree canopy and tree-specific litter impacted soil respiration. However, Liu et al., (2016), reported that soil microclimate had a greater effect on soil respiration beneath a tree cover than soil carbon input (litter and fine root biomass). Conversely, Prevost et al., (2010) showed that soil respiration was significantly affected by the addition of fresh litter. Lee (2018) discovered a strong correlation between the rise in root biomass and soil respiration. In long-term soil incubations, Birge et al., (2015) found no correlation between soil respiration and microbial biomass. According to published research, it's critical to comprehend how various tree species affect soil properties before deciding which course of action to take in a production project.

This present study was set considering the huge uncertainty surrounding the intricate relationships that certain trees have with soil microbes as well as the natural seasonal and geographic fluctuations. There was a great need for a comprehensive study on how various tree types affect the respiration of soil microbes. The study was conducted to provide a more realistic view of different tree effects on soil microbial populations and soil microbial respiration. Knowledge of microbial population effects on nutrient cycling linked to various tree species would be very essential in describing the nutrient uptake of various tree species and for subsequent interpretation of the impact of different tree species on soil processes. This would play a greater role in agricultural production endeavours.

## OBJECTIVES OF THE STUDY

The primary goal of this study was to examine how soil respiration varied under various tree canopy covers. More specifically, the study sought to find out how increasing the horizontal distance between tree trunks affected microbial respiration, how soil depth affected soil respiration under various tree species, and how soil respiration varied seasonally under native and exotic tree species.

## MATERIALS AND METHODS

### *A description of the study location and the tree species*

The Chilunga forest in the district of Zomba served as the study site. Zomba is in the southern region of Malawi. It receives a mean annual rainfall and temperature of approximately 2000 mm and 26.3°C (79.34ºF), respectively. The study used three different tree species. These tree species were selected due to the fact that farmers commonly utilise them in the agroforestry production. The three species chosen were *Gmelina arborea*, *Julbernardia paniculata*, and *Uapaca kirkiana*. Soil respiration under the three different tree species (in triplicate) were studied. *Uapaca kirkiana* and *Julbernardia paniculata* are indigenous (native) species while *Gmelina arborea* is an introduced (exotic) tree species.

### *Soil sampling*

Using a soil auger with a 4.8 cm diameter, soil samples were taken at two different depths: 0-10 cm and 10-20 cm. The three tree species (in triplicates) with isolated crown cover and a canopy radius of at least 3.5m were studied. For each tree trunk soil samples at various horizontal distances (0.5 m, 1.5 m, 2.5 m, and 3.5 m) were collected. Sampling was performed in the wet season (March) and the dry season (October). Soon after soil sampling, samples were taken to the laboratory, and after the exclusion of large stones and plant roots, 2 kg of each sample was obtained for soil respiration scrutiny.

### *Analysis of soil respiration*

Laboratory measurements of soil respiration were made for this investigation. Soil respiration was determined following the alkali absorption technique (Bloem et al., 2006). Moist soil (10g) was weighed out into a scintillation vial. In order to capture the $CO_2$ that would be emitted by bacteria, 25 ml of 0.05M NaOH solution was placed into plastic cups. The opened vials now containing the soil were placed in the plastic cups containing NaOH solution and closed for incubation. Three incubation vessels without soil were used as blanks. Equation (1) states that carbon dioxide generated by the soil is captured in the sodium hydroxide solution.

$$CO_2 + 2NaOH \longrightarrow Na_2CO_3 + H_2O \qquad \text{Equation 1}$$

According to chemical theory, NaOH reacts with $CO_2$ to produce a precipitate of sodium carbonate. At the end of incubation (4 hours), the plastic cups were opened, and in each plastic cup, 2 ml of 0.5M barium chloride ($BaCI_2$) was added to precipitate carbonate as $BaCO_3$, followed by 3 drops of phenolphthalein indicator, which made the solution turn red. To estimate the amount of $CO_2$ that reacted with NaOH, the acid-base titration method followed, where 0.05M HCI **w**as added to each sample until the red colour was clear. Then the amount of HCI was recorded. Microbial respiration (mg $CO_2$-C/g dry soil /hr at 22 $^0$C) was calculated using equation 2.

$$RS = \frac{M_c(V_0-V)S}{S_{dw}t*2} \text{………………………………………………………………………………Equation 2}$$

Where $M_c$ is the molar weight of carbon (12.01); $V_o$ and $V$ *are the* volumes in ml of 0.05 M HCI consumed during titration of the blank and sample respectively; $S$ is the strength of HCI (normality); $t$ is the incubation time; $S_{dw}$ is the gram weight of the sample.

*Statistical Data Analysis*

The collected data was subjected to Genstat for analysis of variance (ANOVA). Whenever differences were found between treatments, couples of means were tested using the least significant difference (LSD).

## RESULTS AND DISCUSSIONS

Table 1 shows that soil respiration increased with an increase in horizontal distance from the trunk of exotic tree species (*Gmelina arborea*) during the dry season. On the other hand, for native tree species (*Julbernardia paniculata* and *Uapaca kirkiana*), soil respiration declined as the horizontal distance from the tree trunk increased. These variations were statistically different ($p$ > 0.005) at different horizontal distances. Notably at a distance of 1.5m *Uapaca kirkiana* (0.0749$^{b}$) and *Julbernardia paniculata* (0.0686$^{b}$) had significantly higher soil respiration than the exotic *Gmelina arborea* (0.0521$^{a}$) tree species. *Uapaca kirkiana* recorded the highest (0.0886$^{c}$) significant difference in soil respiration at 0.5m and was followed by *Julbernardia paniculata* (0.0783$^{b}$). The least soil respiration was for *Gmelina arborea* tree (0.0461$^{a}$). This study revealed that soil respiration is higher at lower distances for the two native studied trees (*Uapaca kirkiana* and *Julbernardia paniculata*) than the exotic (*Gmelina arborea*) one (Table 1). Soil respiration drops with increasing horizontal distance from the stem in dry weather (Moyano et al., 2012; Orchard & Cook, 1983).

Table 1: The impacts of horizontal distance and tree species on dry-season soil respiration ($CO_2$/g/hr)

| Tree species (TS) | Horizontal distance from tree trunk(HD) | | | | |
|---|---|---|---|---|---|
| | 0.5m | 1.5m | 2.5m | 3.5m | |
| *Gmelina arborea* | 0.0461$^{a}$ | 0.0521$^{a}$ | 0.0556$^{a}$ | 0.0672$^{a}$ | |
| *Julbernardia paniculata* | 0.0783$^{b}$ | 0.0686$^{b}$ | 0.0617$^{a}$ | 0.058$^{b}$ | |
| *Uapaca kirkiana* | 0.0886$^{c}$ | 0.0749$^{b}$ | 0.0689$^{b}$ | 0.0615$^{a}$ | |
| Fpr (HD)=0.493<br>LSD (HD)=0.01314 | Fpr (TS *HD)=0.107<br>LSD(TS*HD)=0.02277 | | | | Fpr (TS)=0.008<br>LSD(TS)=0.01138 |

A substantial difference ($p$ < 0.005) is present for values that have distinct subscripts. Values are means of three triplicates.

Significantly different results were obtained for the association concerning soil depth and soil respiration during the dry season ($p$ < 0.005, Table 2). For all tree species, soil respiration was substantially higher between 0 and 10 cm than between 10 and 20 cm. For depths of 0–10 cm and 10 – 20 cm, correspondingly, the highest soil respiration was 0.0896 mg $CO_2$/g/h and 0.0574 mg $CO_2$/g/h. These were observed in the native *Uapaca kirkiana* tree species (Table 2). The native tree species revealed significantly higher figures for soil respiration closer to the soil surface (0-10cm) than the deeper depth (10-20cm) (Table 2). The exotic tree species (*Gmelina arborea*) showed the least soil respiration in both distances (0-10cm~0.0672) and 10-20cm~0.0434) (Table 2).

Table 2. Impacts of tree species and soil depth association on soil respiration (mg $CO_2$/g/hr) during the dry season.

| Tree species (TS) | Soil depth (SD) | Soil depth (SD) | |
|---|---|---|---|
| | 0-10cm | 10-20cm | |
| *Gmelina arborea* | $0.0672^a$ | 0.0434a | |
| *Julbernardia paniculata* | $0.0788^b$ | $0.0545^b$ | |
| *Uapaca kirkiana* | $0.0896^c$ | $0.0574^c$ | |
| Fpr (SD)=<0.001<br>LSD (SD)=0.007 | Fpr (TS*SD)=0.59<br>LSD (TS*SD) =0.01245 | | Fpr (TS)=<0.001<br>LSD (TS)=0.0088 |

A substantial difference ($p < 0.005$) is present for values that have distinct subscripts. Values are means of three triplicates

The impacts of soil depth on soil respiration during the dry season were significantly different for all the studied tree species. The higher microbial soil respiration in the surface layer observed could be attributable to better soil conditions such as aeration and soil moisture content as compared with the subsurface soil.

During the dry weather, there was a substantial spatial vertical variation of soil respiration on soils collected under *Gmelina arborea* tree species ($p< 0.005$, Table 2). In comparison to 10-20 cm depth, soil respiration was substantially higher between 0 and 10 cm (Table 2). When compared to the sub-surface soil, the larger microbial population in the surface layer can be linked to superior soil properties including aeration and soil moisture content (Lee & Jose, 2003). The season had a noteworthy impact on soil respiration under *Gmelina arborea*. Compared to the dry season, the rainy season saw a marked increase in soil respiration. This seasonal variation might be due to the availability of low water content during the dry season, which results in a low microbial population and hence low soil respiration (Lee & Jose, 2003).

Table 3. The impacts of tree species and horizontal distance on soil respiration ($CO_2$/g/hr), during rainy-season

| Tree species (TS) | Horizontal distance from tree trunk (HD) | | | | |
|---|---|---|---|---|---|
| | 0.5m | 1.5m | 2.5m | 3.5m | |
| *Gmelina arborea* | $0.1058^a$ | $0.1125^a$ | $0.1156^a$ | $0.1208^a$ | |
| *Julbernardia paniculata* | $0.1731^b$ | $0.1654^b$ | $0.1497^b$ | $0.1164^a$ | |
| *Uapaca kirkiana* | $0.1898^b$ | $0.1753^b$ | $0.1522^b$ | $0.1265^a$ | |
| Fpr (HD)=0.58<br>LSD (HD)=0.05476 | Fpr(TS *HD)=0.925<br>LSD(TS*HD) =0.0227 | | | | Fpr (Ts)=0.118<br>LSD(TS)=0.09485 |

A substantial difference ($p < 0.005$) is present for values that have distinct subscripts. Values are means of three triplicates

Soil samples collected under native tree species (*Julbernardia paniculata* and *Uapaca kirkiana*) revealed significantly higher soil respiration at distances of 0.5m, 1.5m and 2.5m when compared to exotic tree species (Table 3). Both native tree species (*Julbernardia paniculata* and *Uapaca kirkiana*) showed that soil respiration reduced with an increase in horizontal distance from the tree trunk during the rainy season. However, soil respiration increased in tandem with an increase in the horizontal distance from the exotic tree's (*Gmelina arborea*) trunk. For every tree species under investigation, there was no discernible difference in soil respiration at a distance of 3.5 meters. In general, during the rainy season, soil respiration was higher than during the dry season (Tables 1 and 3).

Changes in root activity relative to different tree trunks, which reflect the geographical distribution of soil microorganisms, may have contributed to the spatial horizontal variation in soil respiration seen in this study. Nacke et al., (2016) reported that there was a significant drop in fine root biomass at tree distances greater than 2 meters (fine root biomass and tree distance had a negative relationship). Therefore, the spatial horizontal variation recorded on both native tree species could be partially explained by increased fine root biomass close to tree trunks, which drops with an increase in horizontal distance from the trunk, which results in high microbial activity and population due to higher aboveground litter closer to the tree trunk (Nacke et al., 2016).

Lower values of soil respiration rate in soils located close to tree trunks versus soils far from tree trunks (0.5m versus 3.5m) reflect the inhibition of microbial activities in soils closer to tree trunks. This is in line with findings in other studies that showed that *Gmelina arborea* trees have a microbial suppression effect because of microbial suppression substances like alkaloids, saponins, phenolics, tannins, and anthraquinone in their leaves and fruits (Agusto et al., 2002; Yogendra, 2003). In another study by Wardle (1992), the author speculated that the presence of bioactive substances like alkaloids, saponins, phenolics, tannins, and anthraquinone in the leaves and fruits of *Gmelina arborea* may have contributed to the significant anti-microbial activities of crude leaf and stem bark extracts of *Gmelina arborea* against gram-positive and gram-negative organisms. Manodeep et al., (2012) also reported that the roots of *Gmelina arborea* contain alkaloids, sugar, resins, tannins, dyes, and some astringent compounds that display a wide range of anti-microbial activities, including fungal growth inhibitors. The higher soil respiration recorded during the wet season may be explained by high nutrients and soil moisture availability (Metcalfe, 2011).

Soil depth and tree species had a substantial impact on soil respiration during the rainy season ($P < 0.005$, Table 4). Under all three species during the rainy season, soil respiration was substantially higher at 0 –10 cm depth than at 10 – 20 cm depth (Table 4). From 0 to 10 cm of depth, soil respiration was not significantly different although from 10 to 20 cm of depth, it was evident that soil respiration was significantly higher for native tree species than exotic tree species (Table 4). During the rainy season soil respiration was substantially higher for all studied tree species compared to the dry season (Table 2 and 4).

Table 4. Impacts of tree species and soil depth association on soil respiration (mg $CO_2$/g/hr) during the rainy season

| Tree species (TS) | Soil depth (SD) | Soil depth (SD) | |
|---|---|---|---|
| | 0-10cm | 10-20cm | |
| *Gmelina arborea* | $0.1728^{a}$ | $0.0545^{a}$ | |
| *Julbernardia paniculata* | $0.2257^{a}$ | $0.0766^{b}$ | |
| *Uapaca kirkiana* | $0.2438^{a}$ | $0.0781^{b}$ | |
| Fpr (SD)=<0.001 | Fpr (TS*SD) =0.012 | | Fpr (TS)=<0.001 |
| LSD(SD)=0.00719 | LSD(TS*SD) =0.01245 | | LSD(TS)=0.0088 |

A substantial difference ($p < 0.005$) is present for values that have distinct subscripts. Values are means of three triplicates

Results showed a significant decline in soil respiration with soil depth under the native tree species in the rainy season (Table 4). The different levels of organic material on top and subsoil might partially explain the differences in soil respiration between 0–10 cm and 10–20 cm depths. As soil depth causes a decrease in the amount of litter input and organic carbon content, changes in nutrient availability are likely to be the cause of the vertical drop in soil microbial respiration under all tree species (Alexander, 1996). The fact that there is less organic matter available at deeper depths while large amounts of plant matter continue to decay above the surface may be the source of the dramatic decline in mineral nutrients with depth (Alexander, 1996). Additionally, it has been shown that microorganisms develop slowly as soil depth increases owing to soil compaction as well as a lack of mineral nutrients (Richter & Markewitz, 1995; Hoorman, et al., 2011). Therefore, a higher microbial population in the top layer as opposed to the deeper soil may be related to enhanced soil conditions and biomass in terms of nutrients and thus contribute to high soil respiration as observed in this study (Table 2 & 4).

The seasonal changes had significant impact on soil respiration under the two native tree species ($P < 0.005$). On both tree species, soil respiration was lower during the dry season than in the rainy season (Table 1, 2, 3 and 4). The lower values of microbial respiration recorded in October (dry season) than in March (rainy season) for both native tree species could be related to the presence of nutrients and other favourable circumstances, including moisture, in March. Alexander (1996) stated that an adequate water supply is essential for the physiological activity of microbes since water is the major component of protoplasm. Therefore, an increase in water supply during the rainy season (March) may have resulted in a higher population of microbes than in the dry season (October). Furthermore, due to their impact on the activity of tree roots, seasonal variations (rainy and dry seasons) are a significant driver of soil respiration (Mwamba, 1983). Akinnifesi et al., (2004) highlighted the seasonal changes in phenol accumulation and quality at different times of the year in trees and this may potentially account for the variances in the results of the current study. Both authors found that root exudates were more heightened during the wet season as opposed to dry season for such tree species as the ones under the present study. Moisture content in rainy season favours shoot development and growth in tree species. According to Gherardi (2004), more shoot development increases exudation from roots. Therefore, an increase in root activity, nutrients, and soil moisture availability may be one of the reasons for the higher soil respiration recorded in the wet season as opposed to dry season.

A comparison of the effects of native and introduced tree species showed that native tree species had microbial proliferation effects while introduced tree species had microbial suppression effects since soil respiration was decreasing with an increase in horizontal distance (higher at 0.5m versus 3.5 m) from the trunk of *Uapaca kirkiana* and *Julbernardia paniculata* tree species. In contrast, soil respiration under *Gmelina arborea* increased with increasing horizontal distances from trunk (Tables 1 and 3). The higher respiration under *Uapaca kirkiana* at 0.5m, 1.5 m, and 2.5m than on *Julbernardia paniculata* tree species (Tables 1 and 3) might be caused by tree species-specific above-ground and below-ground litter that influences microbial diversity and population under each tree species. However, Liu et al., (2016) reported that soil carbon intake has far less impact on the respiration of soil beneath the canopy of trees than does soil microclimate. So, the soil respiration variation in this study might partially be due to the variation in type and amount of root exudes that each tree species releases into the soil. Andrade et al., (1996), showed that the presence of energy-rich carbon compounds caused by mycorrhiza fungus colonizing plant roots significantly enhanced the rhizosphere microbial community and population. Organic chemicals created by extra radical hyphae and the hyphae themselves, which contribute to the soil particles' agglomeration, might offer stimulatory compounds that are expelled and enhance soil structure, which could serve as microbes' locations of colonization and growth. Therefore, mycorrhiza colonizing the roots of *Uapaca kirkiana* may have resulted to the increased soil respiration beneath that plant (Ngulube et al., 1995). Although *Julbernardia paniculata* is a leguminous tree and was expected to have high respiration due to the high nutrients in its leaves and the presence of naturally nitrogen-fixing bacteria, it recorded lower respiration compared to a non-leguminous *Uapaca kirkiana* tree. This is in line with Patrick (1998) and Frost (1996), who reported that the leaves and bark of *Julbernardia paniculata* contain tannin and do not fix atmospheric nitrogen. Tannin is harmful to microbes since it slows the pace at which organic matter decay (Hackel et al., 2005). Therefore, the lower soil respiration on 0.5m, 1.5m, 2.5 and 3.5m under *Julbernardia paniculata* as opposed to *Uapaca kirkiana* might be partially caused by the presence of tannin in its leaves (Table 1and 3).

## CONCLUSION

In conclusion, tree species strongly shape respiration of soil microbes. The respiration of soil microbes was noticeably different between topsoil and subsoil for all tree species. The respiration of soil microbes was higher in the topsoil than in the subsoil. The study also found that the abundance of microbial populations decreased in the soils with increasing distances from the tree trunks of *U. kirkiana* and *J. paniculata* (higher at 0.5m versus 3.5 m). However, for *G. arborea,* the population's relative density was higher at 3.5m unlike at 0.5m. Furthermore, microbial respiration under all trees revealed more pronounced seasonal fluctuation. For each type of tree, higher levels of microbial respiration were seen during the wet season as opposed to the dry season.

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