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Research Article

Effects of hedgerow systems on soil moisture and unsaturated hydraulics conductivity measured by the Libardi method

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Abstract : The hedgerow systems are the agroforestry practices suggesting any positive impacts and negative impacts on soil characteristics. This study evaluated the effects of hedgerows on the unsaturated hydraulic conductivity of soil with the Libardi method approach. This study was conducted in North Lampung for 3 months on the hedgerow plots of *Peltophorum dassyrachis* (P), *Gliricidia sepium* (G), and without hedgerow plot (K), with four replications. Each plot was watered as much as 150 liters of water until saturated, then the soil surface were covered with the plastic film. Observation of soil moisture content was done to a depth of 70 cm by the 10 cm intervals. Soil moisture content was measured using the Neutron probe that was calibrated to get the value of volumetric water content. Unsaturated hydraulic conductivity of soil was calculated by using the Libardi Equation. Data were tested using the analysis of variance, the least significant different test (LSD), Duncan Multiple Range Test (DMRT), correlation and regression analysis. The results showed that the hedgerow significantly affected the soil moisture content and unsaturated hydraulic conductivity. Soil moisture content on the hedgerow plots was lower than the control plots. The value of unsaturated hydraulic conductivity in the hedgerow plots was higher than the control plots. Different types of hedgerows affected the soil moisture content and unsaturated hydraulic conductivity. The positive correlation was found between the volumetric soil moisture content and the unsaturated hydraulic conductivity of soil.

***Keywords**: unsaturated hydraulic conductivity, soil moisture, hedgerow*

Introduction

The hedgerow culture system is the practice of agroforestry where trees, shrubs and annual crops are planted on a plot of land. The annual crops are planted in between trees and shrubs that serve as the hedgerow (Oyedele et al., 2009). Pruning of the hedgerow canopy are done before planting of annual crops and the periodical prunings are done when the intensity of light received by the annual crops are reduced due to the hedgerow shade. The pruned biomass is returned to the soil as mulch and green manure (Oyedele et al., 2009). The hedgerow systems suggested any positive impacts on the soil, i.e.: improve soil characteristics, reduce weed growth (Oyedele et al., 2009), improving nutrient cycling and soil fertility (Lin et al., 2009; Oyedele et al., 2009), reduce soil erosion and increase soil moisture (Smolikowski et al., 2001; Lin et al., 2009; Oyedele et al., 2009). However, application of the hedgerow cultivation can intensify the competition of light, water and nutrients between the annual crops and the hedgerows. Choice of the hedgerow species are the important factor in the success of the hedgerow systems.

Legume species are commonly used as hedgerows because of their ability to fix nitrogen through increased activity of bacteria in their soil rizosphere (Oyedele et al., 2009). Some components to consider in choosing the species of hedge in the hedgerow system are: the species are easy and quick to grow (the fast growing species), the deep root system, the strong leaves, the fast regeneration after pruning, the good coppicing ability, easy to eradicate, and can fix nitrogen. Types of crops in the hedgerow systems suggested the significant impacts on the physical characteristics of the soil, where the soil under the *Pterocarpus* and *Enterolobium* showed the lower field capacity than soil under the *Leucaena*, while the soil under *Pterocarpus* and *Enterolobium* showed the higher porosity than soil under the other treatments (Oyedele et al., 2009).

Soil moisture retention and unsaturated hydraulic conductivity are the important components in the soil hydraulic curve. Soil moisture retention curve illustrates the moisture in soil, whereas the unsaturated hydraulic conductivity defines the relationship between hydraulic conductivity and soil moisture. Unsaturated soil hydraulic conductivity varies in space and time because it is influenced by the moisture tension and moisture content (Wu et al., 2011). Unsaturated hydraulic conductivity is affected by vegetation (Yan Li et al., 2008) and soil-tillage (Fuentes et al., 2004; Farkas et al., 2006; Odofin et al., 2012). Lichner et al. (2007) reported that the unsaturated hydraulic conductivity is strongly influenced by the hydrophobic layer of soil that varied with the cover crop types.

The unsaturated hydraulic conductivity of soil constituted one of the major components affecting the water movement in soil (Perkins, 2011; Rasoulzadeh 2011; Ghanbarian-Alavijeh and Hunt, 2012), solutes transport in soil (Ghanbarian-Alavijeh and Hunt, 2012; Rasoulzadeh 2011), planning of irrigation and land drainage, and Model of groundwater (Rasoulzadeh, 2011). Measurement of the unsaturated hydraulic conductivity of soil are generally more difficult with the low accuracy (Wu et al., 2011; Perkins, 2011; Yongfu Xu, 2013) and it required a long time (Jarvis et al., 2002; Ghanbarian-Alavijeh and Hunt, 2012; Jarvis et al., 2013; Nasta et al., 2013; Stoffregen and Wessolek, 2014).

Some techniques of the unsaturated hydraulic conductivity measurements can be performed in the laboratory and field measurements (Genuchten, 1980; Abbaspour et al., 2001; Assouline and Tartakovsky, 2001; Ghanbarian-Alavijeh and Hunt, 2012; Nasta et al., 2013). These each measurement method showed the level of accuracy that varies with soil type and field conditions (Rasoulzadeh, 2011). Libardi et al. (1980) introduce the measurement techniques of the unsaturated hydraulic conductivity in the field. Unsaturated hydraulic conductivity measurement required one variable of volumetric soil moisture content (θ) that vary with time; the field measurement are usually conducted during the drainage process (Comegna et al., 2012).

This study was conducted to determine effects of the hedgerow systems on the soil moisture content and the unsaturated hydraulic conductivity of soil. *Peltophorum dassyrachis* and *Gliricidia sepium* plants were used to determine effects of different types of hedgerows on the soil moisture content and unsaturated hydraulic conductivity of soil. Soil moisture content was measured by using the Neutron probes, whereas the unsaturated hydraulic conductivity of soil was calculated by using the Libardi method approach.

Materials and Methods

This study was conducted in the regions of Karta, North Lampung, for three months. Soil analysis was carried out in the laboratory of soil physics, the Soil Department, Faculty of Agriculture, University of Brawijaya. The type of soil at the study site is Grossarenic kandiudult. The study was conducted on a hedgerow plot of *Peltophorum dassyrachis* (P); *Gliricidia sepium* (G) and without hedgerow plot (C), each such treatment with four replications.

The study was conducted by installing two access tubes in the middle of each plot observations. The access tubes were installed to a depth of 70 cm and the height above ground level was 10 cm. Furthermore, 150 L of water was applied into the each observation plot until soil reached the saturation condition (Comegna et al., 2012). Once the soil became saturated the soil surface was then covered by plastic film to prevent evaporation through the surface of soil and prevent infiltration of rainwater into the soil profile (Comegna et al., 2012).

Soil moisture measurements were carried out to a depth of 70 cm by seven intervals of depth, namely: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm and 60-70 cm. Soil moisture measurements were carried out at two hours after saturation, every day for 3 days, every 3 days for 30 days, and every week for two weeks. Measurement of soil moisture in the field was done using the Neutron probe and these measurement results were calibrated with the gravimetric soil moisture content (Fouépé et al., 2009).

Determination of the neutron probe calibration equation needs the secondary data of the volumetric moisture content, soil fresh-weight, soil dry-weight, soil bulk density, soil moisture tension (Fouépé et al., 2009). Volumetric soil moisture content data were obtained by soil sampling at the several depths. These soil samples were weighed to determine the fresh-weight of soil (FW). These soil samples were dried for 24 hours at 105^0 C, it was then weighed to determine the dry weight of soil (DW). The percentage of moisture content were calculated using the following equation:

$$\% \text{ WC} = \frac{\text{FW} - \text{DW}}{\text{DW}} \text{ x } 100\% \quad 1)$$

Bulk density of soil (BD) was used to change into the volumetric form through the equation of:

$$\%\text{V} = \%\text{WC x BD} \quad 2)$$

Soil moisture content was determined by the calibration equation of the Neutron Probe:

$$\theta = \text{a x } \frac{\text{R}}{\text{Rw}} + \text{b} \quad 3)$$

where: θ = volumetric soil moisture (m^3 m^{-3}), R= measurement of neutron probe in soil (cps), Rw= measurement of neutron probe in water (cps), a and b= constants, r= correlation coefficient.

Unsaturated hydraulics conductivity was calculated by using the Libardi method; the equations are:

$$K(\theta) = K_0 \exp\left[\beta(\theta_0 - \theta)\right] \quad 4)$$

$$\ln\left[z\left(\frac{d\theta}{dt}\right)\right] = \beta(\theta_0 - \theta) + \ln K_0 \quad 5)$$

where: β= constant, K_0 and θ_0= value of K and θ at the saturated condition.

Analysis of variance (ANOVA) was conducted to evaluate the effects of treatments on the observation parameters. If the ANOVA analysis showed significant effects ($p< 0.05$), it was further analysed with the least significant different test (LSD) and The Multiple Duncan Range Test (MDRT) to evaluate the significant different among the treatments. Correlation and regression analysis were applied to evaluate the relationships between the two research variables.

Table 1. Calibration equation of the Neutron Probe

Value	Depth (cm)							
	10	20	30	40	50	60	70	80
r	0.880	0.560	0.690	0.790	0.850	0.850	0.930	0.089
b	-0.0022	0.0295	0.0482	0.0547	0.0066	0.0411	0.0154	-0.0722
a	0.6421	0.4988	0.5064	0.4636	0.5846	0.5049	0.5506	0.7495

Results and Discussion

Hedgerows affected soil moisture levels. Figure 1 shows that the soil moisture profile in the hedgerow plot of *Peltophorum dassyrachis* and *Gliricidia sepium* was lower than the control plot (without hedgerows). The lower levels of soil moisture has already occurred at the 0 day observation, when the soil was saturated. Decreased levels of soil moisture observation continued until the 33th day. Soil moisture levels are influenced by the physical characteristic of soil, vegetation, climatological factors, and evapotranspiration. This is supported by Scanlan and Hinz (2010) who states that changes in soil moisture is influenced by soil texture, species of plants and distribution of rainfall.

Hedgerows are shrubs or trees planted on the sidelines of cultivated annual crops, therefore, their presence can increase the population of vegetation in an area. Increasing vegetation population is followed by the increase need for water, nutrients and light for their growth. Increased competition among plants results in a decrease in nutrient moisture reserves in the soil, if not offset by the sufficient inputs. In this study, the presence of hedgerows increased the competition in soil moisture uptake, it resulted in a decrease of soil moisture in the plot hedgerows. Loss of soil moisture in the control plots was caused by evaporation, while that in the hedgerow plots were caused by the evaporation and transpiration, so the loss soil moisture more than the control plot.

The bare land without vegetation generally has lower soil moisture content than the vegetated land, this is caused by the high rate of evaporation on the bare land. This opinion supported results of this study showing that soil moisture levels on the vegetated land is 0.429 cm^3/cm^3, whereas soil moisture on the bare land is 0397 cm^3/cm^3 (Fouépé et al., 2009). Furthermore, Wang et al. (2013) explained that the soil under natural forest vegetation is more porous than the bare land, this is because the ability of trees to loosen soil and the accumulation of organic matter increase the rate of infiltration, increase soil moisture retention capacity and soil moisture storage capacity. Increased soil moisture in vegetated land is also influenced by the interception of rainwater by the canopy of vegetation and moisture retention under the litter layer (Wilcox et al., 2003)

At all observation periods, it was found that level of soil moisture decreased at a depth of 10-20 cm in the treatment plots (Figure 1). Peak levels of soil moisture in the control plots and plot of *Gliricidia sepium* suggested the same trend, i.e. at a soil depth of 50-60 cm and then there was a slight decline in soil moisture in the soil depth of 60-70 cm. While the hedgerows plot of *Peltophorum dassyrachis*, the tendency of the peak levels of soil moisture in the soil depth of 60-70 cm. Soil moisture content varies over space and time (Fouépé et al., 2009), soil moisture content increased with soil depth (Qiu et al. 2001; Fouépé et al., 2009). While the research results of Bana et al. (2013) showed that the soil moisture content at a depth of 30-60 cm relatively constant, while the soil porosity decreased with the soil depth.

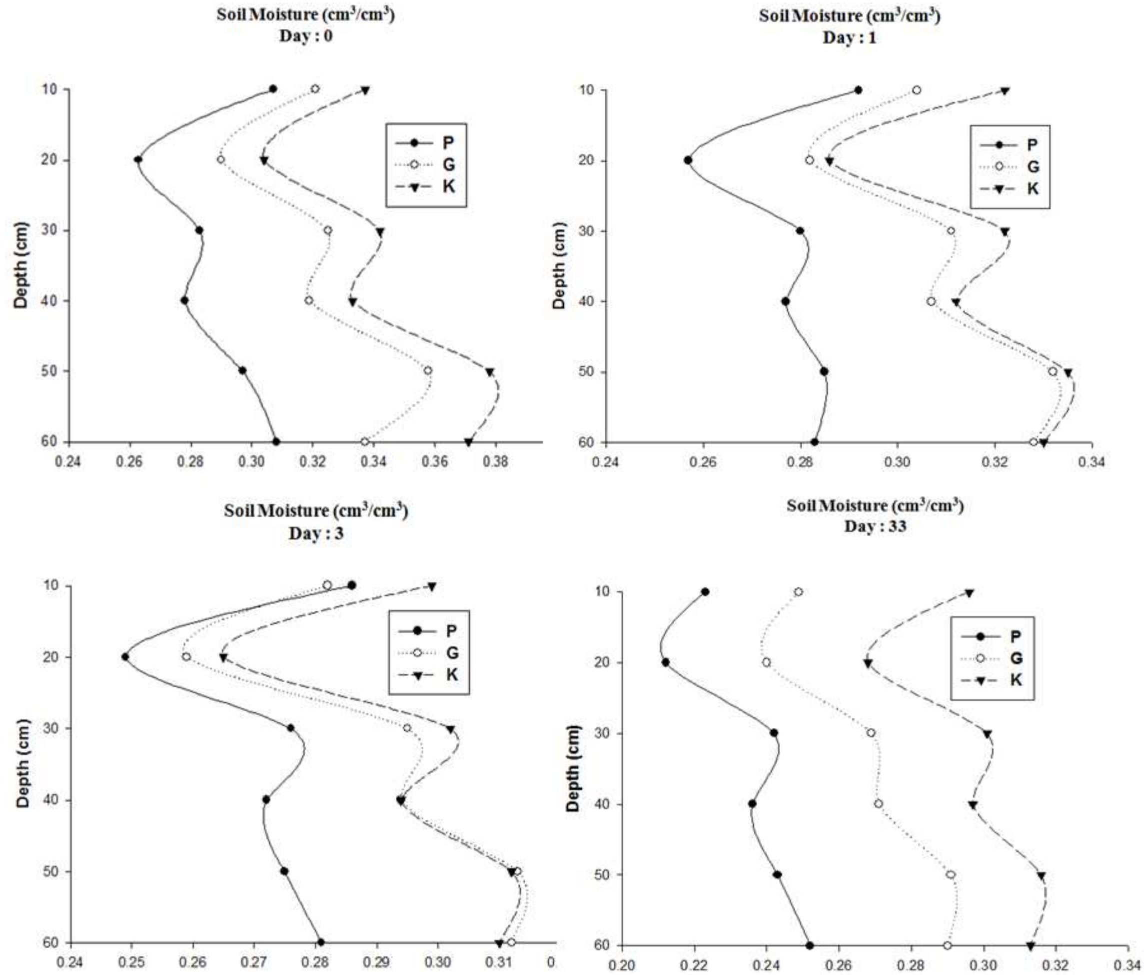

Figure 1. Effects of the hedgegrow plant on the soil moisture profile.

The different types of hedgerows affected the soil moisture content, soil moisture profile in the hedgerow plot of *Peltophorum dassyrachis* is lower than the plot of *Gliricidia sepium* (Figure 1). These results are consistent with the previous studies showing that the availability of water at the field capacity conditions on the hedgerow plot of *Pterocarpus* and *Enterolobium* are lower than the hedgerow plot of *Leucaena* and the control plot (Oyedele et al., 2009). Results of the study on the same plot with the same slope indicates that the soil under vegetation of *P. crassifolia* suggests the highest moisture content, while the soil under vegetation of *S. przewalskii* suggests the lowest moisture content (Wang et al., 2013). The earlier study concluded that the herbaceous hedgerows are more effectively control soil erosion and loss of soil moisture than the woody hedgerows, otherwise the woody hedgerows are more effectively improve soil organic matter content than the herbaceous hedgerow plants (Lin et al., 2009). Differences in the pattern of plant canopy cover causes the difference in the level of solar radiation at ground level, it causes the difference of evapotranspiration rate (Wang et al. 2013). It is supported by Rompas et al. (2012) which states that the different types of vegetation causes the difference in soil moisture management system as a result of differences in the architectural model of vegetation. Architectural model of tree (i.e. canopy shape) affects the translocation of rainwater in the form of throughfall, stem flow, infiltration, and surface runoff (Prijono et al., 2012). The differences in root systems of plants also affects the soil moisture content. A simulation carried out for many years using rainfall data show that plant roots induced changes the soil moisture balance (Scanlan and Hinz, 2010). Hedgerows affect the unsaturated soil hydraulic conductivity. The unsaturated hydraulic conductivity in the hedgerow plots of *Gliricidia sepium* and *Peltophorum dassyrachis* are higher than the control plot (Figure 2). It is supported by the results of previous studies that showed that the unsaturated conductivity value are significantly higher in soil under vegetation canopy than the open land (Wilcox et al., 2003).

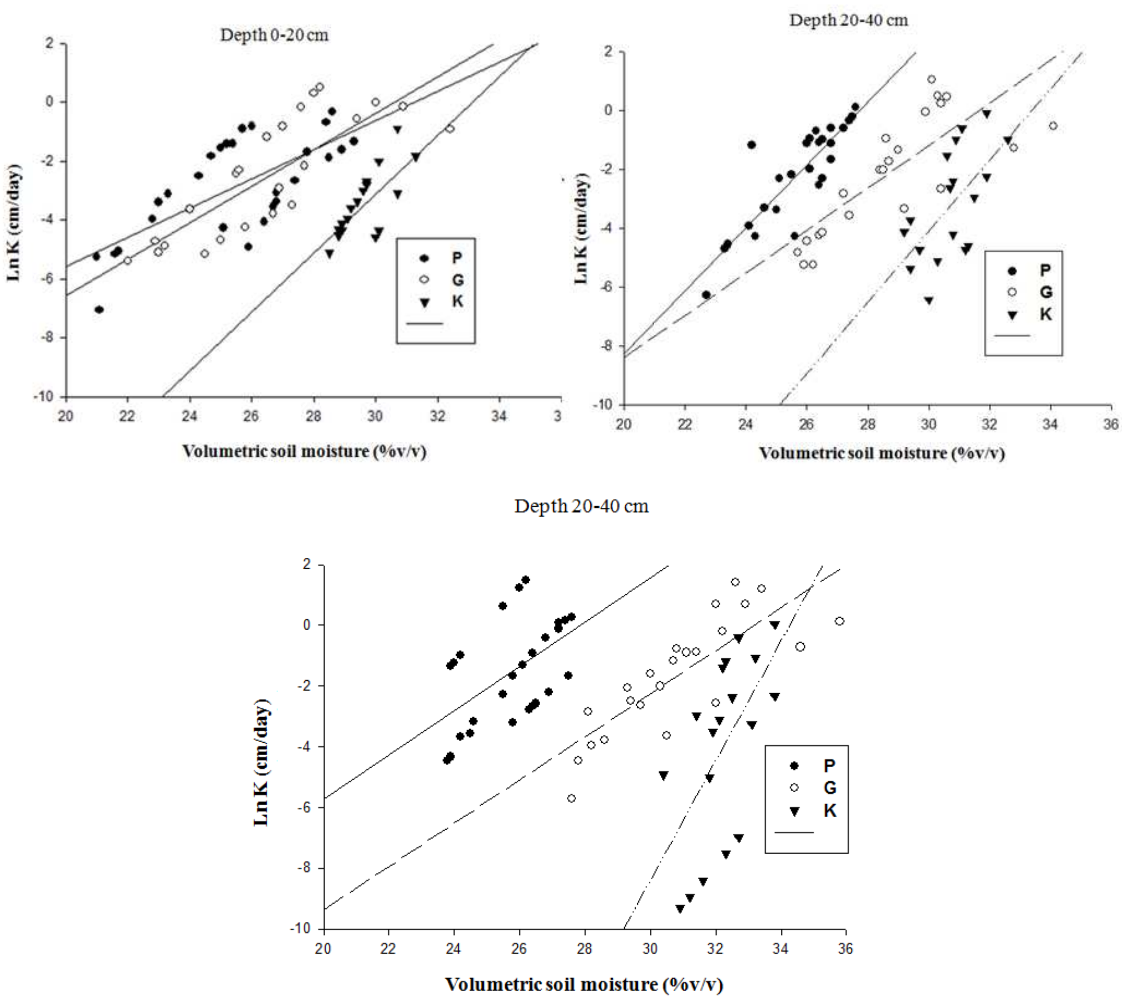

Figure 2. Relationship between volumetric soil moisture (%v/v) and unsaturated hydraulics conductivity (cm/day) using the Libardi method at different hedgegrow plants,

The existence of the hedgerow roots can increase the amount of macro pores in soil and increased the soil infiltration rate. Root activity in soil is correlated with the geometry and size distribution of soil pore (Fredlund et al., 1997). This is similar to the results of Yan Li et al. (2008) which shows that the unsaturated hydraulic conductivity at a tension of 30 [K(30)] in the soil under vegetation is 180 mm/h, while on the bare soil is 20 mm/h. This is a reflection of a high rate of infiltration through the root burrows. The simulation results showed that the soil hydraulic conductivity increases in clay soil modified by the presence of plant roots, compared to clay soil without root modification it allows a more rainwater infiltration (Scanlan and Hinz, 2010). It is related to the effect of plant roots on the increase of the soil moisture uptake and soil moisture storage.

At all of the soil depth, the hedgerow plots of *Peltophorum dassyrachis* had a higher value of the unsaturated hydraulic conductivity than the hedgerow plots of *Gliricidia sepium*. It suggests that differences in vegetation affects the variation of unsaturated hydraulic conductivity of soil. This opinion is supported by the results of previous studies that the unsaturated hydraulic conductivity of soil on the forest plots dominated by *Pinus sylvestris* was lower than the grassland plots dominated by *Agrostis capilaris* and *Cynodon dactylon* (Lichner et al., 2007).

Soil hydraulic conductivity under the matric-suction of 0.5 cm (K0.5) was highest on the hedgerow plots of *Gliricidia* compared with other types of hedgerows (Oyedele et al., 2009). Differences in the unsaturated hydraulic conductivity of soil between plant species are thought to be caused by the differences in their root system. The root system influenced the macro pores in soil, in which these macro pore affected the soil moisture movement. These opinion are based on results of previous studies which concluded that the unsaturated hydraulic conductivity are correlated with the soil macro pores under the taprooted plant cultivation compared under the shallow root plant cultivation (Uteau et al., 2014)

Table 2 and Figure 2 show that there are a positive correlation between volumetric soil moisture content and the unsaturated hydraulic conductivity of soil. These results are consistent with the opinion that the unsaturated hydraulic conductivity varies with space and time due to the unsaturated hydraulic conductivity values depend on the moisture tension and moisture content (Wu et al., 2011).

Table 2. Regression relation between the volumetric soil moisture content (X) and the unsaturated hydraulics conductivity of soil (Y)

Observation Plot	**Linear Regression**	**R^2**
Peltophorum dassyrachis	Y = 0.50X – 15.24	0.5882
Gliricidia sepium	Y = 0.57X – 19.26	0.6498
Control Plot	Y = 1.48X – 49.93	0.5158

The unsaturated hydraulic conductivity of soil are varied at each soil as the soil moisture content fluctuate (Yongfu Xu, 2013). While the results of another study showed that a high level of soil moisture is contrasted with the unsaturated hydraulic conductivity tend to be low at 0.52 mm/h at -15 cm (Buytaert et al., 2005).

Conclusions

The hedgerows significantly affected the soil moisture content and the unsaturated hydraulic conductivity of soil. The different types of hedgerows affected the soil moisture content and the unsaturated hydraulic conductivity of soil. Soil moisture content in the control plot was higher than the hedgerow plot. While the unsaturated hydraulic conductivity of soil were lower at the plot control compared with the hedgerow plots. There is a positive correlation between the volumetric water content and the unsaturated hydraulic conductivity of soil. Soil moisture content and unsaturated hydraulic conductivity of soils in the *Peltophorum dassyrachis* plots were higher than the *Gliricidia sepium* plots.

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