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Assessing the Root Development and Biomass Allocation of *Magnolia champaca* under Various Mulching at Montane Rainforest Cameron Highlands, Pahang, Malaysia

Wahidullah Rahmani[1,*], **Frahnaz Azizi**[1] **and Mohamad Azani Bin Alias**[2]
[1]*Department of Forestry and Natural Resources, Faculty of Agriculture, Herat University, Herat 3001, Afghanistan*
[2]*Faculty of Forestry, University Putra Malaysia, 43400 Serdang, Malaysia*

Abstract

The successful restoration program requires a comprehensive understanding of variables influencing seedling efficiency. Below-ground is hypothesized to have a major impact on seedling performance of species when planted in agriculture, and degraded areas with different types of mulching. This study investigated on Sg. Terla Forest Reserve in Cameron Highlands Pahang, Malaysia. In this study randomized complete block design (RCBD) was used. The excavation method was applied to study the root system development, above, and below ground biomass distributions under different types of mulching: coconut mulching (CM), oil palm mulching (OM), plastic mulching (PM) and control (CK). The root diameter, main root length, lateral root length, root coiling, and root direction toward to sun were recorded. The results in this study indicate that mulching had significant effect on root diameter, main root length, and root distributions among treatments while for lateral root length, root: shoot ratio, dry biomass distributions, and above and below ground biomass did not showed significant effect among treatments. The highest values for root diameter, lateral root length, main root length, root distributions, dry biomass distributions and above and below ground biomass were showed in CM treatments. However 75% of root coiling was observed in seedlings between treatments.

Key Words: mulching, organic mulching, root development, biomass, montane forest

Introduction

Forest soil plays a key role throughout the cycling of nutrients, water and energy flows in forests to maintain their productivity and protect biodiversity (Abari et al. 2017). However, soil pores are compressed or damaged with soil compaction, and the particles are then redistributed through soil pores. Soil compaction could have many effects on various plants, such as, reduced water absorption, reduced primary root length, reduced nutrient absorption and photosynthetic rates, increased leaf water deficits, and a general decrease in growth (Benjarano et al. 2010; Alameda and Villar 2012). Severe soil compaction can only compress and thicken roots, but it can also alter their branching patterns (Gomez et al. 2002; Ampoorter et al. 2007), and usually reduces the absorption of significant mineral nutrients (Bejarano et al. 2010; Pérez-Ramos et al. 2010; Alameda and Villar 2012). The effect of soil compaction on saplings

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Corresponding author: Wahidullah Rahmani

Department of Forestry and Natural Resources, Faculty of Agriculture, Herat University, Herat 3001, Afghanistan
Tel: +93798005686, E-mail: wahidrahmani72@gmail.com

and regeneration is usually negative; thus for broad species groups, it is one of the main factors contributing to a decline in biomass (Bulmer and Simpson 2005). The protection of young trees from species of non-crop plants (including some hardwoods, shrubs, grasses, and forbs) is the key to success in new tree planting. Consequently, environmentally friendly, cost-efficient, effective, and socially acceptable methods for managing non-crop vegetation are required to protect young trees. Mulching and its professional use will contribute to this growth by improving the soil organic matter content and affecting other soil characteristics (Ferrini et al. 2008). There are hundreds of monitored studies showing that mulches increase seed germination and seedling survival, improve root establishment and transplant survival, and improve total plant production compared to un-mulched conditions (Chalker-Scott 2007). Mulch would prevent soils from erosion and compaction caused by wind, water, and traffic, both of which contribute greatly to root pressure and poor plant health (Chalker-Scott 2007; Ni et al. 2016). During heavy rain, mulches moderate the soil temperature and enhance infiltration (Wang et al. 2015). They protect the soil from erosion caused by wind, water, and traffic. Mulches also enhance soil properties by increasing moisture retention ability, releasing different nutrients, and enhancing biological activity (Qu et al. 2019). As a result, with improved soil properties, plants grow faster (Siwek et al. 2015). Mulches are typically categorized into three major groups: inorganic, organic, and living mulches. Green mulches are derived from organic substances such as agricultural waste (straw and rice husks), wood waste (saw and bark), and green waste (leaves and wood chips), (Kader et al. 2017). Inorganic mulches include gravel, polyethylene film, bricks, and cobblestones. Living mulches include Manila grass, clover, dwarf lily turf, ryegrass, and other types of grasses (Qian et al. 2015). Each type of mulch has a specific set of characteristics. Organic mulches were widely used as post-planting treatments. Some of the benefits of organic mulching include decreased competition with herbaceous vegetation and post-fire erosion (Ceacero et al. 2012); improvement of soil conditions, such as runoff, available nutrients, moisture, and temperature (Guo et al. 2010); and the soil physical properties, i.e. bulk density, aggregate stability, porosity (Jordán et al. 2010); assists in rehabilitating soil characteristics to pre-impact condition especially in the upper soil layer (Ojanen et al. 2017); and increases in the survival and growth of seedlings (Dostálek et al. 2007). Moreover, Polyethylene is one of the most widely used mulching plastic materials, since it is simple to process, has excellent chemical resistance, high toughness, resilience and is odorless compared to other polymers (Helaly et al. 2017) and low cost (Zhang et al. 2017). Black plastic mulch provides good weed control, moderate soil temperature, improves soil moisture, high carbon dioxide levels, and improves photosynthesis (carbon dioxide and gas of primary importance in photosynthesis) (Ahirwar et al. 2019). Although, the choice of mulch depends on the soil type, the environment, and the nutritional requirements of the plants (Wang et al. 2015). However, little research has been done in tropical to assess mulching's efficacy on the root system and biomass distribution. This study aimed to determine the root system development, and biomass distributions under three types of mulching (organic and inorganic) on a degraded montane rainforest.

Materials and Methods

Study site

The present study was conducted in a former agriculture areas which is located in montane rainforest at Terla Forest Reserve Cameron Highlands (Fig. 1). It is located on the Main Range between 4°20"N-4°37"N and 101°20"-101°36"E. The mean temperature of the Cameron Highlands is be-

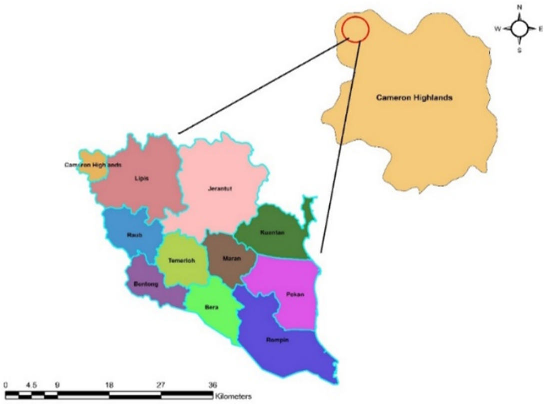

Fig. 1. Study site located in Terla Forest Reserve Cameron Highlands, Pahang, Malaysia.

tween 17°C and 20°C during the year (Razali et al. 2018). Although the local temperature has increased up to 5°C in 2014 relative to the previous 15 years (RTD 2003 Maximum rainfall (wet season) is during October to November and April to May while minimal rainfall (dry season) is during January to March and June to August. The mean elevation of study site is 1404.5 m above sea level. The study soil was a compacted soil with silt loam texture and soil color was between yellow and brownish-yellow.

Experimental design

The experiment was carried out with four replications in a randomized complete block design (RCBD). The four treatments are include:

Coconut treatment mulching (CM)
Palstic treatmnet mulching (PM)
Oil plam treatment mulcing (OM)
Control treatment without any cover (CK)

Only with a single species namely of *Magnolia champaca*. Each treatment contain 40 tress (trees age varied between 3 to 4 years) in four rows of 10 trees. The space between rows and plants was 4 m×4 m with total 160 trees.

Biomass and root development

Excavation method was chosen for biomass of *Magnolia champaca* and trees were selected based on Table 1 according to different size mean (<130 cm, <150 cm and >200 cm), and each tree size had three replication in each block and the total trees were 12.

After the trees were chosen, the plant height, root collar diameter, and diameter at breast height of trees were recorded. The top sections of the seedlings were cut before the excavation and the root crown was tightly fixed to preserve it in its original location. Excavation began from the trunk which for safety reasons, had been cut, eventually scraping the soil layer by layer before the first main roots were revealed. Standard excavation tools have been used to prevent root destruction. After the first layer of horizontally growing roots was uncovered, a grid of rope was spread across the surface of the soil. The width of the grids was 10×10 cm. A wooden framework was mounted directly above the grid net to provide convenient access to all parts of the root system, and rood diameter, root lateral length, main root depth, root coiling, and root direction were recorded for each seedlings (Wells 1981). Destructive sampling method (or harvesting method) for above and below ground biomass were used. The seedlings were cut down and different components of samples (leaves, branches, stems, roots) were weigh in the field respectively. After field survey the components of the sample seedlings were collected and immediately took to the laboratory to oven-dried at 80°C until a constant weight was reached. The aboveground biomass components is calculated by the measurement of the amount of the biomass of the shoots, leaves and stems. Other components were root mass as the biomass below ground and total seedling biomass as the sum of the biomass above ground and root biomass.

Statistical analysis

The experimental design was randomized complete block design, whereby plots were randomly assigned to the treatments. Generalized linear modelling (GLM, one way analysis of variance) was applied to relate root system and seedlings responses with treatment. When the ANOVA analysis found significant differences between treatments, post hoc comparisons of the treatment group means were performed using Tukey test with a 95% confidence level. Treatment effects were considered statistically significant when $p \leq 0.05$. SPSS (release 17.0; Chicago, IL, USA) statistical package was used for analyses. All statistical anal-

Table 1. Tree selection based on the mean height

Treatments	Mean	Minimum	Maximum	Valid N	Missing N
Coconut	142.33	51.86	229.14	40	0
Oil palm	147.34	76.14	201.71	40	0
Plastic	143.91	68.86	210.43	40	0
Control	143.76	79.43	233.71	40	0

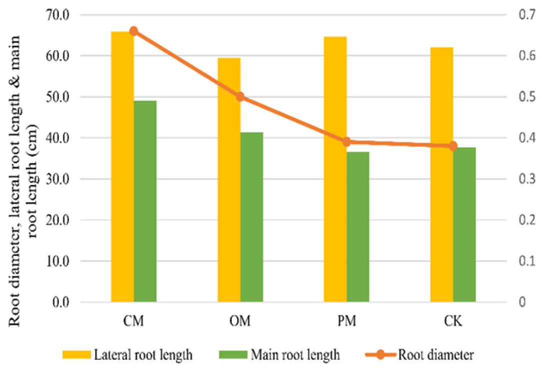

Fig. 2. Root diameter, lateral root length and main root length under different types of mulching.

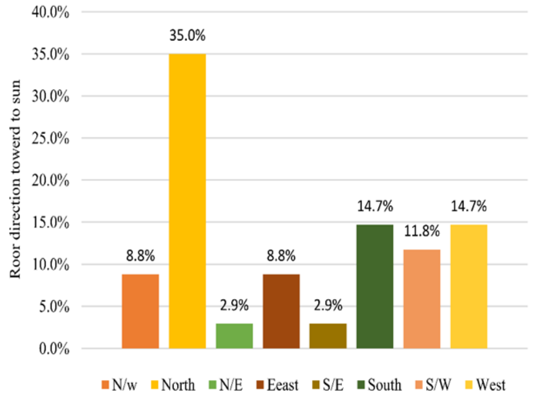

Fig. 3. Root direction toward to sun under different types of mulching.

yses were performed at a 95% confidence level.

Results

Root development

Tree fitness, stability, and survival are influenced by the ability of roots to explore the under-ground ecosystem in forest settings. In this study, the root diameter was recorded during the study as root development parameters. Based on Fig. 2, there was a significant difference between treatments. The highest root diameter increment (0.66 cm) showed in CM and it was higher than OM (0.50 cm), PM (0.39 cm), and CK (0.38 cm) treatments, respectively. The lowest root diameter increment was recorded in CK between treatments. Based on Fig. 2, the lateral root length increment did not showed significant difference among different mulching treatments. The highest lateral root length showed in CM (65.83 cm) and slightly higher than PM (64.70 cm), CK (62 cm) and OM (59.42 cm) respectively. Based on Fig. 2, there was a significant difference between treatments. CM treatment showed significant difference than PM and CK treatments, but there was no significant difference between CM and OM treatments. Main root length increment in CM treatment was slightly higher than OM (41.33 cm), CK (37.76 cm) and PM treatment (36.67 cm) respectively. The root direction was significant difference toward to sun directions. The roots direction toward to sun was varied between directions. Fig. 3 shows that 35% of roots toward to north, 14.7% south, 14.7% west, 11.76% south-west, 8.82% west, 8.82% north-west, 2.94% northeast and 2.94% to the south-west respectively. Moreover, there was no correlation between root direction and soil compaction among treatments. For root distribution Fig. 4, shows that root horizontal and vertical were significant difference between treatments. The horizontal root was significantly higher in CM (65.8 cm) than PM (64.7 cm), CK (62 cm) and OM (59.4 cm) treatment respectively. In another word CM (65.8 cm) treatment showed the highest value and OM 59.4 cm treatment showed the lowest value among treatments. Moreover, the root system in the vertical direction CM (49 cm) treatment compared to OM (41.3 cm) treatment, CK (37.6 cm) treatment, and PM (36.6 cm) treatment showed higher horizontal root distribution, respectively. In another word, the root, distribution affected by CM in horizontal and vertical directions between different types of mulching treatment. Results in Fig. 5 shows there was no significant difference between treatments for

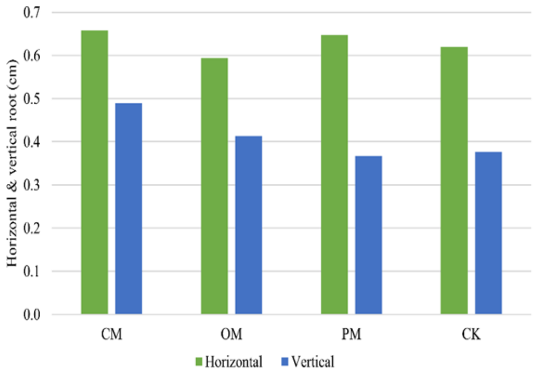

Fig. 4. Root distribution in horizontally and vertically under different types of mulching.

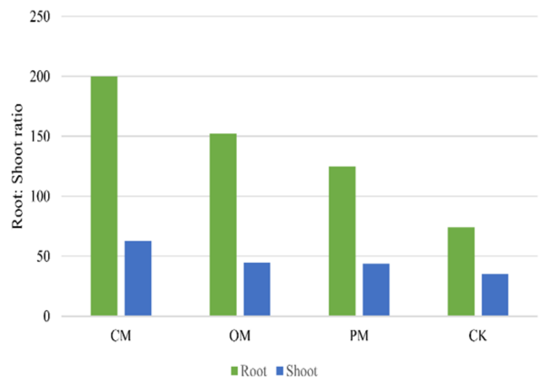

Fig. 5. Root: Shoot ratio under different types of mulching.

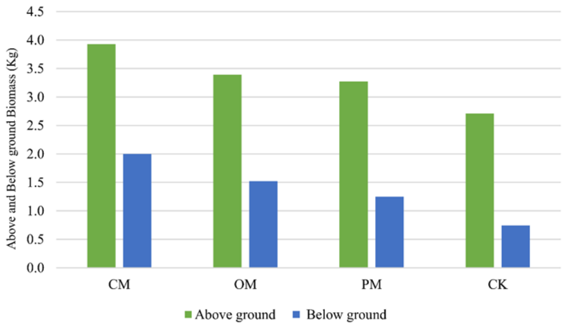

Fig. 6. Dry biomass allocation under different types of mulching.

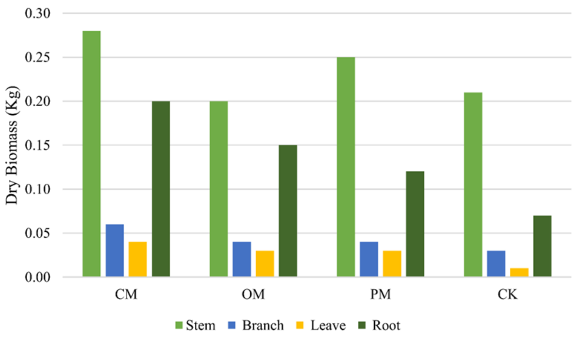

Fig. 7. Above and below ground biomass under different types of mulching.

root shoot ratio. Compared between treatments, OM treatment (3.40 gr) was significantly higher than CM (3.17 gr), PM (2.85 gr) and CK (2.11 gr) treatments, respectively. We observed that root coiling was significant coiling for *Magnolia champaca* after three years plantation. The root pictures showed there was 75% of the tree had significant coiling, and 25% showed no coiling among trees.

Biomass distribution

According to Fig. 6, the dry biomass fraction did not showed significant different between stem, branch, leaf and root in CM, OM, PM and CK treatments. CM treatment showed a greater amount of stem biomass of 0.28 kg than PM (0.25 kg), CK (0.21 kg) and OM (0.20 kg) among treatments. The lowest branches dry biomass value among treatments showed in PM (0.04 kg) and CK (0.03 kg) treatments. Dry leaf biomass with a maximum value of 0.04 kg in CM treatment, while the minimum value 0.01 kg was in the CK treatment. Dry root biomass with the highest 0.20 kg in CM treatment and the lowest 0.07 kg, in CK treatment. However, the dry total stem, branch, leaf, and root biomass among treatments ranged from 0.58 kg to 0.32 kg, with the highest amount in CM and the lowest in CK treatment. Fig. 7 shows there was no significant difference for dry above and below ground biomass between treatments. Compared between treatments CM showed the higher value (0.39 kg) than PM (0.32 kg), CK (0.28 kg), and OM (0.27 kg) treatments. In dry below-ground biomass CM treatment showed higher value (0.20 kg) than CK (0.15 kg), PM (0.12 kg) and OM (0.07 kg) between treatments respectively. Total dry biomass ranged from 0.59 kg to 0.34 kg for above and below biomass among treatments. CM treatment showed greater value for total dry above and below-ground biomass among the treatments.

Discussion

The significant effect of mulching observed in the root development, and biomass allocation for Magnolia spp species and suggest that the effect of various types of mulching and environmental conditions cloud be more or less on tropical montane rainforest seedlings. There are several reports that root diameter increased by different types of mulching (Gupta 1991; Gao et al. 2014; Huang et al. 2020). Moreover, there is a possibility as Bécel et al. (2012) found that with soil penetration resistance the mean diameters dramatically increased. However, this study indicates that rood diameter in organic mulching treatments had better growth, probably due to more organic matter, less soil compaction and high soil carbon than no-mulching treatments. This study agrees with the early study (Gupta

1991; Gough 2001) that lateral root length in organic mulching treatments was higher and it may be due to more soil moisture content, and organic matter. Main root length is a stronger root growth metric to be compared with the absorption of water and nutrients, as a high root length is associated to a short distance of water and solutes (Andrews and Newman 1970). The early studies indicated that the root length increment was significant in mulching than control treatment (Gupta 1991; Yao et al. 2009; Benigno et al. 2013; Gao et al. 2014). However, these study findings are by the earlier studies that main root length decreased in control treatments. The key factors are presumably due to the limitations of gas diffusion (Fründ and Averdiek 2016), the higher accumulation of CO_2 in the top soil (Conlin and van den Driessche 2000), and lower soil respiration rate (Fründ and Averdiek 2016), which contribute to reduced root respiration and microbial activity across the root system (Cambi et al. 2017). When roots expand through the soil, they must either follow pores or canals, or they must infiltrate and displace the soil layer. Mechanical impedance refers to the resistance against deformation given by the soil matrix and has a major impact on root growth (Bengough et al. 2011). As soil impedance rises due to naturally high bulk density, soil drying or soil compaction (commonly caused by vehicle traffic and cultivation in agricultural soils), root elongation is increasingly delayed (Lynch et al. 2012). Nevertheless, roots are growing where the resources of life are available. They're not rising toward anything. Generally, if there is little oxygen or where the soil is compacted and difficult to penetrate, they do not grow (Perry 1989). According to early study root development is opportunistic, only if the soil condition will support it (Dobson 1995).

Tree roots are the key contributors to the development of soil structure and in the longer term, to soil composition. According to Dobson (1995) the most significant root concentration is located at the soil surface where the soil is loose, and water, oxygen and nutrients are most easily accessible. Yao et al. (2009), Ni et al. (2016) and Thidar et al. (2020) observed that most of the roots were vertically found in organic and plastic mulching treatments than control. Benigno et al. (2013) demonstrated seedlings in the restoration (organic mulching) treatments produced a branching root architecture confined in the top 40 cm of the soil profile while seedlings in control treatment consistently formed a single taproot. Therefore the present results are consistent with the those of Chalker-Scott (2007) who found that in soils treated with organic mulches, root growth and density are more significant than in those treated with nothing or plastic or living.

The volume of the root system and also the root/shoot ratio demanded for the supply of nutrients, water and growth regulators depend mainly on the concentration of nutrients in the root environment and the chemical, physical, and biological properties of the substrate that affect root growth and the formation of new roots. Zhang et al. (2020) Indicated that mulching had significant effect on root/shoot ratio than control treatment also Thidar et al. (2020) found that root: shoot ratio was significantly higher in straw mulching than plastic mulching. The root/shoot ratio is related to the nutrient supply/fertilization ratio, with a higher ratio at low nutrient supply (Lynch et al. 2011). However, this study findings attribute to the level of resources as Ong et al. (2015) stated that with increased resources, both shoot and root biomass increase, but the maximum root biomass is typically obtained at a lower resource level than maximum shoot biomass. Hence, according to the availability of resources, the shoot: root ratio changes. In other word, if the growth limiting factor is below ground level (e.g. nitrogen, water), plants can devote comparatively more biomass to roots. On the other side, they can devote comparatively more biomass to shoots if the limiting factor is above ground (e.g. light, CO_2). When seedlings are left too long in the greenhouse, the roots do not find any way to extend their way down in the restricted area. Davis and Jacobs (2005) stated that poly bags and plastic containers experienced low seedling growth and root coiling. However, the root coiling of the seedlings was due to the using small size of poly bags in the nursery, old seedlings and poor management practices. According to Fang et al. (2008) and Agele et al. (2010), dry grass and black polythene sheet mulches dramatically increased dry root weight over bare soil. Moreover, according to Scharenbroch (2009) in a meta-analysis, organic surface mulch generally improves shoot and root growth. However, in general, this study findings indicate that mulching treatments had a better effect on the stem and root biomass, it might be due to the soil compaction and low temperatures that have a strong effect on root mass fraction. In addition, plant ontogeny may also have a great impact on the allocation of biomass patterns (Coleman et al. 1994). Although the leaves and branches biomass was lower than stem and root biomass it's due to the low temperatures (photosynthesis, nutrient uptake, growth), and low soil nutrients (Lambers and Oliveira 2019). Many studies have found that mulching increased above and below ground plant biomass (Watson et al. 2014; Jourgholami et al. 2020). Moreover, Yao et al. (2009), Agele et al. (2010) stated that the growth of belowground biomass was greater under mulching than under bare soil. Although McIntyre et al. (2000), and Kosterna (2014) stated that, compared to non-mulched plots, soil mulching resulted in a higher aboveground plant biomass. In contrast the present study findings are similar to the earlier studies that mulching increased the total above and below-ground biomass than control.

Conclusion

The various mulching materials had different effect on the plant root system and plant biomass distribution. Mulching had a significant effect on root diameter, main root length, and root distributions. However, mulching did not show a significant effect on lateral root length, root: shoot ratio, dry biomass distributions, and above and below-ground biomass. Therefore, considering the effect of mulching on root development, and biomass, coconut mulching and oil palm mulching are better than plastic and bare soil in the degraded area at tropical rainforest plantation. Further studies are required to determine the long-term effect of mulching on the tropical restoration area.

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