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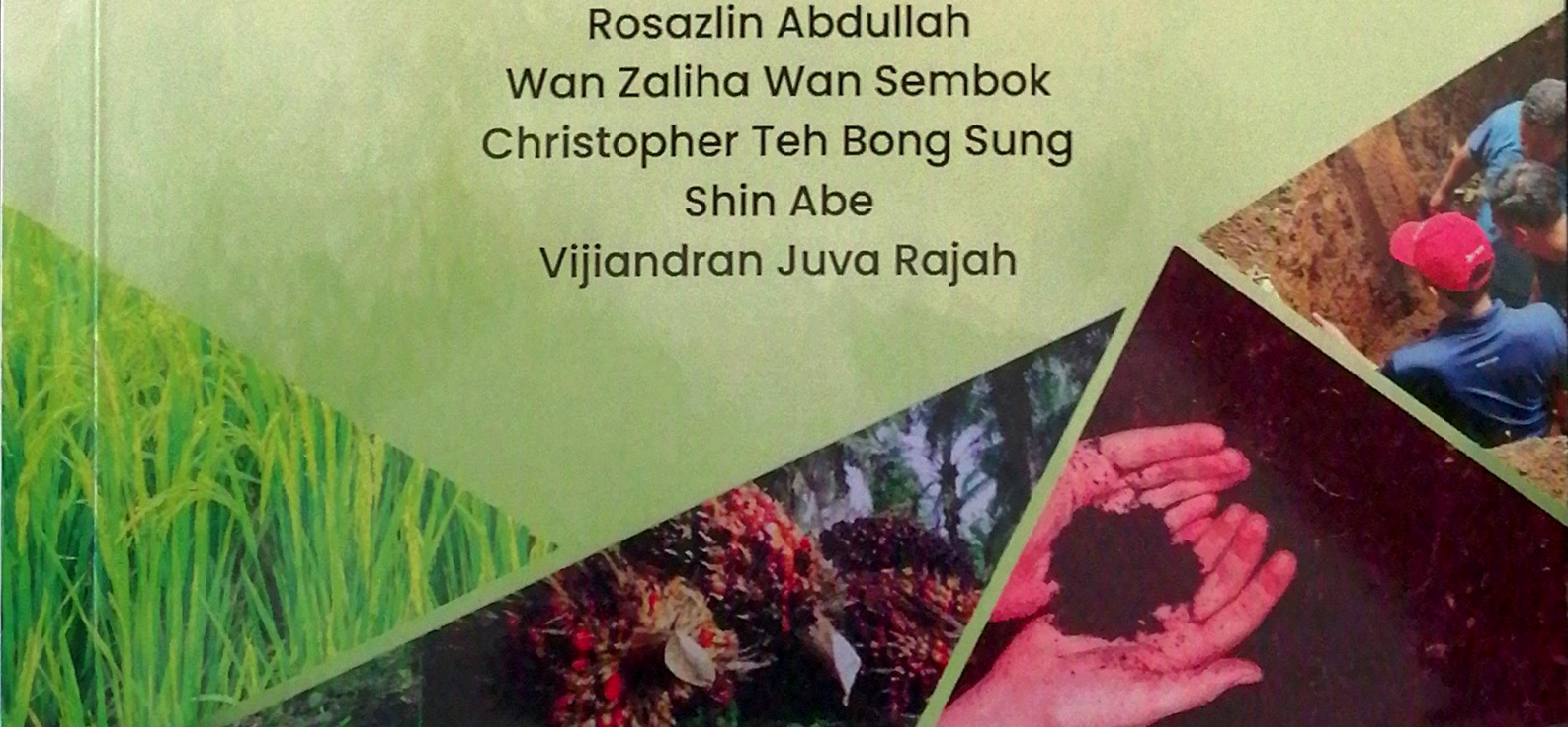

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USING THE ONE DROP PENETRABILITY METHOD TO EXPRESS SOIL COMPACTION AT THE FOREST LANDSCAPE RESTORATION SITES ALONG BATANG KAYAN ULU, SARAWAK, MALAYSIA

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INTRODUCTION

Soil compaction greatly impacts plant growth and mortality rates (Kozlowski, 1999; Hattori et al., 2013). Although mild compaction may be advantageous to plant growth, heavy mechanical use at logging sites and heavy foot traffic in recreational areas typically hinder plant growth, survival, and yield (Alameda and Villar, 2009; Kozlowski, 1999). In Southeast Asia, commercial logging has caused tropical rainforest degradation, and the use of heavy machinery during these operations has exacerbated soil compaction (Hattori et al., 2013). Compaction typically negatively affects soil structure and hydrology by increasing bulk density, soil strength, water runoff, and erosion as well as breaking down soil aggregation, and decreasing porosity, aeration, and infiltration capacity (Bruenig, 1996; Jusoff, 1992; Jusoff and Majid, 1986, 1987; Kozlowski, 1999; Van der Plas and Bruijnzeel, 1993).

The main strategy for accelerating the regeneration and rehabilitation of degraded forests is through enrichment planting of logged-over sites with dipterocarp trees (Dipterocarpaceae), which are the dominant canopy species and significant timber sources in Southeast Asian forests (Ådjers et al., 1995; Appanah and Weinland, 1996; Kenzo et al., 2011). However, severe soil compaction may make enrichment planting less successful by reducing the development and survival rates of seedlings that have been planted. One drop penetrability (ODP) is a measure of soil compaction, and it has been discovered that at the research sites, it is highly correlated with root growth to sustain sufficient turgor pressure (Sakurai et al., 1995; Ishizuka et al., 1998; Hattori et al., 2013). Therefore, this study was conducted to evaluate the soil compaction using the one drop penetrability (ODP) method at *Shorea macrophylla* forest landscape restoration sites along Batang Kayan Ulu, Sarawak, and adjacent secondary forests.

MATERIALS AND METHODS

This research was conducted at Sampadi Forest Reserve (N01°34’13”, E109°53’12”) which is located along Batang Kayan Ulu, Lundu, Sarawak, and adjacent secondary forests (N01°30’26.2”, E109°58’56.7”). The study site received approximately more than 4,100 mm of precipitation with an annual surface temperature ranging from 22^{o}C to 31^{o}C (Department of Irrigation and Drainage, 2010; Meteorological Department, 2010). According to our earlier research in the study area, the morphological characteristics of the soils resemble the Bako and

Kayan soil series as a dominant unit in association with the Saratok series and are primarily categorised under the Grey-White Podzolic soil group interspersed with Red-Yellow Podzolic soils and Arenaceous soils based on the Sarawak soil classification system (Andriesse, 1972; Perumal et al., 2015; Department of Agriculture Sarawak, 2018). The soils in the study area were derived from a mixture of sandstone, coarse-grained, humult Ultisols, and sandy residual parent material (Perumal et al., 2015; 2017a; Mohd Jaffar et al., 2018a). This soil group corresponds to the Typic Paleaquults of Soil Taxonomy based on the USDA-NRCS classification system (Teng, 2004; Soil Survey Staff, 2014; Perumal et al., 2015; 2017a; Mohd Jaffar et al., 2018a; Perumal et al., 2021). Twelve (12) experimental plots of 20 m x 20 m were established at the *Shorea macrophylla* forest restoration sites (RS), and three (3) plots of 20 m x 20 m were established at the adjacent secondary forests (SF). Soil compaction was measured by using a fall-corn-type penetrometer (Hasegawa Type H-60) until the depth of 100 cm (Figure 1a), with a total of 60 random points in RS and 15 random points in SF. The horizontal axis represents the penetrating depth (cm) per one drop of the weight (termed as one drop penetrability, ODP), and the vertical axis does the cumulative depth (cm). The smaller the value of ODP (cm), the harder the soil. Soil compaction is classified using the value plotted on the horizontal axis as follows: very hard, ODP less than 0.5; hard, ODP between 0.5 and 1.0; moderate, ODP between 1.0 and 2.0; soft, ODP more than 2.0 (Sakurai et al., 1995; Ishizuka et al., 1998) (Figure 1b).

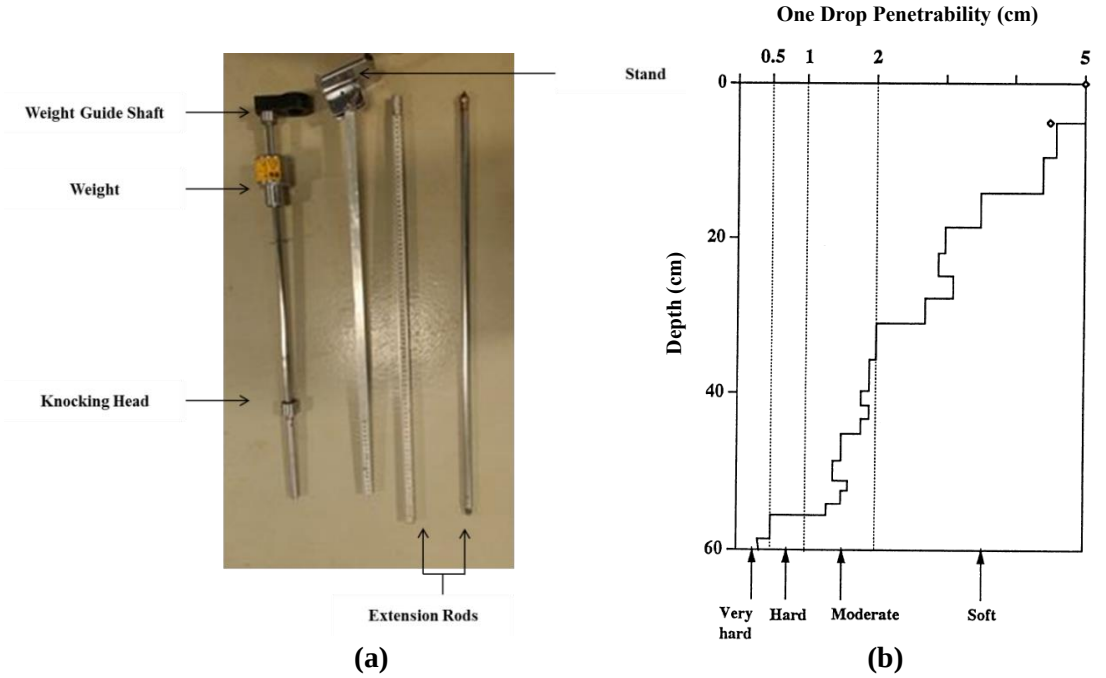

Figure 1: (a) Fall-corn-type soil penetrometer (Hasegawa Type H-60); **(b)** One drop penetrability (ODP) and definition of soil compaction.

RESULTS AND DISCUSSION

Soil Compaction at Restoration Sites and Secondary Forests along Batang Kayan Ulu, Sarawak

Soil compaction measurement offers useful data on soils to forecast a considerable physical risk to plant growth (Sakurai et al., 1995). The assessment is pivotal to measuring soil strength in forest management as it reflects the productivity of the forest area (Merotto and Mundstock, 1999; Dinis et al., 2014). Figure 2 shows the typical pattern of soil compaction at restoration sites and secondary forests. Based on the results in Figure 2, restoration sites (119 drops)

depicted a higher total count of soil compaction measurement down to 100 cm than secondary forests (85 drops). The one drop penetrability (ODP) value at the restoration sites (RS) from the 0 to 7.3 cm surface soils was more than 2.0 (Figure 1). At 9.2 cm to 89.7 cm of soil depth, the ODP values were between moderate (1.0 – 2.0) to hard (0.5 – 1.0). Based on the results obtained, the subsurface soils at the depth of 90.1 cm to 100 cm were very hard with ODP values of less than 0.5. On the other hand, a similar pattern of soil compaction was observed in secondary forests (SF). At 0 to 4.9 cm of soil depth, the ODP value was more than 2.0 which indicates that the soil was soft. The soils were moderate (1.0 – 2.0) to hard (0.5 – 1.0) at 7.8 cm to 100 cm of soil depth. There were no ODP values below 0.5 detected in secondary forests.

In general, the surface soils at both the restoration sites and secondary forests were softer due to well-developed root mat layers and fewer gravel materials in the soils. On the contrary, as for the subsurface soils, the ODP values ranged from moderate, hard to very hard at restoration sites whereas at secondary forests the ODP values ranged from moderate to hard. Severe distribution of root elongation and gravel materials to a depth of 100 cm could be one of the factors resulting in lower ODP values, especially at restoration sites in this study.

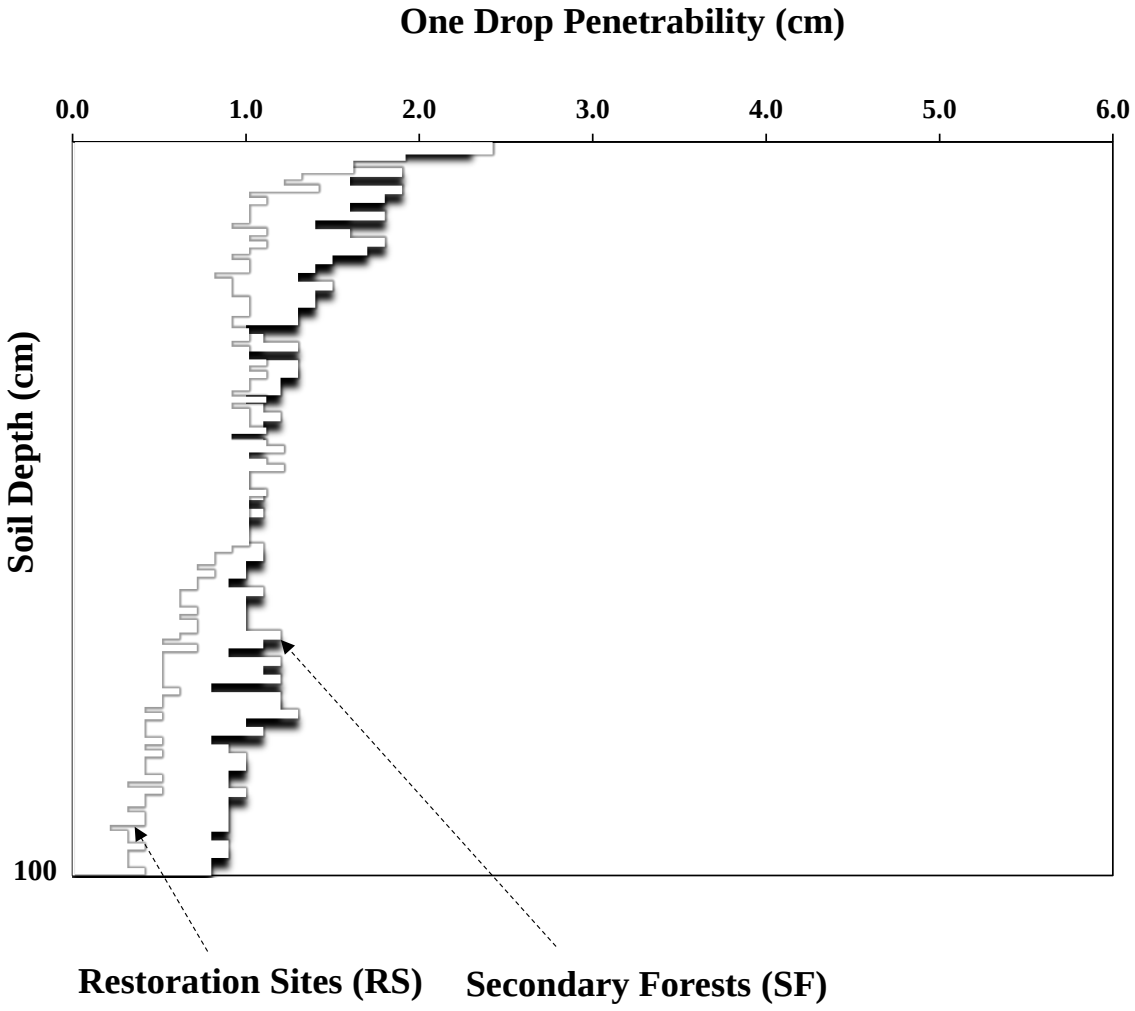

Figure 2: Typical pattern of soil compaction at Restoration Sites (RS) and Secondary Forests (SF).

Although trees may suffer from the hardness of surface materials, *Shorea macrophylla* roots have a natural ability to penetrate the deeper part of the soil when it is soft (Sakurai et al., 1995; Lipiec and Stepniewski, 1995; Mohamad Jaffar et al., 2018b). The typical pattern of soil compaction revealed that very hard soil conditions were present in some areas of the study area, especially at the restoration sites. Based on the previous history of the forests along Batang Kayan Ulu, this was attributed to anthropogenic activities such as hardness from the degraded land and selective logging using the bulldozer. Nonetheless, high soil compaction at the restoration sites presumably reflects the impact of periodic inundation which occur during the monsoon season in Sarawak (Perumal et al., 2017b).

CONCLUSION

In conclusion, a similar soil compaction pattern was depicted at the restoration sites and secondary forests in this study. In some of the restoration sites, the subsurface soils were very hard which could be due to the presence of gravel materials and the accumulation of stagnant water from the nearby river of Batang Kayan Ulu. However, based on the previous studies, it was reported that planted *Shorea macrophylla* was able to survive, grow rapidly, and thrive under extreme conditions such as periodic inundation that naturally occurs in the study area.

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