

Characterizing Soil Penetration Resistance of Planted Sago Palm (*Metroxylon spp.*) Under Mineral Soils Ecosystem

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Article history

Received: 06-08-2021

Revised: 26-09-2021

Accepted: 16-10-2021

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Abstract: In-situ soil assessment such as field soil compaction can often be a helpful approach in help determining soil suitability for certain crops. In this study, an assessment was conducted to characterize the Soil Penetration Resistance (SPR) in planted sago palm (*Metroxylon spp.*) plantation at different growth of rosette and trunking stages under mineral soils ecosystem. SPR in-situ assessment would provide a beneficial guideline and site indicator in determining land suitability before establishing sago plantations, especially on mineral soils. The study was conducted in Mukah, Sarawak, with two study sites at Oya and Talau. The growth stage of sago palm at Oya and Talau site were at the rosette and trunking stage, respectively. The soil types at both study sites consisted of Gley soils (clayey) with significant mineral development at the subsoil horizon. SPR measurements were taken using a Hasegawa-type cone penetrometer. Soil compaction in SSSSED Oya was more compact than Talau river research station from shallow depth to subsurface soils. SPR at SSSSED Oya ranged between 7.5 to 46.8 J cm⁻¹ while Talau river research station ranged between 1.9 J cm⁻¹ to 11.1 J cm⁻¹. Although there was a significant difference between the growth stage of 0-20 cm and 80-100 cm soils depths, both SSSSED Oya and Talau river research station are considered suitable areas for sago palm plantations. Using a practical and convenient approach in assessing soil suitability for sago cultivation, SPR assessment to identify potential areas for the establishment of sago cultivation area can be the fundamental tools for landowners in preparing their land for future cultivation.

Keywords: Soil Penetration Resistance, *Metroxylon spp.*, Mineral Soil

Introduction

Sago palm (*Metroxylon spp.*) brings many economic and ecosystem services secondary to oil palm; thus, it has the potential to be a crop that deserves prompt attention. The sago palm industry in Sarawak has become one of the important industries contributing to export revenue for sago-related initiatives in Malaysia (Mohamad Naim *et al.*, 2016; Bujang, 2018). Mainly, it was found in the wild, semi-wild, or cultivated by smallholders along the coastal

belt, low-lying river areas of the region, including peat swamps. There are two types of sago palms commonly found in Sarawak: The smooth sheathed (*Metroxylon sagu*) and spiny sheathed (*Metroxylon rumpii*). According to Tie *et al.* (1991), the main areas of sago cultivation in Sarawak were mainly located at Oya-Dalat and Mukah region. Since 1992, the total area covered with sago palm in Sarawak has expanded due to the introduction of estate sago plantations by the Sarawak State Government (Karim *et al.*, 2008). In achieving sustainable substantial

yield production, good agriculture management practices must be done simultaneously from the land cleaning stages until harvesting stages (Omori *et al.*, 2002; Pei-Lang *et al.*, 2006; Jong, 2018).

However, very few studies are available on the management of smallholder farmers' practices in improving sago palm growth with increased starch yield (Khan, 2005; Yong, 2014). The excellent growth performance of crops must start with a suitable planting site, good planting materials and an effective planting system (Bujang, 2018). The challenges in cultivating sago palm in Sarawak on peat soils are the inability of the sago palm to develop trunk, long maturity period, low survival rate, slow growth performance, low starch yield and soil problem (Pei-Lang *et al.*, 2006; Khan, 2005; Yong *et al.*, 2018). Due to these characteristics, peat swamp is unfavorable for the use of sago palm cultivation due to fewer fertilizers and pesticides being applied (Bujang, 2018).

Several reports discuss the influence of various soil properties in sago palm growth development and production when cultivated under smallholder or commercial scale plantations (Bintoro *et al.* 2018; Okazaki and Sasaki, 2018; Nelsi *et al.*, 2021; Uthumporn *et al.*, 2014; Yong *et al.*, 2018). While in-situ soil assessment such as field soil compaction and other soil physical attributes are often found to be a helpful approach in determining soil suitability for certain crops, information on characterizing the state of soil compactness, especially in sago plantation, is still scarce.

Soil physical properties play a vital role in the growth of plants. Improving the soil fertility of agricultural lands can be done even for a shorter period by adopting various technologies, such as adding amendments, i.e., organic and chemical fertilizers. However, this may not be the case when dealing with limitations due to soil physical properties since improving soil physical properties requires more effort and investment (Sakurai *et al.*, 1995). Conventionally, a soil pit will be dug at specific points within a land area when soil physical properties are to be assessed. This allows the field assessor to assess certain soil depth; in most cases, digging soil pits within a land area may cause certain forms of disturbance, especially in land areas that consist of standing vegetation or crops. To properly study the effects of these properties, it is necessary to establish a method that can estimate the soil structure quantitatively with minimal disturbance to the actual soil structure that leads to a more practical diagnosis of the soil condition in the field (Mohamad Jaffar *et al.*, 2018).

Considering the statement above, this research note was conducted to characterize the Soil Penetration Resistance (SPR) in planted sago palm at different growth of rosette and trunking stages under mineral soils ecosystem. SPR in-situ assessment would provide a beneficial guideline and site indicator in determining land suitability before establishing sago plantations, especially on mineral soils.

Materials and Methods

Study Area

This study was conducted at the Sago Smallholder Satellite Estate Development (SSSED) Plantation located at Mukah Division, Sarawak. Two study areas were selected for this study, namely, SSSED Oya (N02052'06.9" E111053'49.2") and Talau River Research Station (N02048'59.0" E111054'22.4") as shown in Fig. 1.

The soil types in SSSED Oya and Talau research station consist of Gley soils (clayey). The assessment and sampling were selected based on two different growth stages of sago palm under mineral soils.

Two growth stages of sago palm were selected: Rosette stage (one-year-old) and trunking stage (more than five years old). At SSSED Oya, the sago palm is in the rosette stage, while the Talau River research station is at the trunking stage. In general, land preparation for sago palm plantations included land clearing and bush slashing. Each sago palm was planted in a triangular system with a spacing of 7 × 10 m.

Soil Penetration Resistance Evaluation

A Hasegawa-type penetrometer (Daito Techno Green Co., Tokyo, H-60) was used to estimate soil compaction from surface soils to 100cm depth. The soil compaction at different soil depths was expressed in One Drop Penetrability (ODP), as shown in Fig. 2. The horizontal axis shows the penetrating depth (cm) per one drop of weighing; meanwhile, the vertical axis represents the cumulative depth (cm) (Mohamad Jaffar *et al.*, 2018). The degree of soil compaction was classified using the value plotted on the horizontal axis following Sakurai *et al.* (1995).

The Soil Penetration Resistance (SPR) was evaluated using Hasegawa type-cone penetrometer. The soil depth range for each assessment was at a depth of 100cm. The total number of strikes was counted to 20 cm interval depth and SPR was calculated using the following formula:

$$E = M \times G \times H \times C$$

where, E is the soil penetration resistance (J), M is the mass of the penetrometer (2.0 kg), G is the gravitational acceleration (9.8 m s⁻²), H is the vertical drop of the penetrometer weight (0.5 m) and C is the count of strikes for each depth (Sakurai *et al.*, 1995; Hattori *et al.*, 2013; Mohamad Jaffar *et al.*, 2018). The data on SPR were statistically analyzed using a Student t-test to compare the significant difference between the different growth stages. The statistical test was performed using SPSS version 17.0 for Windows.

Agronomic Practices in the Sago Plantation

The standard agronomy procedures and practices for sago palm under mineral soils were established by CRAUN research as a guideline for farmers. The selection of planting material is a part of agronomic practices. In sago plantations under SSSSED, only planting materials that had achieved all standard criteria will be used for field planting. Commonly, sago palm underwent 5 to 7 months of hardening period, the height of 60 to 76 cm, having more than six healthy fronds, base girth diameter of more than 6 cm, green frond and dark red spear of not more than 30 cm height (Yusup *et al.*, 2007).

Agronomic practices included in sago palm maintenance were weed control, cluster maintenance,

manuring and pest management. Weed control is done within each plot by slashing followed by a chemical spray of contact herbicides three times annually. The activities included in cluster maintenance were removing creepers and weeds within the cluster, pruning the dead or damaged fronds and sucker. As for manuring, the types of fertilizer applied for sago palm at present were straight and compound fertilizer. Types of straight fertilizers used were Urea (46% N), Rock Phosphate (37% P) and Muriate of Potash (63% K).

Meanwhile, the compound fertilizer used is N-P-K 12-12-17. Fertilizers were applied via broadcasting surrounding the palm, mainly at the root zone. The rate, frequency and types of fertilizer involved were systematically arranged following the standard practice in sago palm plantations (Yusup *et al.*, 2007).

For pest management, sago palms were monitored monthly and control measures were taken if a severe outbreak occurred. Although pest and disease issues are relatively uncommon for sago palm cultivation, the increased cultivation intensity has likely posed a danger for such attacks. Gumbek and Jong (1991) reported that few pests had been identified within the sago palm plantation area in Sarawak, namely Hispid beetles (*Botronyopa grandis*), termites (*Captotermes* spp.) and Red striped palm weevil (*Rhynchophorus* spp.).

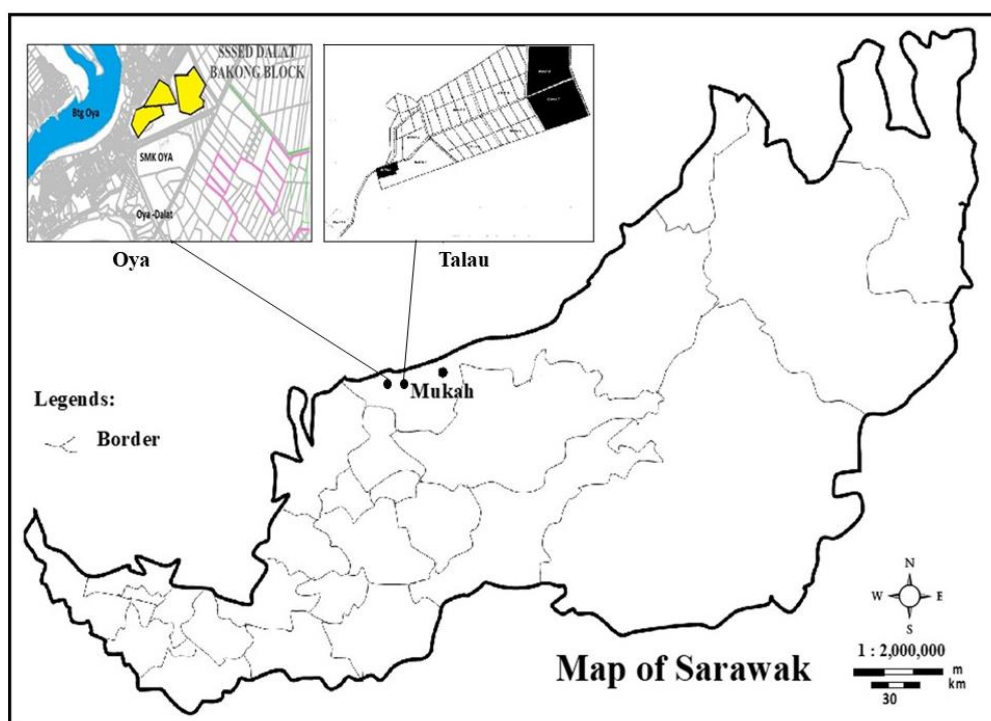


Fig. 1: Map of the study area

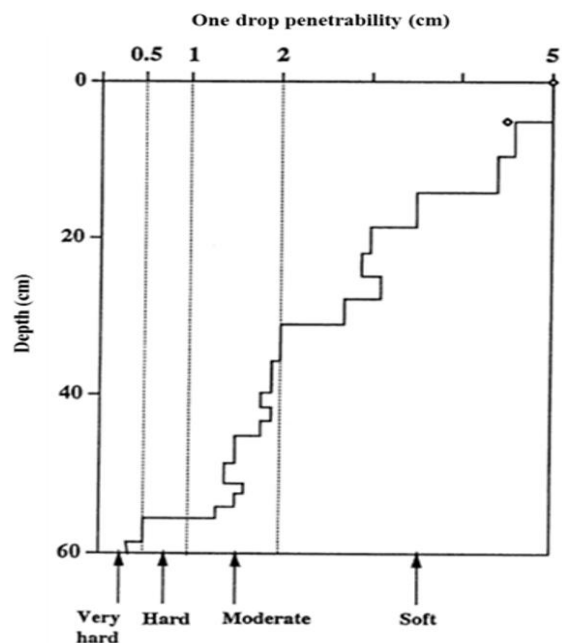


Fig. 2: One drop penetrability (ODP) and definition of soil hardness (Mohamad Jaffar *et al.*, 2018; Sakurai *et al.*, 1995)

Results and Discussion

Soil Penetration Resistance (SPR)

Soil compaction is a significant determinant of plants' plant growth and mortality rates (Hattori *et al.*, 2013). Furthermore, it can provide a fundamental component that indicates land degradation as it reflects the productivity of the land areas (Iwasaki *et al.*, 2020). Overuse of heavy machinery, intensive cropping, short crop rotations, intensive grazing and inappropriate soil management will lead to compaction (Adnan *et al.*, 2017). Figure 3 indicates the soil ODP for both study sites. The results showed that the soil compaction in Talau River was categorized as soft soil from 0-45cm depth, while soils from 45-100 cm depth were classified as moderate. It was noted that based on our field observation, the presence of peat soil at the soil surface with alluvial soil formed at subsoil layers with well-drained conditions. On the other hand, soil compaction for the site at Oya indicated that soil compaction was categorized as hard to very hard, starting from 25cm and below.

Based on Fig. 4, there was a significant difference between planting stages at 0-20 cm and 80-100 cm soil depths. The highest average of compaction was shown on the rosette stage at 60-80 cm soil depth with 46.8 J cm⁻¹, followed by 40-60 cm soil depth with 24.2 J cm⁻¹ and 20-40 cm soil depth with 15.0 J cm⁻¹. For both study areas between 20-80 cm, there was no significant difference between the growth stage of rosette and trunking.

High compaction up to 80 cm soil depth probably

occurs due to heavy machinery during the land preparation at the initial establishment of study plots. In addition, the water table in study areas may likely affect the soils and palm growth. The water table height for palm trees was varied in which the atmospheric and water pressure influenced the grounded level of soils. At the trunking stage, SPR for soil depth 80-100 cm was 2.0 J cm⁻¹ which is less than the value of the rosette stage with 10.5 J cm⁻¹. The factor that resulted in low SPR on the trunking stage may be the soil's physical properties in the study area.

SPR at trunking stage at 20-40 cm and 40-60 cm soil depths was 4.9 J cm⁻¹ and 8.2 J cm⁻¹, respectively. The study site of the trunking stage consists of a waterlogged condition and its influence on SPR reading. The ideal layer of mineral soils condition allows the palms' anchorage on trunking and reduces the time consumed by the palm in developing the runners on the ground. In addition, optimum soil compaction allows for more efficient uptake of water and nutrients for the crop of the vacant layer. Thus, the application of soluble forms of fertilizers such as Nitrogen (N), Phosphorus (P) and Potassium (K) was readily available for the requirements of palm trees under mineral soils. The optimum level of soil compaction might help reduce fertilizer losses such as surface runoff and leaching if the loose grounds were available.

Sago palm under will develop large and medium roots predominated at deeper soil layers. For sago cultivation in deep peat soil, such conditions to the root system might cause oxygen deficiency which would be expected to be severe in the deeper part of the soil depth (Miyazaki *et al.*, 2011). However, this may not be the case as observed in the Talau River site as although the soils are high in moisture, especially in the surface soil, the deeper part of the soils were consists of mainly clayey-textured mineral soils. For the case of Oya sites, the deeper soil layers were mostly compacted even at a depth of 30 cm (Fig. 3), leading to a decrease in porosity, which is often associated with obstructive drainage with a high bulk density.

In-Situ Observation of Sago Palm Plantation Under Different Growth Stages

Based on field observation and sago palm physical indicator standard of previous studies done by Yong (2014), the growth performance of sago palm was summarized in Table 1.

The growth performance indicators were based on observing a number of fronds and the stage of the palm. The indication of poor fronds development is frond count less than 10, which means the sago palm fails to develop a sufficient number of fronds to be categorized as a "healthy" palm. Poor frond development of sago palm can be influenced by soil fertility, nutrient deficiency, disease and pest infestation. Based on in-situ observation, sago palm at SSSSED Oya has moderate sago growth because

frond counts of sago palm are between 10-15 and base girth diameter of sago palm more than 6 cm. On the other hand, sago palm at Talau river research station was at the trunking stage with frond count of more than 15.

Figure 5 illustrates the sago palm in the study areas at SSSSED Oya and Talau river research station. According to Flach (1983), the maturity stages of healthy sago palm after flowering planted in peat soils are 10-14 years and 8-11 years under mineral soils ecosystem, respectively.

There are few possible factors lead to affect the performance of palm growth.

Ambak (2000) reported that over-draining causes the rapid decline and drying out of the soils layers, adversely affecting the development of the sago palms. Thus, the optimum water table should be determined and maintained by reducing the water flow rate between 20-40 cm from the soil surface (Ambak (2000). Besides, bushes and creepers should be slashed to a point no higher than palm trees to avoid the competition between planted and pioneer trees. Tree stumps and logs in abundance at study sites need to be removed because compacted soil continues to shrink the grounds.

Nozaki *et al.* (2004) reported that starch concentration was lower in sago palms grown under problematic soils are often susceptible to utilize storage compounds in order to overcome such adverse circumstances; however, this may not be the case for sago palm cultivated under mineral soil. Meanwhile, the root system of sago palm cultivated under peat soils was less developed than that on mineral soils (Miyazaki *et al.*, 2011). The differences in growth of sago palm might be attributed to the lower soil fertility as the soil nutrient contents in the deeper soil layers of mineral soils were lower than those in the upper layers (Perumal *et al.*, 2017; Ho *et al.*, 2019). Moreover, soil compaction at subsoil may cause inhibition of the root development into the deeper layers of the soil where soil pore space is largely restricted.

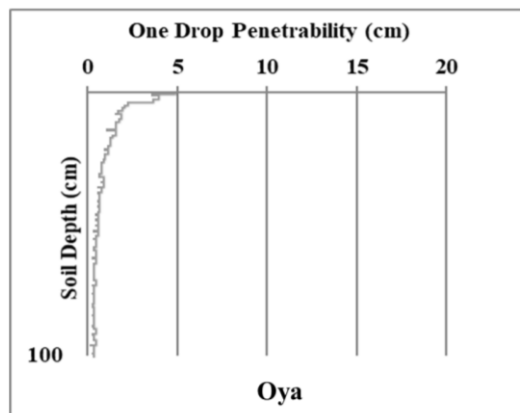


Fig. 3: One Drop Penetrability (ODP) in both study sites from 0-100cm depth

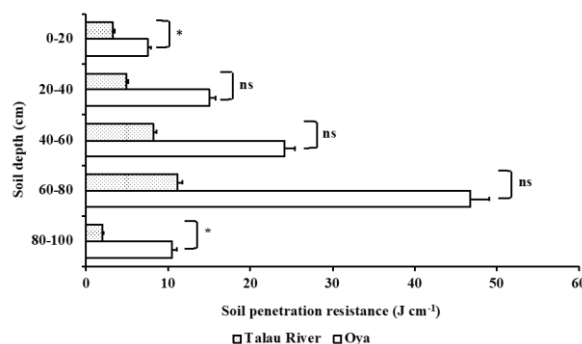


Fig. 4: Soil Penetration Resistance (SPR) in both sites; *in the same depths means significant differences at 5% using Student t-test; ns means no significant differences

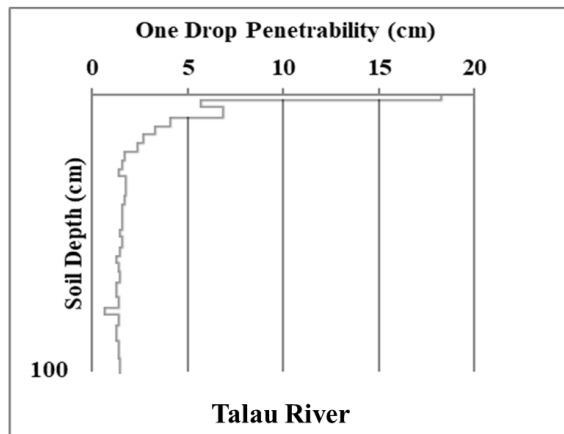


Fig. 5: Trunking stage at Talau river research station (left) and rosette stage at SSSSED Oya (right)

Table 1: Summary of sago palm growth status (Yong, 2014)

| Study area | Growth stage | Palm age | Frond count |
|------------------------------|--------------|----------------------|--------------|
| SSSED Oya | Rosette | 1 year old | 10-15 |
| Talau river research station | Trunking | More than 5years old | More than 15 |

Conclusion

This preliminary study concludes that soil compaction in SSSSED Oya was more compacted than Talau river research station at shallow depth (0-20 cm) and subsurface soils (80-100 cm). There was no significant difference between the two planting stages of 20-40 cm, 40-60 cm and 60-80 cm soil depths. Based on SPR assessment, soils at SSSSED Oya can support the growth performance of sago palm, although soil compaction in SSSSED Oya was higher than in Talau River. Using a practical and convenient approach in assessing soil suitability for sago cultivation, SPR assessment to identify potential areas for the establishment of sago cultivation area can be the fundamental tools for landowners in preparing their land for future cultivation. It is noteworthy that further investigation in linking SPR attributes with other soil variables at temporal changes or growth stages in promoting better growth and yield production of sago palm should be considered. Such study will assist in developing proper agriculture management practices that cover the appropriate understanding of the soil-plant relationship in sago cultivation. Furthermore, this specific approach for early prediction of land suitability before sago palm cultivation may apply to particular soil conditions. Further field trials and assessments are essential to determine the applicability of SPR as a suitable parameter for land suitability sago cultivation under mineral soil.

Acknowledgment

This research was financially supported by Tun Open Chair, Universiti Malaysia Sarawak. The authors wish to express gratitude to CRAUN Research Centre, especially to Mdm. Fariza Zaini and Mr. Peter Stanley Howell for their supportive assistance during the duration of this study.

Funding Information

Tun Openg Chair, Universiti Malaysia Sarawak (F07(ORC22)/1228/2015(09)).

Author's Contributions

Mohd Effendi Wasli: Project leader of the research. Contributed in fieldwork, data analysis and preparation of manuscript.

Nurul Hidayah Che Ali: Researcher contributed in fieldwork and data analysis.

Roland Yong: Project member and contributed in experimental design, field sampling and data analysis.

Awang Ahmad Sallehin and Awang Hussaini: Co-researcher of the research project and provide considerable contribution on research idea.

Meekiong Kalu: Researcher contributed in drafting and reviewing the manuscript as well as data analysis.

Sim Siong Fong: Co-researcher of the research project and provide constructive suggestion for the manuscript.

Aina Nadia Najwa Mohamad Jaffar: Researcher contributed in drafting and reviewing the manuscript as well as data analysis.

Mugunthan Perumal: Researcher contributed in field assessment, data analysis and draft of the manuscript.

Ethics

The authors declare that there are no conflicts of interest regarding this paper publication.

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