Study of oil palm root architecture with variation of crop stage and soil type vulnerable to drought

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Abstract. Root architecture is affected by watertable level, characteristic of soil, organic matter and also the crop stages. Root architecture spread horizontally and vertically which each consist of primary, secondary, tertiary and quaternary downward root. The oil palm root observation with variation of crop stage and soil type showed that the root of oil palm plant year 2008 on spodosols soil spread along 650 cm horizontally from the trunk and penetrate downward in range of 9-28 cm vertically. Planted in the same type of soil, the root of oil palm plant year 2004 spread along 650 cm horizontally and reached to downward in a larger range from 3 to 57 cm vertically. As a comparison, the root architecture of oil palm on inceptisols soil established the range much greater vertically than the previous. The root of oil palm plant year 2008 spread along 640 cm horizontally and penetrate downward in range of 52-90 cm vertically. With the variation of crop age, the root of oil palm plant year 2003 spread along 650 cm horizontally and reached to downward in a larger range from 150 to 200 cm vertically.

Based on this study, root architecture of oil palm was varied and need to be detailed. The precise root architecture of oil palm allows a better understanding on hydrological properties of oil palm root particularly which is cultivated on soil type vulnerable to drought. Referring to this root architecture, it was enable to develop the study on early drought detection of oil palm to optimise production and towards oil palm sustainablility.

Keywords: Root Architecture, Oil Palm, Drought, Spodosols Soil, Inceptisol Soil

1. Introduction

Root architecture describes root topology and distribution [8]. Root architecture varies among plant species, it even varies among individual plants within the same species. Root architecture is an important factor of root function such as nutrient and water intake [12]. The roots of oil palm can grow only to a depth of 1 m if the plants get enough water and nutrients. However, on condition of limited water availability, it can reach more than 5 m. In mature palm oil plants, total dry weight of roots increased after a radius of 2 m to 3.5 - 4.5 m from the stem [2].

According to Jourdan et al. [3], the oil palm (Elaeis guineensis Jacq.) has a root system consisting of primary (or order 1) roots, which are either orthogravitropic (R1 VD, with positive gravitropism) or diagravitropic (R1 H). Order 2 roots may have vertical upward (R2 VU) or downward growth (R2 VD) or even horizontal growth (R2 H). Order 3 roots are usually agravitropic. When they grow
upwards, R3 VU, their amyloplasts are located near the proximal wall. Likewise, the growth direction of R4 varies, but they have little or no statolith Sedimentation.

Jourdan and Rey [4] described the growth dynamics and architecture of the oil-palm root system consisted of a transitional juvenile phase and eight different morphological types of roots have been distinguished according to their development pattern and state of differentiation: primary vertical and horizontal roots, secondary horizontal roots, upward growing secondary vertical roots and downward growing secondary vertical roots, superficial and deep tertiary roots and quaternary roots. The relative position of these types of roots determines a morphological and functional unit of the root system called "root architectural unit" of the oil palm. The quantitative parameters of different root types of oil palms in the juvenile phase. RI2_5-primary root emitted for a 1 to 5-month-old oil palm, R15_12 primary root emitted for a 5 to 12 month-old oil palm.

The development of oil palm is currently directed to marginal land, such as spodosols and inceptisols. There are limiting factors on spodosols such as the depth of spodic layer and sandy soil texture and acidic for tropical area. The depth of spodic layer is the main factor for root growth because it is related to the ability of roots in penetrating soil, whereas the sandy soil texture will reduce the soil ability to retain water as well as greater chance of nutrients leaching. Other limiting factors that could potentially inhibit plant growth are poor drainage and soil acidity.

According to Kasno and Subarja [5], the depth of spodic layer on spodosols ranges from 30 to 70 cm below soil surface. Oil palm requires solum depth equal to or greater than 80 cm without layers of rock for optimal growth and development [7] and at least the layer is more than 75 cm depth [13].

Inceptisols is one of the acid mineral soils with low nutrient availability. The productivity of oil palm planted on the soil is low, and there are symptoms of decreased productivity in certain months of the year. The use of inceptisols for agricultural land has faced many problems in physical, biological and chemical properties of the soil. The problem with its physical properties is that the topsoil has a coarse texture, but less coarse in the lower texture. Therefore, the permeability is rapid on the top surface but low in the lower layer. The topsoil structure is granular or crumb and the lower layer is unstructured, with lower density on the surface and increased with the increasing depth. The problems related to biological properties such as species, population, and biota activities. And the problems related to chemical properties are high C-organic content (5.06 – 5.39%) while N-total is relatively low (0.15 – 0.42%) resulted in moderate C/N ratio which is about 12 – 35%. Cation Exchange Capacity is relatively moderate at about14.1-17.3 me/100 g, while base saturation is low 24-29%. This high base saturation results in low nutrient and CEC availability [10].

Empty fruit bunches are soil and nutrients enhancers for plants. Empty fruit bunches contain organic matter and have relatively high nutrient content. The utilization of empty fruit bunches can be done by direct application as mulch or composting. It has high C/N rate which is about 45-55.

The results from research in Pontianak, West Kalimantan using electrical resistivity method showed that on the peat land the oil palm plant has a horizontal root distribution reaching 3.5 m with a depth of 1.74 m [9]. The results of oil palm resistivity measurements at PTPN 13 showed that tertiary root distribution and the dominant quarter were in the horizontal direction between 2.5 - 4.0 m from the trunk with maximum depth of 0.3 m. While the secondary roots were generally located between 0.3 m - 0.5 m depth and a small part appear to the surface. The primary roots are at a depth of 0.5 - 1.08 m and tend to move downward along vertical direction.

The distribution of roots in spodosols is limited only to the surface of soil layer. On sandy soil, around 90% lateral root is found from the surface to 30 cm depth [1]. Root distribution has an important role in water and nutrient intake. It is also closely related to groundwater level on a field. The studies regarding empty fruit bunches application on spodosols and inceptisols were conducted to observe the influence of this application to the changes of root architecture on oil palm. The observation included distribution/range of primary, secondary, and tertiary roots both in vertical and horizontal direction.

Root architecture was affected by water table level, soil characteristics, soil organic matter, and as well as crop stage. The ability to grow at any time in response to soil conditions might be an essential
prerequisite for phreatophytes (deep-rooted plant) if they are to survive fluctuating water table conditions in seasonally water-limited environments. Based on this study, root architecture of oil palm was varied and need to be detailed. The precise root architecture of oil palm allows to better understanding on hydrological properties of oil palm root particularly which is cultivated on soil type vulnerable to drought. Referring to this root architecture, it enables to develop the study on early drought detection of oil palm to optimize production and towards oil palm sustainability.

This research was aimed to study the root distribution of different soil type: spodosols and inceptisols, root distribution of different crop age: plant year 2008 and 2004, and root distribution in response to water level and empty fruit bunches (EFB) application.

2. Materials and Methods
The research was conducted in Pundu Central Kalimantan on April to May 2017, where the humid tropical climate with marked seasons is characterized by (i) average annual rainfall was 3002 mm/year(ii) average annual temperatures varied between21.4 – 33.8 °C and, (iii) the average sunshine hour was around5.9 hours of sunshine per year (based on the climate data series 2008-2015 from climate station of Pundu Plantation). The observation was on oil palm field planted in 2004 and 2008 on spodosols and inceptisols covering the area of 24,457.7 hectare.

The observation of root distribution in spodosols and inceptisols soil type.
The measuring water table using automatic water level sensor HOBO U20-001-04-Ti (13-Foot Depth Titanium Water Level Data Logger). The water level HOBO was installed 9 separate points, with details of 4 tools at the location of the oil palm plant, 4 tools on the surface of the nearest river and one device mounted for reference. The equipment was installed by drowning it in groundwater as deep as ± 20 cm or in a river as deep as ± 1 meter. It is intended that the water fluctuations that occur will still drown the water level HOBO. In the meantime as a reference, HOBO should be installed in a condition not submerged in water, therefore mounted above ground level. Each HOBO is recorded depth of mounting or tool height, as a basis for determining the depth of the groundwater level. Pressure data retrieval was done automatically every 30 minutes during the observation. The readable pressure on each device will be adjusted to the reference HOBO, so that the actual pressure difference is known. Furthermore, from the pressure value recorded by the HOBO will be converted to the depth of groundwater at each observation point.
The effect of Empty Fruit Bunches on root distribution in spodosols and inceptisols observed with the variation of oil palm age (plant year 2008 and 2004). The Empty Fruit Bunches application to the oil palm field near the mill for nutrient cycling.

3. Results and Discussions
The roots of oil palm can only grow to 1 m depth when the plants receive adequate water and nutrients, but on condition where there is limited water availability, the roots can reach more than 5 m. In mature palm oil plants, total root dry weight increased after a radius of 2 m to 3.5 - 4.5 m from the stem [2].

The observation of root distribution was conducted in marginal land (spodosols and inceptisols) in Central Kalimantan. Spodosols with the soil texture consist of 89.29% sands, 3.44% silt and 7.28% loam and spodic layer has root distribution spread on the soil surface and shallow water table. While inceptisols which has soil texture 52.38% sands, 16.24% silt and 31.38% loam and deep water table, the roots were spread similarly shown in Figure 1. Root distribution of oil palm plant year 2004 Root distribution of oil palm plant year 2004 and 2008 could be seen in details in Table 1. Visually, the root architecture on spodosols is illustrated in Figure 2.
Figure 1. The observation of oil palm root distribution on spodosols (left) and inceptisols (right)

Table 1. Oil palm root distribution on spodosols plant year 2008 and 2004

| Observation Parameter       | Spodosols 2008 No EFB | Spodosols 2004 EFB |
|-----------------------------|------------------------|---------------------|
| Water table                 | 22 cm                  | 14 cm               |
| Spodic layer                | 56 cm                  | 56 cm               |
| Primary horizontal          | 28 cm                  | 57 cm               |
| Primary vertical downward   | 28 cm                  | 57 cm               |
| Secondary vertical downward | 28 cm                  | 57 cm               |
| Tertiary vertical downward  | 28 cm                  | 3 cm                |
| Quaternary vertical downward| 9 cm                   | 3 cm                |

Figure 2. The architecture of oil palm root on spodosols plant year 2008 (left) and 2004 with EFB application (right)

The oil palm root observation with variation of crop stage and soil type showed that the root of oil palm plant year 2008 on spodosols spread along 650 cm horizontally from the trunk and penetrate downward in range of 9-28 cm vertically. Planted in the same type of soil, the root of oil palm plant year 2004 spread along 650 cm horizontally and reach downward in a larger range from 3 to 57 cm vertically.
The observation of root distribution on spodosols in Pundu Central Kalimantan indicated that the depth of the spodic layer in both sites was 56 cm depth. Primary root coverage in horizontal direction with and without the application of empty fruit bunches showed no difference. The range of secondary root with the application of empty fruit bunches was further than without the application. The application caused the tertiary and quarter roots to appear in soil surface within 3 cm, while without the application the tertiary and quarter roots reached 28 and 9 cm, respectively. The use of empty bunches can improve the ability of soil to store water, improve physical and chemical properties of soil that the growth of tertiary and secondary roots appeared much in the soil surface.

The addition of empty fruit bunches in spodosols is very beneficial for plants due to more roots spread in the surface. Vertical roots distribution of tertiary and quarter roots range of 28 and 9 cm, respectively could not penetrate the spodic layer.
Table 2. Oil palm root distribution on inceptisols plant year 2008 and 2004

| Observation Parameter | Inceptisols; 2008 | Inceptisols; 2004 |
|------------------------|------------------|-------------------|
|                        | **EFB**          | **No EFB**        |
| Water table            | 600 m            | 1000 cm           |
| Primary horizontal     | 640 cm           | 650 cm            |
| Primary vertical downward | 60 cm         | 200 cm            |
| Secondary vertical downward | 90 cm       | 200 cm            |
| Tertiary vertical downward | 52 cm        | 150 cm            |
| Quaternary vertical downward | 52 cm       | 150 cm            |

Figure 5. The architecture of oil palm root on inceptisols plant year 2008 with EFB application (left) and 2004 (right)

As a comparison to different type of soil, the root architecture of oil palm on inceptisols established greater range vertically than the previous. The root of oil palm plant year 2008 spread along 640 cm horizontally and penetrate downward in range of 52-90 cm vertically. With the variation of crop age, the root of oil palm plant year 2003 spread along 650 cm horizontally and reach to downward in a larger range from 150 to 200 cm vertically.

Palm oil roots in inceptisols without the application of empty fruit bunches have a deeper vertical root range compared to with the application of empty fruit bunches (Table 2). Inceptisols is infertile so that it has low nutrient availability. Empty fruit bunches acted as soil enhancer with the capability of binding groundwater. The application of empty fruit bunches resulted in shorter primary, secondary, tertiary and quarter roots to spread vertically than without the application. This result was similar to the research conducted by Kheong, et al., 2010, which stated that the application of empty fruit bunches caused the quarter root of oil palm at 0 - 45 cm depth more than without the application of empty fruit bunches.
Soil physical properties such as texture, structure, effective depth of soil, groundwater level, soil thickness, soil permeability are the factors which influence the development of plant root to support water and nutrient availability as well as supporting plant upright. If the texture is dominated by clay, the drainage will be hampered. On the contrary, if it is dominated by sand, soil will be drained quickly resulting in disturbed root development. Shallow effective depth of soil or high groundwater level (shallow) means that root distributions are limited [11].

Table 3. Root zone levelling for oil palm on inceptisols and spodosols plant year 2008 and 2004

| Root Zone | Inceptisols | Spodosols |
|-----------|-------------|-----------|
|           | Depth (cm)  |           |
| Zone 1    | 2008  | 2004  | 2008  | 2004  |
|           | 0-30  | 0-50  | 0-9   | 0-5   |
| Zone 2    | 30-60 | 50-150| 9-18  | 5-25  |
| Zone 3    | 60-90 | 150-200| 18-28 | 22-57 |

In inceptisols, high groundwater level affected the distribution of primary, secondary, tertiary and quarter roots vertically. The roots spread deeper by the increasing of groundwater level. The root zone levelling for oil palm on inceptisols deeper than on spodosols (Table 3). The application of empty fruit bunches could increase the groundwater level from 1000 cm to 600 cm, and reduce the coverage of primary, secondary, tertiary, and quarter roots vertically. The application of empty fruit bunches did not change much the distribution of horizontal primary roots (Table 2).

4. Conclusions
Based on the research observation about oil palm root distribution on two type of soils, i.e. spodosol and inceptisol, it can be concluded that:

- The primary root spread almost similar along horizontal side.
- The vertical downward root reached much greater area in inceptisols than spodosols.
• The deeper water table, the longer vertical downward root which penetrated the soil.
• The application of EFB on top soils led to the tertiary and quaternary vertical downward root distribution spread upward.

5. Suggestions
Based on the result of root distribution on spodosol and inceptisol with the variation of oil palm age (plant year 2008 and 2004), it could be suggested the root zone levelling as showed in Table 3. The root zone levelling could be the reference for the observation of soil moisture distribution in oil palm root zone.

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