Does the exposure of water shortage in peat soil affect the nutrient uptake of seedlings between different oil palm varieties?

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Abstract. Soil water content is an important property to indicate the quality of peat in supporting plant growth. Soil nutrient is affected by water content, and each plant has varied adaptation to encounter water stress. This study aimed to observe the effect of water stress to leaf nutrients, nutrient uptake dynamics, and biomass on oil palm seedlings with three different varieties (540, Langkat, Dumpy) and four different water stoppage periods (0, 14, 21, 28 days). Results showed that after 28 days, biomass, leaf nutrients, and plant nutrient uptake (N, P, K, Ca, Mg) from 3 varieties were not statistically different. However, different N, P, K, and Mg uptake only occurred if we compared watering period's data. The highest water content and biomass correlation were shown in Langkat variety (r = -0.630). The pH increased longest water stoppage period (r = 0.116). Significant correlation was only found in Langkat and Dumpy’s N uptake (r = -0.431 – (-0.420)), and P uptake of Langkat (r = -0.368). Sensitivity order of nutrient uptake in relation with low water content for 540 variety was N > Ca > Mg > P > K; Langkat variety was N > Ca > Mg > P > K, and Dumpy variety was N > Ca > P > Mg > K.

1. Introduction

Oil palm’s growth and productivity are influenced by synergy of genetic (planting materials) and environmental factors. Rainfall is an essential environmental factor that influences soil water content, nutrient translocation, and crop’s assimilate partition [1, 2]. Global climate change leads to abiotic stress condition and presents negative impacts on water availability for crop growth. Latest El-Nino phenomenon increased drought occurrence, which impacted crops cultivation, from crops morphology, physiology features to its yield. For oil palm, when drought prevailed, productivity was depleted by 30-60% compared to common yield potential [3-5]. Increasing air temperature and fluctuating rainfall are expected to alter water availability in supporting crop production [1-6].

Under abiotic stress, it is necessary to further observe oil palm genetic resources, especially high tolerance and adaptable traits [7-9]. Some varieties were known to portray different drought tolerance in terms of morphological, physiological, and biochemical processes [7, 10-12]. For example, low frond desiccation (LFD) is known as one of morphological adaptation strategies in abiotic stress like drought, which is found either in oil palm cultivation on mineral soil [4] or peat soil [13]. Moreover, the presence of proline, nitrate reductase activity (NRA), chlorophyll content, and abscisic acid were known as physiological response for water shortage [7, 9, 14, 15]. Insufficient water content due to drought stress will also inhibit absorption of nutrients diffused from soil matrix to roots and to all plant tissues [16].
17]. Previous studies have also shown that drought stress can interfere the uptake of macronutrients (N, P and Mg) by plants on mineral and peat soils [18, 19]. Under such water conditions, Sun et al. [9] showed increasing root/shoot ratio, reduced N and P leaf concentration and chlorophyll a/b content. It can be indicated that nutrient uptake is also greatly influenced by water stress.

More than 1.7 ha of Indonesian oil palm plantations were cultivated on peat soil [20]. Peat soil is composed of organic matter and has high porosity, which tends to be more sensitive to changing water and soil moisture [13, 21]. Presence of hydrophobicity traits or irreversible drying and higher soil acidity affects concentration of COOH and OH groups in soil, leading to decreasing the availability of soil nutrients [21, 22]. Hashim et al. [23] and Winarna et al. [13] found that retention ability will decline on dried peat soil condition and commence on nutrient leaching, decreasing nutrient availability and nutrient uptake. Deflation of soil nutrient uptake was not only ensued in macronutrients like Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg), but also found in micronutrients like Cuprum (Cu), Zinc (Zn), Boron (B), and Iron (Fe). Lacking water content will hinder normal nutrient translocation processes within the soil to the plants. Moreover, when drought condition lasts for a long time, it will impair plants' growth and productivity.

Previous studies reported that some oil palm varieties can adapt to a particular abiotic stress condition and show different survival symptoms [24-26]. Physiological responses of plants in translocating nutrients, water, and assimilate, accumulating abscisic acid, antioxidant enzyme activities, and reducing transpiration and photosynthesis rate vary to some extent [27-30]. In oil palm plantations, a knowledge gap remains on adaptation responses to drought stress and plant nutrient uptake in several varieties. Efforts have been carried out to minimize drought effect or water stress conditions in crops, such as adding Calcium [12, 31], Potassium [14], Boron and Silica [32, 33] to the plant, inoculation using Mycorrhiza arbuscular [34, 35] and choosing drought-tolerant varieties [25]. Information of drought or water stress-tolerant cultivars is partially known. Therefore, this study examined cultivars with adaptable water stress condition from Indonesian Oil Palm Research Institute (IOPRI). This paper also explores relationship between water content and soil acidity on varying nutrient uptake and biomass of oil palm seedlings from 3 different PPKS varieties (Dumpy, 540, Yangambi). Water stress was represented by different water content with watering stoppage period (from control, 14, 21, and 28 days).

2. Methodology

2.1. Test site
The research was conducted in a glass house at Aek Pancur experiment field (IOPRI), Tanjung Morawa, North Sumatra province, Indonesia. Observations were held for 4 months between September to December 2020 on main nursery seedlings (9 months old).

2.2. Materials
This study used three IOPRI cultivars, namely DxP PPKS 540, DxP Langkat, and DxP Dumpy. Peat soil used as a growing media was obtained from Panai Jaya, North Sumatra, Indonesia; its characteristic is depicted in Table 1. Peat soil sample was classified as sapric decomposition rate. Fertilizers applied in growing media was NPK Compound fertilizer with composition 15-15-6-4. Main nursery seedlings were planted in polybags of 30 x 40 cm.

2.3. Observed materials and analysis
Randomized factorial block design was used in this research. Two factors were considered, i.e. oil palm varieties (DxP PPKS 540, DxP Langkat, and DxP Dumpy) and period of drying (control or no drying, 14, 21, and 28 days). Fourteen days of drying means that seedlings were only watered for 14 days. Observations included soil physical and chemistry properties, vegetative growth and seedlings biomass measurements, and seedlings nutrient uptake. Soil physical observation involved soil water content using gravimetric method. Soil chemistry included measurements of pH (pH meter), Total Nitrogen (Kjedahl method), P2O5 (Bray 1 Method), K2O (25% HCl), Calcium (Ca), Magnesium (Mg) and Cation
exchange capacity (CEC) (extracted in 1N NH₄OAc pH 7). All soil analysis was conducted in IOPRI’s soil laboratory.

Table 1. Characteristics of growing media

| Parameter        | Unit          | Initiate period (0 day) |
|------------------|---------------|-------------------------|
| pH H2O           |               | 3.6                     |
| Soil water content | (% w/w)      | 235                     |
| N                | (%)           | 0.23                    |
| P                | ppm           | 21.14                   |
| K                | m.e/100g      | 0.51                    |
| Ca               | m.e/100g      | 14.23                   |
| Mg               | m.e/100g      | 6.27                    |
| CEC              | m.e/100g      | 120.82                  |

Data were statistically analyzed using one-way ANOVA, multiple comparisons, and Pearson’s correlation. When results were significant (P < 0.05), we used Duncan test (with α = 5%) to compare the means employing SPSS software.

3. Results and discussion

3.1. Peat soil characteristics

As shown in Figure 1a, at the end of the experiment, soil water content from 3 different varieties decreased significantly in 28 days. Additionally, pH became more acidic as peat became drier (Figure 1b). However, CEC trend tended to drop for Langkat and Dumpy, but increasing CEC was found in the 540 (around 19%) compared to control (Figure 1c). This finding aligned with previous research elucidating that when peat became drier, pH and CEC were also depleted [13].

Significant difference in each watering stoppage period (0 – 28 days) was found for soil water content, pH, and CEC. Due to prolonged water stoppage, peat soil was exposed to water stress condition and altering soil chemical properties. Low soil water content was susceptible to hydrophobicity traits of peat. If so, this condition would govern its ability to hold water, mostly used for nutrient translocation and metabolic activities [13, 23]. The pH and CEC constrain nutrients dynamics and uptake. Prior research generally confirmed that with decreasing pH and CEC, COOH and OH groups were depleted and affected the capability for nutrient retention and leaching in peat soil [21]. Nutrient absorption for supporting plant growth was, therefore, not optimally achieved since roots kinetics, nutrient diffusion, and mass flow were disrupted by water shortage [36, 37]. Impact of water stress, however, might vary; it depends on the intensity and duration [18]. This study demonstrated that peat characteristics after 28 days of water stoppage period were relatively similar. Intensity and duration of water stress until 28 days considerably altered peat soils in the same way.
3.2. Total biomass and nutrient uptake

Figure 2 and Table 2 suggest that total plant biomass, nutrient uptake, and leaf nutrient from three different varieties were statistically similar after 28 days of water shortage. This indicated that all cultivars shared similar response in tolerating limited water exposure. After 28 days of treatment, Langkat (V2) variety showed a greater total biomass, followed by 540 (V1) and Dumpy (V3) at similar level.
Figure 2. Total biomass of oil palm seedlings on different watering stoppage period

| Treatments | Leaf Nutrient (%) | Nutrient Uptake (%) |
|------------|------------------|---------------------|
|            | N    | P    | K    | Ca   | Mg   | N    | P    | K    | Ca   | Mg   | N    | P    | K    | Ca   | Mg   |
| V1P0       | 2.58 a | 0.383 a | 0.477 a | 0.49 a | 0.52 a | 442.65 a | 64.05 a | 82.32 a | 83.71 a | 90.45 a |
| V1P1       | 2.80 b | 0.341 a | 0.707 b | 0.45 a | 0.71 b | 406.49 b | 61.70 a | 64.41 b | 61.41 a | 63.59 b |
| V1P2       | 2.83 b | 0.463 ab | 0.440 a | 0.39 a | 0.44 a | 428.31 b | 81.60 ab | 69.44 a | 64.73 a | 68.30 a |
| V1P3       | 2.72 b | 0.494 b | 0.423 a | 0.42 a | 0.43 a | 484.83 b | 59.63 a | 121.00 a | 76.37 a | 121.00 a |
| V2P0       | 2.71 a | 0.412 a | 0.430 a | 0.41 a | 0.42 a | 560.68 a | 77.36 a | 100.91 a | 87.98 a | 100.91 a |
| V2P1       | 3.06 b | 0.416 a | 0.547 b | 0.47 a | 0.55 b | 509.01 b | 64.77 a | 94.22 b | 87.81 a | 94.22 b |
| V2P2       | 2.79 b | 0.403 ab | 0.450 a | 0.47 a | 0.45 a | 552.46 b | 91.38 ab | 86.35 a | 78.70 a | 86.58 a |
| V2P3       | 2.78 b | 0.377 b | 0.383 a | 0.44 a | 0.38 a | 528.63 b | 77.00 b | 85.30 a | 89.98 a | 84.68 a |
| V3P0       | 2.70 a | 0.516 a | 0.437 a | 0.40 a | 0.43 a | 427.10 a | 69.55 a | 65.82 a | 63.56 a | 65.56 a |
| V3P1       | 2.77 b | 0.354 a | 0.513 b | 0.47 a | 0.51 b | 485.02 b | 90.10 a | 77.19 b | 77.03 a | 77.61 b |
| V3P2       | 2.77 b | 0.450 ab | 0.430 a | 0.41 a | 0.43 a | 603.09 b | 84.60 ab | 86.00 a | 97.55 a | 85.31 a |
| V3P3       | 2.61 b | 0.517 b | 0.440 a | 0.29 a | 0.44 a | 525.89 b | 99.12 b | 83.91 a | 54.96 a | 83.50 a |

Different letters in the columns indicate significant differences between the watering and fertilization treatments at P < 0.05 level.
Nutrient and water translocation elaborated decreasing value of plant biomass [9, 25]. Specifically in oil palm seedlings, biomass partition was highly allocated to below-ground parts, suggesting a higher root-shoot ratio during water stress. Additionally, leaf relative conductivity, stomatal closure and conductance, and chlorophyll a/b influence photosynthetic capacity, CO2 assimilation, and plant biomass partition, which more likely be depleted due to water shortage [7, 9, 15, 38]. Plants, however, were known to show different responses to water stress, in terms of intensity and the duration. Silva et al. [8] reported that two oil palm hybrids might establish different drought tolerance mechanisms; the first hybrid performed a surge of crucial enzyme activities associated with carbon metabolism and sucrose-phosphate synthase. In contrast, the second was considered more tolerant in coping with water shortage. Three varieties studied in this research performed similar adaptation to water shortage since there was negligible difference in total biomass, leaf nutrients, and nutrient uptake. Without extended water input, seedlings growth and performance were critically influenced.

Table 2 suggest significantly different data involved leaf nutrient concentration and nutrient uptake (N, P, K, Mg) in each watering period. They depleted with time of stress exposure. Each oil palm varieties showed different trends of nutrient uptake. For example, in 28 days, Dumpy (V3) reached the highest increasing trends for N, P, and K uptake compared to control (V0). Meanwhile, Langkat (V2) variety was more likely to be sensitive to water stress, as seen from depleted trends of N, P, K, and Mg uptake. The 540 (V1) variety appeared to express a least consistent trend for nutrient uptake; N, K, Mg uptake increased, while Ca uptake was decreased.

It is important to note, however, that observed parameters did not vary and showed a significantly different trend over all varieties. Final water content of all treatments (except control) noticeably shifted chemical properties of peat media since peat soil became drier. Once dried, hydrophobicity feature of peat appears and influences a lower CEC, nutrient retention, COOH, and OH group measurement [13, 22]. Since water shortage was not entirely intense, this research indicated that seedlings were considerably tolerant and were quite adaptive to the situation. This was portrayed by increasing trend of oil palm nutrient uptake for 28 days period.

3.3 Correlation of soil water content, biomass, pH and nutrient uptake

In soil-plant-atmosphere continuum, water plays a vital role in translocating nutrients from soil to plant organs; with partially leached and evaporated. Table 3 summarizes that water content is crucial to improving plant biomass (R = -0.390). Among three varieties, Langkat (V2) biomass was more influenced by water content, followed by 540 (V1) and Dumpy (V3). Langkat variety was more tolerant towards water shortage since the biomass kept increasing until 28 days. Plant growth rate and biomass are relatively low in a water shortage condition. In line with this research finding, Sun et al. [9] discovered that alteration in biomass allocation and decreasing growth rate of oil palm seedlings occurred after three months of drought experiment. Physiological responses affecting biomass included shifting photosynthesis rate, decreasing carbon assimilation, stomatal conductance, osmotic regulatory substances, and the presence of drought stress signals like antioxidant enzymes, Abscisic acid (ABA), and Proline that alter the process of photosynthesis and transpiration [7, 9, 12, 15].

On the other hand, water content showed a low correlation from three different varieties (R = -0.047 – 0.157). It was suggested that 28 days of watering stoppage might affect soil acidity, but it did not significantly impair soil function. Soil acidity shares roles in improving nutrient retention in the soil. Prior research has thoroughly investigated that soil pH becomes lower with an extended drying period, especially in peatland [13]. Goh et al. [29] added that in a drier peat with lower pH, accumulation of organic, phenolic, and free amino acids increases and shares a toxic below-ground environment that halts plant growth.
Sensitivity of nutrient uptake was classified from correlation between water content and major nutrients uptake in oil palm seedlings. Most influenced nutrient uptake was $N > Ca > Mg > P > K$ (for 540), $N > Ca > Mg > P > K$ (for Langkat), and $N > Ca > P > Mg > K$ (for Dumpy). Table 3 indicates that water content significantly regulates Nitrogen and Calcium uptake in Langkat (V2) variety, and only Nitrogen uptake in Dumpy (V3) cultivar. Meanwhile, for 540 variety (V1), sensitivity for all observed nutrients was not clearly seen due to relatively low correlation, except for Nitrogen uptake. Several studies confirmed that some major nutrients like Nitrogen and Calcium during water shortage were more sensitive to change. In a severe drought, concentration of Nitrogen was depleted. This condition may reduce photosynthesis since Nitrogen content, known as a major nutrient in chlorophyll, decreases in an abiotic stress environment [9, 18]. Diminished nutrient uptake may occur due to constraints of root hydraulic conductivity that affects radial movement (nutrient diffusion and mass flow) during water shortage [18, 39]. Assuming nitrogen supply from Nitrate or Ammonia is sufficient, it shares capability to alleviate water stress by improving metabolic activities even with functions of plant tissue function are reduced. It is achievable through rapidly decreasing aquaporin expression, allocating ABA accumulation in roots, and improved a higher stomatal conductance [40]. In this research, since Nitrogen necessity was covered and water shortage did not severely impair plant tissue. Therefore, photosynthesis rate was not highly distracted and was able to produce sufficient biomass.

Calcium content tend to increase during water shortage. Calcium has a primary role in delivering drought signals by expressing physiological responses through plant biochemical activities [15, 41]. In detail, Calcium can overcome stress in the environment [42], involved in cytoplasmic flow [43], accumulation of proline [36], optimizing photosynthesis rate [44], abscisic acid (ABA) transduction in guard cells, plant transpiration, increasing concentration of proline, and antioxidant enzyme activity, and enjoining gene that regulates chlorophyll a/b bond [45]. Additionally, Calcium is also significant in strengthening plant tissue during abiotic stress like water shortage. It affects the increment of cellulose synthesis by increasing the integrity of primary cell. Moreover, this regulation might maintain cell turgor, followed by more tolerant or adaptive continuous growth of plant cells even under abiotic stress [44]. Addition of Calcium to oil palm seedlings could increase resistance towards water shortage [31].

Relationship between water shortage and distinct adaptive mechanisms at physiological to molecular levels is a complex phenomenon and needs to be understood. Previous studies discovered that metabolic activities, enzymes, and specific plant hormones like Pectin and Abscisic acid (ABA) might occur in severe and intense drought conditions. Further work needs to be performed to establish a more detailed research in recovery phase of oil palm under water shortage. More precisely, future areas of research include morphological and physiological change that occur after recovery by re-watering, further assessment of *Arbuscular mycorrhiza*, and nutrients like Potassium, Boron, and Silica, to increase plant resistance.

### Table 3. Correlation Value between water content, biomass, pH, and nutrient uptake

| Parameters                  | Correlation Value with Water content |
|-----------------------------|--------------------------------------|
|                             | 540 (V1)    | Langkat (V2) | Dumpy (V3) | All          |
| Biomass (gram)              | -0.352      | -0.630*      | -0.19      | -0.390*      |
| pH                          | -0.047      | 0.157        | 0.131      | 0.116        |
| Nitrogen Uptake (%)         | -0.317      | -0.420*      | -0.431*    | -0.425*      |
| Phosphorus Uptake (%)       | -0.178      | -0.190       | -0.270     | -0.276       |
| Potassium Uptake (%)        | -0.168      | -0.181       | -0.152     | -0.159       |
| Calcium Uptake (%)          | -0.274      | -0.368*      | -0.272     | -0.213       |
| Magnesium Uptake (%)        | -0.215      | -0.252       | -0.164     | -0.194       |
4. Conclusion
Water shortage may impair plant growth, in terms of intensity and continuity. After water shortage experiments held for 28 days, this research revealed that three oil palm varieties showed a similar drought tolerance mechanism. Nutrient uptake, leaf nutrient content, and biomass did not perform any significant difference. Four weeks of water stoppage was relatively short to understand long-term destructive drought effects to oil palm seedlings under peat soil. Nitrogen and Calcium uptake was portrayed to be more sensitive under different stress conditions.

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