Relation subsidence and water level of peatland cultivated with oil palm in Riau, Indonesia

M Wasilul Lutfi1,*, D P T Baskoro2, S Anwar2, and H B Pulunggono2

1Student of Soil Science Study Program, Graduate School, IPB University, Jl. Meranti Kampus IPB Darmaga Bogor 16680
2Department of Soil Science and Land Resource, Faculty of Agriculture, IPB University, Jl. Meranti Kampus IPB Darmaga Bogor 16680

*Email: luthfy.lacity@gmail.com

Abstract. This study was aimed to determine the relation changes in the subsidence and the depth of water level of peatlands cultivated with oil palm. The research site is the oil palm plantations in Koto Village, Gasib District, Siak Regency, Riau, Sumatera. The observations were in 4 blocks, namely block L1 (shrubs), Block D1 (oil palm aged 15 years), D8 (oil palm aged 10 years), and D31 (oil palm aged 20 years). Research parameters include peat subsidence and groundwater level. The results showed that the value of peat subsidence was fluctuative. This fluctuation was due to the rise and fall of the groundwater level. The highest rate of decline is shown in block L1 with 0.75 cm y⁻¹ with SD 1.03 and the groundwater level in D1 with 52 cm. The water level is influenced by the condition of the monthly rainfall. The correlation between land subsidence and peat water level shows a close and significant relationship (p <0.01, r = 0.871).

1. Introduction

Oil palm (Elaeis guineensis Jacq.) is one of the plantation commodities that has an important role in Indonesia as a vegetable oil and a renewable fuel (biodiesel) producer [1]. Currently oil palm plantations plays an important role in the Indonesian economy. In 2017, total area of oil palm plantations in Indonesia reached 12.30 million ha with an average productivity of 2.80 tonnes of CPO (crude palm oil) and 0.56 tonnes of PKO (palm kernel oil) ha⁻¹ year⁻¹ [2]. Oil palm plantations mostly developed on marginal lands including peat due to the limited availability of land suitable for oil palm cultivation. The potential of peatlands for oil palm plantation development is good enough if done properly, which is based on the level of land suitability and management according to land conditions. However, there are many conditions for oil palm planted on peatlands that resulted in low growth and production. This is due to the low or marginal suitability of the peatlands and poor land management [3].

The management of oil palm plantations on peatlands is faced with various problems, such as high acidity, relatively low soil fertility, easy-to-dry nature of peat soils, and physical characteristics of peat soils that have low bulk density [3]. The development of oil palm plantations on peatlands requires good water management. This system must be able to remove water surplus both on the surface and below the surface directly during the rainy season and also be able to hold water at a predetermined level range as long as possible during the dry season. This is important to be managed because logged
or excessive water can decrease the development of oil palm fruit, while lack of water will cause peatland degradation [4]. Drainage of peatlands is needed for better condition for plant growth. However, over drainage will lead to dryness of peatlands and cause hydrophobicity or irreversible drying [5]. Several research results suggest that the deep water level fluctuation of the peatlands, apart from having an effect on hydrophobicity, also affects the increase in soil CO2 emissions [6, 7], and peat subsidence [8, 9].

Subsidence is a phenomenon that inevitably occurs on peatlands which are used as agricultural land. Subsidence occurs because in its use, it is necessary to drain the soil by making water channels or drainage. Subsidence in peatlands initially occurs mainly as a result of consolidation and compaction of the peat material. Consolidation is the mechanical compaction of a permanently saturated peat layer or under the groundwater level, while compacting is a reduction in the volume of peat material in the layer above the water level [8]. On the other hand, subsidence is also caused by oxidation of the peat material, especially those above the groundwater level. Subsidence is an important issue in the use of peatland as agricultural land. According to [10], subsidence in peat soils is very high at the start of drainage and will gradually decrease over time.

This study was aimed to determine the relation changes in the subsidence and the depth of water level of peatlands cultivated with oil palm. This research is one of the studies on the emission factors of Indonesia's peatlands which are drained for oil palm plantations.

2. Methods

2.1. Study area

Research was conducted at oil palm plantation on peatland in Koto Village, Gasib District, Siak Regency, Riau, Sumatra, namely at coordinates 0° 44' 55.89" N / 101° 45' 14.04" E. The determination of the research location area was carried out using purposive sampling method, namely a method of determining the location of the study deliberately which is considered representative. The selected research sites was consisted of 4 oil palm planting blocks, namely block L1 (scrub), Block D1 (oil palm aged 15 years); D8 (oil palm aged 10 years); D31 (oil palm 20 years) (Figure 1).

![Figure 1](image_url)

**Figure 1.** Location of measurement and sampling in the scrub study area block (L1), oil palm 15 years old (D1), oil palm 10 years old (D8), oil palm 20 years old (D31).

2.2. Field Measurement and Sampling

This research activity includes observations and measurements in the field and laboratory analysis. The research locations are on the block for oil palm plants taken at 2 sampling points and the scrub blocks taken 1 sampling point. Research parameters include the depth of groundwater level and
peatland subsidence. The water level is measured with a piezometer. Peat subsidence is measured by installing a permanent iron rod in the peat soil to reach the peat substratum. Subsidence was determined by measuring the distance between the iron ring on the subsidence rod and the ground surface. This measurement is done by looking at the 4 cardinal points around the iron ring on the subsidence stick. Land subsidence and water level depth are measured in cm every 3 months in 1 year. All data are tabulated and presented in a table with standard deviation (SD).

3. Results and Discussion

3.1. Peat Characteristics.
Physical and chemical characteristics of peat are presented in Table 1. The thickness of the peat in the 4 observation blocks was varied from 300 to 650 cm. Bulk density (BD) gives an average value of about 0.25 to 0.12 g cm\(^{-3}\) with a SD of 0.056 in the total depth of peat, the average ash content was 5.53 to 2.21% in the upper layer with a SD of 1.68%, fiber content of 20.06 to 24.70 with a maturity level classified as hemic, and C-organic content of 55.02 to 56.73%.

| Observation Block | Dept (cm) | BD (g cm\(^{-3}\)) | Ash content (%) | C-organic (%) | Fibre content (%) | Maturity |
|-------------------|-----------|---------------------|-----------------|---------------|------------------|----------|
| L1                | 300       | 0.25                | 5.08            | 55.06         | 20.06            | Hemic    |
| D8                | 500       | 0.18                | 2.21            | 56.73         | 24.70            | Hemic    |
| D1                | 550       | 0.12                | 2.63            | 56.48         | 22.18            | Hemic    |
| D31               | 650       | 0.15                | 5.53            | 55.02         | 20.06            | Hemic    |

3.2. Subsidence.
The rate of peat subsidence is one of indicators of decreasing function of peat ecosystem. The subsidence of peat soil occurs due to the compaction, decomposition and erosion of the peat on the surface which causes the peat to become drier [11]. The data of peat subsidence based on field observations that have been carried out are presented in Figure 2. The average annual peat subsidence from October 2019 to October 2020 indicates that block L1 was the highest rate of subsidence, namely 0.75 cm y\(^{-1}\) with SD 1.03 compared to block D8, D1 and D31 with values respectively 0.08> 0.05> 0.003 cm y\(^{-1}\). It fluctuated in four measurements. The first measurement is in October 2019. In the second observation (January 2020) the value of peatlands subsidence increased in all observation blocks with an average value of L1> D1> D31> D8 with a value of 1.67> 0.89> 0.75> 0.18 cm. In the third measurement (May 2020), it shows that all observation blocks have decreased in subsidence value because in that month the peatlands is experiencing development, so the value of soil subsidence has decreased with an average value of L1> D8> D31> D1 with a value of -0.27 > -0.73> -1.24> -1.29 cm. In the fourth observation (October 2020) the value of land subsidence has increased again with successive values L1> D8> D31> D1 with a value of 1.60> 0.85> 0.70> 0.41 cm.
Figure 2. Subsidence from October 2019 to October 2020.

3.3. Water level Depth.
The data of the groundwater level is presented in Figure 3. Based on field observations, the fluctuation of the groundwater level in block D1 is the deepest compared to other observation blocks, namely L1, D8, and D31. The average groundwater level of D1 from October 2019 to October 2020 are -45.0, -66.5, -36.5, and -53.0 cm, respectively, with SD 15.02. The lowest groundwater level depths at L1 are -38.2, -36.0, 4.0, and -36.0 cm with SD 23.09. In general, the highest to the lowest average groundwater level is D1> D8> D31> L1 with a value of -52.0> -38.7> -37.2> -22.7 cm. Based on the measurement time, the highest groundwater level in all observation blocks occurred in October 2019 and the lowest was in May 2020.

Figure 3. Water Level Depth from October 2019 to October 2020.

3.4. Effect of Rainfall on Water-table Depth.
The dynamics of the rise and fall of water levels in peatlands are influenced by the balance of rainfall, evapotranspiration, and groundwater flows [12]. The data of the groundwater level at the research location is obtained from the data of 7 piezometers installed in each observation block. Fluctuations in
groundwater level which are strongly influenced by rainfall conditions in the study location are indicated by the same tendency from observations of water level with rainfall.

Figure 4 shows the fluctuation in groundwater level during the observation period (October 2019 to October 2020). The pattern shown by this graph has a tendency for groundwater level fluctuation to be directly proportional to the rainfall amount. The groundwater level showed high depth at the beginning of the observation (October 2019), then it decreased in November 2019 and returned to high in December 2019 to February 2020. The movement of the groundwater level has decreased again until its peak in May 2020 at the position 25.88 cm in August 2020 and then rises again until October 2020. When connected with monthly rainfall data, the rise and fall of the groundwater level that occurred in the period October 2019 to October 2020 shows that monthly rainfall can contribute directly to the rise and fall of the groundwater level in the study location. Response to groundwater level fluctuations does not occur directly based on rainfall data. There is a delay response to groundwater level about 1 month compared to variations in rainfall. This is presumably because the water resistance of peat soils is still quite strong, where the water does not immediately disappear after the rain stops. These results of the study are indicated by the results of the correlation analysis of groundwater level with rainfall showing a strong correlation with the value (p < 0.01, r = 0.734). This is consistent with the statement [13] that rainfall has a different effect on changes in the water level of peat lands.

3.5. Relation of Subsidence and Water Level Dynamics.

The peat subsidence in the study has a fluctuating value that is influenced by fluctuations in groundwater level. The results of the correlation analysis showed that the depth of the groundwater level showed a strong correlation and significantly different to subsidence (p < 0.01, r = 0.871). This is consistent with the research [14] which showed a correlation value of p < 0.01, r = 0.824. Thus, changes in the water level depth can affect peat soil subsidence and have a linear relationship with the subsidence rate [15]. A study [8] in Sarawak, Malaysia, states that in the average groundwater level of 100 cm, subsidence was up to 8 cm y⁻¹ and for an average groundwater level of 25 cm, subsidence was about 2 cm y⁻¹. This is presumably because the peat soil undergoes changes in anaerobic to aerobic conditions where in these conditions there is an acceleration of the process of peat decomposition and mineralization resulting in soil compaction [16, 17].
4. Conclusion
This study evaluates the data of land subsidence rate and groundwater level in oil palm plantations. This study found dynamics fluctuations in the rate of land subsidence at 4 observations. This is associated with fluctuations in the value of the water level, so that the subsidence of peat soil that occurs is strongly influenced by fluctuations in water level. This is followed by the significance and positive correlation between land subsidence and groundwater level. One of the causes of water level fluctuation is the monthly rainfall variation. So that in peatlands, the subsidence phenomenon does not always occur subsidence, but there is also an increase in land return as a result of an increase in groundwater level or as a result of replenishing groundwater.

Acknowledgements
Thank you to the employees of oil palm plantation in Riau for their support and permission for the research site, and the Indonesian Ministry of Finance through the oil palm research grant, the oil palm plantation fund management body (BPDP-KS) which has funded research activities.

References
[1] Ariyanti M, Yudithia M, Santi R dan Rachman A I 2019 Pertumbuhan Kelapa Sawit Belum Menghasilkan Dengan Pemberian Pupuk Organik Asal Pelepah Kelapa Sawit dan Asam Humat J. Pen. Kelapa Sawit. 27 71-82
[2] BPS 2018 Statistik kelapa sawit Indonesia 2017 Jakarta, ID: Badan Pusat Statistik. Retrieved from https://www.bps.go.id/publication/2018/11/13/b73f9a5de9f8d964d74635f/statistik-kelapa-sawit-indonesia-2017.html
[3] Winarna, R Farrasati, dan Agus S 2020 Pengaruh Fluktuasi Muka Air Tanah Terhadap Pelepah Bawah Mengering (Low Frond Desiccation) Kelapa Sawit di Lahan Gambut Labuhan Batu, Sumatera Utara J. Pen. Kelapa Sawit. 28 85-98
[4] Ginting E N, Darlan N H and Winarna 2016 Effective Water Management For Oil Palm In Peatland: For Peat Conservation And Yield Optimization 15th International Peat Congress 2016
[5] Winarna, dan H Santoso 2015 Penerapan Tata Air Terkini di Perkebunan Kelapa Sawit pada Lahan Gambut: Peningkatan Produktivitas dan Kelestarian Gambut Prosiding Pertemuan Teknis Kelapa Sawit (PTKS), The Alana Hotel & Convention Center, Yogyakarta, 19-20 Mei 2015, “Aplikasi Teknologi Terkini pada Industri Kelapa Sawit”
[6] Berglund O and K Berglund 2011 Influence of water table level and soil properties on emissions of greenhouse gases from cultivated peat soil SoilBiol&Biochem. 43 923-931
[7] Winarna, M A Yusuf, S Rahutomo dan E S Sutarta 2017 Dampak Muka Air Tanah dan Amelioran Terhadap Kelembaban Tanah, Emisi CO2 dan Produksi Kelapa Sawit Pada Lahan Gambut J. Pen. Kelapa Sawit. 25 147-160
[8] Wosten J H M, Ismail A B and van Wijk A L M 1997 Peat subsidence and its practical implications: a case study in Malaysia Geoderma. 78 25-36
[9] Ishikura K, Hirano T, Okimoto Y, Hirata Y, Kiew F, Melling F, Aeries E.B, Lo K.S, Musin K.K, Waili J.W, Wong G.X and Ishii Y 2018 Soil carbon dioxide emissions due to oxidative peat decomposition in an oil palm plantation on tropical peat Agriculture, Ecosystems and Environment. 254 202–212
[10] Hooijer A, S Page, J Jauhiainen, WA Lee, XX Lu, A Idris and G Anshari 2012 Subsidence and carbon loss in drained tropical peatlands Biogeosciences. 9 1053-1071
[11] Gronlund A, H Atle, H Adersand and P R Daniel 2008 Carbon loss estimate from cultivated peat soils in Norway: a comparasion of the methods NutrCycl Agroecosyst. 81 157-167
[12] Cobb A R, Hoyt A M, Gandois L, Eri J, Dommain, Salim K A, Fuu M K, Suut N S H and Harvey C F 2017 How temporal patterns in rainfall determine the geomorphology and carbon fluxes of tropical peatlands. Proceedings of the National Academy of Sciences of the United States of America. 26 E5187-E5196
[13] Runtunuwu E 2013 Development of Monitoring System for Groundwater Levels Peat for
Agriculture in Banjarbaru City, South Kalimantan Province *Jurnal Tanah dan Iklim*. 37 2

[14] Nusantara R W, R Hazriani and U E Suryadi 2018 Water-table Depth and Peat Subsidence Due to Land-use Change of Peatlands *IOP Conf. Series: Earth and Environmental Science*. 145 (2018) 012090

[15] Wakhid N, S Nurzakiah and Zainudin 2019 Dynamics of High Groundwater Levels on Burned Peatlands *EnviroScientiae*. 15 86-90

[16] Nieveen J P, Campbell D I, Schipper L A and Blair I J 2005 Carbon Exchange of Grazed Pasture on A Drained Peat Soil *Global Change Biology*. 11 607-618

[17] Hooijer A, Page S, Canadell J G, Kwadijk J, Wösten H and Jauhiainen J 2010 Current and Emissions from Drained Peatland in Southeast Asia *Biogeosciences*. 7 223-239