A critical contribution on understanding the mechanism and implication of peat irreversible drying

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Abstract. The term irreversible drying is known as a condition when peat soil material is dry and cannot be re-wet after an intensive drying. This condition is a result of peat soil hydrophobicity that occurs when a contact angle between peat soil particles and water is greater than 90° and is always understood to be associated with water content. However, in South Kalimantan, there was a phenomenon of irreversible drying but soil water content was still around field capacity and there was a visible coating substance on the particle surface. The purposes of this study were 1) to clarify the cause of irreversible drying in this location and 2) to show a possible effect of rock phosphate addition on the hydrophobicity’s disappearance. A hydrophobic peat soil sample was taken from the location that is cultivated for oil palm. Field observation was conducted on the peat soil that had been amended by rock phosphate. The peat soil hydrophobicity was identified by the Water Drop Penetration Time method and the surface coating substance was observed using SEM-EDS. The WDPT result shows that the peat soil was in hydrophobic condition, but the water content was still around field capacity. The results from SEM-EDS indicate that the coating substance was found as sulfate salts. The rock phosphate that had been added in the field shows a positive effect on the disappearance of the peat irreversible drying. However, the mechanism of soil properties change due to rock phosphate cannot be confirmed yet and need further investigation.

1. Introduction

Peat soil consists mostly of organic materials, which are partially decomposed vegetative tissue and other organic substances under wet conditions. One of the peat soil characteristics is irreversible drying. The term irreversible drying is known as a condition when peat soil material is dry and cannot be re-wet after an intensive drying. Irreversible drying is determined by soil hydrophobicity. The hydrophobicity can be characterized by the contact angle between solid particles and water. Hydrophobicity occurs when the contact angle is more than 90°. While, if the contact angle is greater than 150°, it is called superhydrophobic [1]. The peat soil which was formed from wood (fibric), herbaceous (hemic), and sphagnum (sapric) have the hydrophobic contact angle of about 122.1°, 116.8°, and 110.9° respectively [2].

There are several opinions about why peat soil loses its ability to absorb water (or hydrophobic). According to [3], irreversible drying is caused by resinous which covers the peat materials. On the other
side, [4] stated that Indonesia has no peat soil which is coated by resinous. Another opinion mentioned that irreversible drying due to the high content of functional groups such as carboxyl and phenol in peat soil [5]. [5] also stated that irreversible drying occurs in the condition of soil water content below the critical value.

In general, the irreversible drying term is always understood to be associated with water content. However, in a plantation area in South Kalimantan, there was peat soil that lost its ability to absorb water. A naked-eye observation noticed that there was a coating that made the peat become hydrophobic. That phenomenon had precluded the use of the land for agriculture. Surprisingly, after intensive soil fertilization by rock phosphate, the hydrophobicity problem completely disappeared. Hence, the purposes of this study were 1) to clarify the cause of irreversible drying in this location and 2) to show the effect of rock phosphate addition on peat hydrophobicity's disappearance.

2. Materials and Methods

The hydrophobic peat soil sample was collected from an oil palm plantation of PT Astra Agro Lestari in South Kalimantan. The sample was taken in depth of 0-40 cm. On the other moment, field observation was carried out on the hydrophobic peat soil that had been added by rock phosphate after 1.5 years. The whole analysis was conducted in the Department of Soil Science and Land Resources, IPB University and Soil Research Center Bogor, West Java, Indonesia.

2.1 Measurement and Observation

Measurement of the water content of sample in hydrophobicity condition was conducted by gravimetric method. The hydrophobicity observation was done using Water Drop Penetration Time (WDPT) method. This method is the easiest and most common to recognize the hydrophobicity of peat soil. The flat surface sample with a diameter of 3 cm was placed on the stative and clamp. In this analysis, the sample was dropped with distilled water (aqua dest) 3 drops. The time for water drops to penetrate the surface of the peat was recorded by the stopwatch. The time threshold in this WDPT method was 5 seconds. Theoretically, if the contact angle is greater than 90° and water drops remain on the surface, then the sample is considered to be at the hydrophobic condition. On the contrary, the hydrophilic condition refers to the contact angle of fewer than 90° when capillary force will pull the water into the soil. The classification of water repellency is shown in table 1. To test if the hydrophobicity is permanent, then the sample was dropped with NaOH and was observed for its re-wettability. The camera and microscope set were used to observe and record the hydrophobicity and the coating substance. The coating substance was identified by SEM-EDS. The SEM photos were used to examine the morphological appearance, whereas the EDS diffractogram was used to identify the elements. The SEM-EDS examination was carried out for one sample, but was done on two sides of the sample, namely, side A and side B.

| No. | WDPT (seconds) | Classification         |
|-----|----------------|------------------------|
| 1.  | <5             | Wettable               |
| 2.  | 5-60           | Slightly water repellent|
| 3.  | 60-600         | Strongly water repellent|
| 4.  | 600-3600       | Severely water repellent|
| 5.  | >3600          | Extremely water repellent|

*Based on [6]
3. Results and Discussions

3.1 Hydrophobicity vs Water Content of Sample from Study Site

Soil water content is a general indicator used to determine the occurrence of peat soil hydrophobicity. Peat soil naturally has a high water-holding capacity, which is associated with high porosity [7]. Peat soil can absorb and store water as much as 1-13 times its weight [8]. According to [9], the peat soil that suffered from excessive dryness become unwettable. According to [5], the critical value of water content of peat soil to become hydrophobic is around 118.42-223.33% w/w for sapric peat and 184.39-307.30% w/w for hemic peat. On the other hand, [10] mentioned that the condition of hydrophobicity (irreversible drying) can be found in the water content of less than 100% w/w.

Observation of contact angle of the sample (the hydrophobic peat soil from study site), based on WDPT, is presented in figure 1. The contact angle between soil particles and the water drops was 101°. According to the definition, it is greater than 90°, and therefore, the sample is considered to be at a hydrophobic condition. This hydrophobicity was classified in the class of extremely water repellent because the water cannot be infiltrated into the sample at the time of observation for 2 hours (table 1).

![Figure 1. Contact angle on hydrophobic peat soil](image)

In this hydrophobic condition, the water content of the sample was 248% w/w which is still in the range of field capacity. This phenomenon is in contradiction with the general theory which says that irreversible drying occurs at very low water content. It suggests that the irreversible drying occurred at the study site was not caused by a severe loss of water content, but there was another cause. Field observations with naked-eye indicated that the hydrophobic peat condition in this study location was coated by ‘some element’.

According to its name, irreversible drying means a soil condition that will not be able to re-wet. But in fact, when the pH of the sample was raised, the irreversible drying condition has been eliminated. In this experiment, when the hydrophobic sample surface was dropped with a NaOH solution pH 8, the sample became moister as shown in figure 2. It proved that the irreversible drying, in this case, is not permanent.
3.2 Coating Substance
The facts that the hydrophobic sample actually still has water content at around field capacity, the impermanent hydrophobicity when the pH was raised, and the visible appearance of the sample with the naked-eye observation (figure 3a) strongly suggest that the hydrophobicity in this study location was caused by a surface coating mechanism. There were white and slightly yellow colors on the hydrophobic sample surface. The microscope image that was captured by a camera is shown in figure 3b. The investigation revealed that the white materials were salts. Three possible types of salt are sulfate salts, phosphate salts, and chloride salts.

![Figure 3. The hydrophobic peat soil sample: a) naked-eye observation and b) observation under microscope](image)

The photographs of coating substance are presented in figure 4, 5, and table 2. The SEM’s photos in figure 4 show some crystals on the surface clearly. According to EDS diffractogram (figure 5), the elements in the coating substance on the side A of the sample are O, Si, Al, Fe, S; while the elements contained in the coating substance on the side B are O, Al, Fe, S, Zr, N. There are slight differences in the element composition between the two sides (both were of the same pad of the sample). However, the results show that S and O were common elements in the coating substance. Although the results of EDS analysis only determined the presence and relative portion of the elements, the presence of S, O, Al, and Fe all together in the coating substance strongly indicates that the white salt is a complex of Al and Fe sulfate.
The sulfate salts on the sample surface originated from acid sulfate contained in flooding water during flood season after long dry season. When the flood was over and the flooding water evaporated from the surface, then the sulfate salts crystallized. The source of acid sulfate in the flooding water was from acid sulfate soil around the peatland. The acid sulfate was a product of oxidation of sulfide minerals (predominantly pyrite) contained in the acid sulfate soil. At this point, the contact between acid sulfate and clay led the crystal of clay is broken resulted in dissolution of the clay elements, mostly Al and Si and other incorporate elements [11]. It proved why the salt discussed above coated the peat soil materials.

**Figure 4.** SEM results of sample on side A and B: a) magnification 500x, b) magnification 5000x, and c) objects for EDS
Figure 5. EDS Diffractogram of sample on side A and B

Table 2. The interpretation of EDS diffractogram on side A and B

| Side | Element | Unnormalised C (wt.%)* | Normalised C (wt.%)* |
|------|---------|------------------------|---------------------|
| A    | O       | 25.50                  | 59.23               |
|      | Si      | 11.51                  | 26.74               |
|      | Al      | 3.96                   | 9.20                |
|      | Fe      | 1.20                   | 2.78                |
|      | S       | 0.88                   | 2.05                |
|      | Total   | 43.06                  | 100.00              |
| B    | O       | 15.99                  | 66.61               |
|      | Zr      | 4.53                   | 18.90               |
|      | Fe      | 1.28                   | 5.33                |
|      | Al      | 0.93                   | 3.89                |
|      | S       | 0.72                   | 3.01                |
|      | N       | 0.54                   | 2.27                |
|      | Total   | 24.00                  | 100.00              |

* Unnormalised C (wt%)=unnormalised concentration in weight percent of element; normalised C (wt%)=the normalised concentration in weight percent of the element

3.3 Effect of Rock Phosphate on Hydrophobicity of Peat Soil
As the part of the plantation land management, rock phosphate (Ca₃(PO₄)₂) of 10 kg/tree, for the first time, had been added to the peat soil at the hydrophobic condition (1.5 years before field observation of this study was carried out). The addition of rock phosphate actually was aimed to increase the P element for oil palm growth and to neutralize the aluminum (Al), together with lime and other fertilizers (urea,
TSP, and KCl) application. The photograph of physical appearance after 1.5 years of rock phosphate addition is presented in figure 6.

![Figure 6. Peat soil after 1.5 years of addition of rock phosphate](image)

Surprisingly, the figure shows that after the first time of the rock phosphate addition, previously hard and dry soil mass was found become more friable and moister. It strongly indicates that the peat soil became hydrophilic and wettable. This fact suggests that rock phosphate had given a positive effect on the hydrophobic soils. The mechanism of the hydrophobicity disappearance in this study site is not clearly understood yet. However, it can be assumed that the change was a result of the interaction between chemical, biological, and physical processes involving the rock phosphate. It is indeed a necessity to do further research to clarify its mechanism.

4. Conclusion
Based on the discussion above, it can be concluded that:
1. Peat irreversible drying is not only caused by an extreme decrease in soil water content but also can occur because of the coating substance on peat surface by salts.
2. The addition of rock phosphate to a hydrophobic peat soil is strongly considered as the cause of the elimination of the hydrophobicity in that the hydrophobic peat soil was found to become more friable and moister.

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