Magnetic Susceptibility and Heavy Metal Content of Palm Oil Plantations Soil as a Function of its Depth

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Abstract. The magnetic susceptibility and heavy metal content of oil palm plantations soil has been determined. The magnetic particles of the soil were separated from non-magnetic particles using neodymium iron boron (NdFeB) magnet. The magnetic induction of the soil was measured using Pasco Probe PS-2162. The magnetic susceptibility value on the surface of the oil palm plantation soil varies between (685.99 to 1081.96) x 10^-5. This value is higher than the reference soil magnetic susceptibility that is 457.30 x 10^-5. The magnetic susceptibility values decrease as soil depth increases and at a depth of 40 cm the magnetic susceptibility value is close to the value of reference soil magnetic susceptibility. The X-Ray Fluorescence Spectroscopy (XRF) test result showed that the plantation soil has been contaminated with Cr, Fe, Ti, Sr, and V, this is in accordance with the magnetic susceptibility value of the plantation soil surface which is higher than that of the reference soil.

Keyword: Magnetic Susceptibility, Heavy Metals, Soil Depth, Oil Palm Plantation, X-Ray Fluorescence.

1. Introduction
Some oil palm plantations in Indonesia are planted on peat swampland with poor soil conditions and thus require fertilization process on an ongoing basis [1]. Soil quality is very important to support oil palm to growth. It is commonly known that excessive amount of heavy metals accumulation in oil palm plantation soils may affect plants product quality.

Riau Province has oil palm plantations covering an area of 2,424,545 hectares, with a production of 3,386,800 tons every year [2]. Peatlands are acidic with a pH <3.5 [3]. As a result, it needs to be fertilized continuously to increase soil nutrients and increase palm oil production. However, it also led to the increase in heavy metals content in soil and affects the levels of magnetic susceptibility ($\chi_m$) of the soil [4]. Soil depth also affects the content of the soil composition[5]. The magnetic susceptibility of soil or natural sand can be determined based on the total magnetic induction and magnetic induction of a solenoid [6]. In this paper, we report the magnetic susceptibility and heavy metal content of the soil of oil palm plantation in in TuahKarya Village, Kampar Regency, Riau Province, Indonesia.

2. Methods
Samples were collected from oil palm plantation land located in Tuah Karya Village, Kampar Regency, Riau Province, Indonesia. Soil samples were taken at the surface of the land for 100 points, while nine point samples were taken as a function its depth which is up to 50 cm. Neodymium Iron Boron (NdFeB) magnets were used to separate between magnetic particles and non-magnetic particles. Magnetic induction of the soil samples was measured using the Pasco magnetic Probe2162 equipped
with a solenoid. Based on this magnetic induction value, the magnetic susceptibility values can be calculated using the equation:

\[
\chi_m = \frac{B_T - B_0}{B_0}
\]

where \( B_T \) is total magnetic induction and \( B_0 \) is magnetic induction of the solenoid.

The magnetic susceptibility value of oil palm plantation soil is compared to reference soil which is taken from empty land far from the main roads so that it is avoided from air pollution and also away from residential areas so that the soil is free from waste in the form of heavy metals. The composition and heavy metal content in the soil was measured using XRF.

3. Results and Discussion

The results of the magnetic susceptibility of oil plantation soil and reference soil as a function of depth are shown in Table 1.

| Depth (cm) | Highest \( \chi_m \) (\( \times 10^{-5} \)) | Lowest \( \chi_m \) (\( \times 10^{-5} \)) | Reference soils \( \chi_m \) (\( \times 10^{-5} \)) |
|-----------|---------------------------------|---------------------------------|---------------------------|
| Soil surface | 1081.96 | 685.99 | 457.30 |
| 10 | 935.45 | 509.30 | 322.20 |
| 20 | 738.00 | 374.18 | 197.50 |
| 30 | 426.20 | 249.55 | 103.90 |
| 40 | 115.90 | 115.90 | 72.76 |
| 50 | 93.55 | 93.55 | 41.58 |

Figure 1. Dependency magnetic susceptibility of the soil to the depth. Solid line is the fitting plot.

From Table 1, it can be seen that the magnetic susceptibility value of plantation soil varies between (685.99 to 1081.96) \( \times 10^{-5} \), this value is higher than the reference soil magnetic susceptibility value that is 457.30 \( \times 10^{-5} \). The magnetic susceptibility is tend to linearly decrease over the depth. This is because the plantation soil is routinely given chemical fertilizers which higher distributed on the top soil [7]. It can also be seen that there is a decrease in the magnetic susceptibility value as a function of depth [8] and starting at a depth of 40 cm the magnetic susceptibility value is relatively the same. The difference in magnetic susceptibility values on oil palm plantation soil can be caused by the presence
of water erosion and deposition ratio [9] and is also influenced by magnetic particles which are mostly contained in the soil surface [10].

Table 2. The results of X-Ray Fluorescence (XRF) for plantation soil surface, 30 cm depth and reference soil.

| Depth (cm) | The content of the element (ppm) |
|------------|---------------------------------|
|            | Topsoil Surface | Depth 30 cm | Reference soil |
| Mg         | 17810           | 89850       | 6560           |
| Al         | 154640          | 126620      | 168140         |
| Si         | 708560          | 540560      | 783320         |
| P          | 27170           | 104260      | 9090           |
| K          | 17790           | 7370        | 1550           |
| Ca         | 8040            | 22710       | 3150           |
| Ti         | 34500           | 6390        | 12940          |
| Fe         | 12250           | 1580        | 9240           |
| Ni         | 60              | 70          | 20             |
| Cu         | 60              | 40          | 10             |
| Ag         | 5540            | 0           | 1700           |
| Zn         | 100             | 40          | 30             |
| Mn         | 70              | 0           | 30             |
| Cr         | 170             | 100         | 120            |
| Sr         | 130             | 0           | 30             |

The results of the XRF analysis of the oil plantation soil at the surface surface, 30 cm depth and reference soil are shown in Table 2. Table 2 shows that in general the elemental content on the surface of the oil palm plantation soil is higher than that of the 30 cm deep and reference soil, Silicon (Si) is the element with the highest content and Ni is the element with the lowest content.

The oil palm plantation soil contains of higher level of Aluminum (Al) which is very acidic (pH <3.5) so that Al is easily absorbed by the soil [11]. The second highest composition content is Silicon (Si). It is well known that Al and Si are not ferromagnetic element, the high levels of Al and Si do not affect the magnetic susceptibility value of the soil.

Theoretically, soil particles on the surface of the oil palm plantation are released and transported by water both into the soil and into waterways. At that time there is a process of sedimentation and the soil particle distribution, and therefore, the value of magnetic susceptibility is higher the surface and tends to decrease as a function of its depth. Beyond the depth of 40 cm the value of magnetic susceptibility is almost constant. However, the magnetic susceptibility values of soil from certain area and certain depth of oil palm plantation varies greatly in each soil depth [12,13].

The relationship between magnetic susceptibility and heavy metal content is shown in Table 3. This table shows the heavy metal content on the plantation soil surface and at a depth of 30 cm, as well as reference soil and threshold values are also included as a comparison [14,15].
Table 3. Heavy metals content of the samples.

| Element | Threshold value (ppm) | Topsoil (ppm) | At depth of 30 cm (ppm) | Reference soil (ppm) |
|---------|-----------------------|---------------|-------------------------|----------------------|
| Mn      | 100-4000              | 70            | 0                       | 30                   |
| Ni      | 10-1000               | 60            | 70                      | 20                   |
| Cu      | 2-100                 | 60            | 40                      | 10                   |
| Zn      | 10-300                | 100           | 40                      | 30                   |
| As      | 0.1-40                | 20            | 10                      | 10                   |
| Pb      | 2-200                 | 130           | 0                       | 20                   |
| Cr      | 75-100                | 170*          | 100                     | 120*                 |
| Fe      | 10,000                | 12250*        | 1580                    | 9240                 |
| Ti      | 50                    | 34500*        | 6390*                   | 12940*               |
| Sr      | 0.0001                | 130*          | 0                       | 30*                  |
| V       | 1                     | 310*          | 0                       | 30*                  |

Note:* indicates over the threshold (polluted)

The XRF results showed that Titanium (Ti) is the highest levels of the heavy metal and it is exceeded the threshold value up to 35,340 ppm and As was the heavy metal with the lowest levels. Some of the heavy metal content in the soil is obtained at levels that exceed the threshold level therefore, it is acknowledged as polluting metal such as Fe, V, Sr, Al, Cr, and Ti. It can be seen that in the reference soil there is also a composition that has exceeded the threshold value, namely Cr and Ti of 120 ppm and 13 ppm, however, they have a lower value than that of the soil sample.

High level of heavy metals in the oil palm plantation soil is due to the presence of high magnetic mineral which results from fertilizers, buried waste in the form of metals that are difficult to decompose in the soil and high absorption of metals by plants, while low levels of heavy metals are thought to be due to interactions between metals. Therefore, there is a resistance to absorption of these metals by soil and differences in soil pH and soil type also affect differences in the quantity of heavy metals [16].

The main contributor to heavy metals in plantation land is fertilizer, which causes the land to become contaminated. The most dominant elements contained in inorganic fertilizers are N, P and K [17]. The compounds contained in fertilizers contain a lot of heavy metals so that these heavy metals increase along with the increasing quantity of fertilizer use on the soil [18]. Heavy metals continuously pollut the soil, making the heavy metals in the soil unbalanced and then easily absorbed by plants through the roots. Heavy metals are difficult to break down so they are toxic. Heavy metals that have the potential to cause pollution to the environment and soil are Fe, As, Cd, Pb, Hg, Mn, Ni, Cr, Zn, and Cu [19].

4. Conclusion
The magnetic susceptibility at the topsoil surface is higher than that for a certain soil depth and the reference soil. This is due to the routine and continuous usage of chemical fertilizers to oil palm plantations soil. Continuous application of fertilizers also causes an increase in heavy metal content, this is confirmed by the XRF test results.
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