Physical Simulation for Effect Seasons and Fertilizer on Solidified Fabric Peat Soil; A Soil Column Model Study

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Abstract. Soil stabilization is a method to improve the weakness of fabric peat soil structure which is a result of larger particle size pore. Therefore, the fabric peat soil is solidified using mixture of cement, fly ash and bottom. The present study aimed to investigate the physical simulation of soil column model as a response for affecting the wet and dry seasons and fertilizer on the solidified fabric peat soil. The column model was investigated by analysis the water leaching micronutrient using atomic adsorption spectroscopy (AAS). The results revealed that the nitrate has the highest concentration (35.55 mg/L) on Run 3 (Fabric, rainwater, solidified peat and fertilizer) at upper area in the dry season. In comparison, potassium (K) recorded the lowest concentrations (1.14 mg/L) on Run 2 (fibric, rainwater and fertilizer) at upper area in the wet season. The highest (22.92 mg/L) and lowest (0.10 mg/L) calcium was recorded on Run 3 and Run 2 with both at upper area in wet season. These findings indicated that the chemical binder used as stabilization soil influenced the nutrient quality especially calcium which is one of the major compound materials in cement.

1. Introduction
Peat represent a challenging soil due to the low engineering properties compared to other soft soils. Therefore, the peat stabilization is necessary for restoring the soil structure to accommodate the load. Peat and organic soil can be classified according to the degree of humification or decomposition. Fibric peat is the least decomposed soil with 67% of the fibre content. In contrast, the hemic layer is an intermediate decomposed, while the sapric layer is the most decomposed with less than 33% of the fibre content [1]. The decomposition of the organic content in the peat soils is depended on the density, depth and functionality of the drains, water regime and soil hydraulic properties, land-use and climate as well as the structure and composition of the peat [2]. The combination of soil stabilization materials with characteristics of peat should be leading to enhancing the soil strength compressibility and permeability for the construction involving.

Cement is the main additive binder which is used for peat soil solidification. Kalantari and Prasad [3] used cement as a basic material to improve the strength of peat soil. However, Wong et al. [4] claimed that the kaolin is used as a natural pozzolan replacing cement applications. Kazemian et al. [5] used sodium silicates as filler to be compatible with cement and get strong bonding properties. Fly ash (FA) and Bottom ash (BA) combined with Ordinary Portland cement (OPC) which are waste product of coal power plant after the combustion process has been used for the solidification of the peat by Rahman and Chan [6]. The utilization of FA and BA for soil stabilization promotes sustainable construction through reduction of greenhouse gases and reduction of energy use [7]. Besides, FA has great potential...
for construction purposes as low-cost alternative to Portland cement and other stabilizers because of its pozzolanic properties. Das and Yudhbir [8] stated that the strength of solidified soil was enchanted by using cement or lime indicates pozzolanic FA reaction occurred due to the dependence on carbon content, fineness and the quality and quantity of glassy phase in the FA. FA is classified into class F and C, Class F of FA is used for soil stabilization by adding another activator such as lime or cement, while class F differ substantially compared to Class C which can give more stability [9]. BA serves as filler in soil stabilization process due to the density, grain size distribution, shear strength, compaction and hydraulic conductivity [10]. The unconfined compressive strength of mixed soil, bottom ash, and cement increase with the increase of BA content due to the frictional resistance and the pozzolanic effect [11].

The efficiency of the peat solidification is depended on the resistance for the environment factors such as rainfall which might effect on the stabilized soil due to the chemical composition and the pH of the rainwater [12]. The fertilizer might also interfere the strength of the binder especially in the palm oil plantation area, nitrogen, phosphate rock, potassium chloride and kieserite are among the fertilizers used [13]. The use of excessive fertilizers for long term might contribute to reduce soil organic matter (SOM) content resulting a decrease in the quantity of agricultural land and increasing soil acidity. OPC, FA and BA are alkaline which can be affected by soil acidity attributable to the use of fertilizer minerals. In this study, the erosion of soil stabilization materials through water leaching process using a physical model was investigated to simulate the environmental effect of rainwater and fertilizer.

The movement of nutrients in soil is controlled by water transport through the soil. Water is added naturally to the soil through the precipitation process. The movement of nutrients in the soil is closely related to the leaching mechanism. Rainfall is known as the main cause of leaching process. Nakamura [14] stated that nutrient leaching is considered to occur mainly during high precipitation or during irrigation activities. The water is homogeneous with nutrients from the fertilizer down the gradient from the region of higher to lower potential energy. This is because some nutrients are soluble in the water. The significance of the nutrients and water movement through the soil profile involves the process of infiltration. Infiltration is the process whereby water percolates into the soil structure from the surface. There are two main factors affecting infiltration which are the rate and hydraulic conductivity [15]. The infiltration rate is determined by the interaction of a number of physical and chemical soil characteristics. In addition, soil properties vary from one location to another and changes over time due to cultural practices, water management and biological processes are also other factors that influences the soil infiltration rate within surface irrigated field [16].

2. Materials and Methods

2.1. Sampling
The fibric peat soil samples were collected from Parit Baru, Batu Pahat, Johor, Malaysia. The process begins by manually identifying the soil using Von Post Scale. The peat soil samples were placed in bins and covered with plastic bags. The samples were taken to the laboratory for soil segregation process, the fiber that greater than 1 cm was removed from the container. Then, the wet peat was sieved through 2 mm sieve size. The physical and chemical characteristics of collected samples (Moisture content, Liquid limit, Specific gravity, Bulk density, Acidity and pH) were determined according to BS1377: Part 2 [17] while fiber content test was done in accordance to ASTM D 1997-91 [18].

2.2. Peat solidification process
The moisture content in the cement was removed by drying the cement at 105°C. The amount of cement was calculated based on dry weight of peat soil. BA and FA were obtained from local coal power plant at Pontian, Johor. BA was passed through 2 mm sieve. BA was oven dried at 105°C for 24 hrs to ensure moist free.

The peat samples were mixed with binders and filler using food mixer for soil less than 2 mm together at low speed for 1 minute followed by medium speed for another 4 minutes. The preparation of soil solidification was focused on the mixture between peat and solidified materials. The formulation used was based on previous study by Rahman and Chan [6]. The OPC mixture value was calculated to be
equal to the dry mass of the peat while the bottom ash in the range of 23 - 34% of the total mixture. The value for fly ash was set to 25% fly ash of the total mass of binder.

The Physical and chemical properties of solidified materials (Moisture content, specific gravity and pH) value were determined according to BS1377: Part 2 [17].

2.3. Peat soil column design

Peat that free from foreign objects was remoulded in soil column by hand layer by layer. The solidified peat placed in the middle upper part of the soil column in UCS testing size (38 mm diameter × 76 mm height) as represents the soil surface in the field. The presence of rainwater stimulates nutrient and metals in solidified peat to come out to the surrounding peat in the soil column. The dimension of the soil column was 280 mm height and 110 mm diameter and consist of 4 outlets as illustrated in Figure 1. The difference between the outlets was 70 mm from the top and bottom of the soil column. The rainwater was used to simulate the actual conditions on the site. The rainwater is entered from the upper area which is the soil surface, then the process of infiltration is occurred in soil structure. The duration of one run is depends on the soil condition where the movement of water is using gravitational force. The water source is divided into two season which are dry season, 100 mL and wet season of 1500 mL based on intensity of rainwater during the peat collection as Table 1. As peat is commonly fully saturated during raining season and even inundation in heavy rain, a volume of fully saturated in the soil column was reversely calculated to get the amount of water needed for dry season simulation based on rain water intensity report obtained from Malaysian Meteorological Department [19].

Figure 1. Schematic diagram of soil column with peat and solidified peat use in study
Table 1. Intensity of rainwater during the peat collection

| Season       | Rainwater intensity | Calculation       |
|--------------|---------------------|-------------------|
| Dry season   | 49 mm (Rainwater intensity on July 2017) | 49 mm = 110 mL |
|              |                     | Therefore, 110 ml ≈ 100 mL |
| Wet season   | 120 mm (Rainwater intensity on January 2017) | 120 mm = 1520 mL |
|              |                     | Therefore, 1520 ml ≈ 1500 mL |

2.4. Leaching experiment
The method was used based on the falling head permeability method (ASTM D 2434) suitable for soil with low discharge for very fine grained of soil. The water leaching was undergone a filtering process before to analytical process by using Atomic absorption spectroscopy (AAS) and Ion Chromatography (IC). The test run that involved are fibric and rainwater (Run 1), fibric, rainwater and fertilizer (Run 2) and fibric, rainwater, fertilizer, solidified peat (Run 3) (Table 2). The calculation of amount of fertilizer used was based on Table 3. The water leaching micronutrient including (Potassium, Calcium, Sodium and Magnesium ions) was determined using atomic adsorption spectroscopy (AAS), while nitrate and orthophosphate in the leaching water was determined according to APHA [20].

Table 2. Operational design for simulation run in this study

| Simulation          | Constant                               |
|---------------------|----------------------------------------|
| Run 1               | Fabric and rainwater                   |
| Run 2               | Fabric rainwater and fertilizer        |
| Run 3               | Fabric, rainwater, fertilizer, solidified peat |

Table 3. Calculation amount of fertilizer used

|                          | Data on field (personal interview to local farmer) | Data based on laboratory scale |
|--------------------------|---------------------------------------------------|--------------------------------|
| Size of surface area of soil | 1 acre = 4.047 × 10⁹ mm²                         | 6.362 × 10³ mm²               |
| Amount of fertilizer used | 50 kg                                             | 6.362 × 10³ mm² × 0.01235 × 10⁻³ g |
|                          | 50 kg ÷ 4.047 × 10⁹ = 0.01235 × 10⁻³ g           | = 0.07857 g fertilizer        |
|                          | Then, 1 mm² 0.01235 × 10⁻³ g fertilizer          |
| Total fertilizer used in soil column | 0.07857 g ≈ 0.08 g |

3. Results and Discussion
The physical and chemical properties of fibric peat investigated in the present study is illustrated in Table 4. It can be noted that the moisture content of peat was low, this is contrary to the nature of the fibric that is able to store more water than hemic and sapric. The retaining of water in peat is influenced by the pore size to make the water tied between the soil particles to fill the empty space [17]. Fibric peat is generally located on a soil surface layer, hemic is middle layer and sapric which represents the lowest layer in soil. Therefore, fibric are susceptible to sunlight to stimulate evaporation. This is related to the time and area that sample were collected.
Table 4. Physical and chemical properties of fibric

| Properties          | Value | Standard                  |
|---------------------|-------|---------------------------|
| Moisture content, % | 171.9 | BS1377 Part 2 : 1990      |
| Fiber content, %    | 68.8  | ASTM D 1997-91            |
| Liquid limit, %     | 251   | BS1377 Part 2 : 1990      |
| Specific gravity    | 1.10  | BS1377 Part 2 : 1990      |
| Bulk density        | 9.20  | BS1377 Part 2 : 1990      |
| Acidity, pH         | 3.8   | BS1377 Part 2 : 1990      |

The fibre content indicates for the less decomposition which is carried out from activity of microorganisms forming soil particle where generally increases with depth below the ground surface [21]. This makes the geometric mean pore diameter and active porosity simultaneously decrease. The peat soil is generally acidic for all type of peat. The extremely low pH because of fiber content and high organic content which make the soil pH reduces to low level [22]. However, there is no clear guidance on pH value when it involves all three types of peat soil. Environmental factors are a very important parameter in influencing soil acidity through the use of chemical fertilizers [21].

The binders and filler were free from the moist to prevent hardening reaction to occur. Chemical reactions such as pozzolonic are able to stimulate the material to become hard and strong when there is presence of water [7]. The specific gravity is closely related to identify the porosity of every substance where the material is denser if the porosity is low. Table 5 shows that the specific gravity in binder where cement is 1.26, fly ash is 1.13 meanwhile bottom ash is 2.3 as filler. However, there is no fixed value that can be used as a guide for specific gravity due to parent materials influences. Rezanezhad et al. [23] indicated that the specific gravity of fly ash and bottom ash from Tanjung Bin power plant were 2.3 and 1.99 respectively. Meanwhile, studied by [24] shows fly ash and bottom ash in the same plant were 2.19 and 2.39.

Table 5. Physical and chemical properties of solidified materials

| Properties       | Binder | Filler | Standard                  |
|------------------|--------|--------|---------------------------|
| Moisture content | Free from moist | Bottom ash | BS1377 Part 2 : 1990      |
| Specific gravity | 1.26   | 1.13   | 2.30                      | BS1377 Part 2 : 1990 |
| pH value         | 12.36  | 11.55  | 9.17                      | BS1377 Part 2 : 1990 |

The discussion is focus at two areas which are outlet 1 representing upper area and outlet 4 representing lower area on actual site. Each run also implies two different season which are dry and wet. The difference of season is to identify if water is affects the solidified peat and nutrient or vice versa.

The standard of nutrient in the soil is not yet set for Malaysian guideline. The most closely related is Safe Drinking Water Act (SDWA) standard established by The Environmental Protection Agency (USEPA). In this study, nitrate is use as a guide for other elements to set the standard limit for analysis.
and discussion purposes. The Environmental Protection Agency (USEPA) set 10 mg/L as the maximum concentration allowed in contaminant level for nitrate (NO\textsubscript{3}\textsuperscript{−}) according to Safe Drinking Water Act (SDWA) standard. Meanwhile, the Environmental Quality Standards Regulations (1999) suggested 0.4 mg/L for orthophosphate (PO\textsubscript{4}\textsuperscript{3−}) and 10 mg/L for potassium (K\textsuperscript{+}) in groundwater standard limit.

Generally, all of the run at upper area either in dry or wet season is more than 10 mg/L (Figure 2). Nitrate is one of the elements that contained in total nitrogen (TN) which is very important for plant intake nutrient and present in the form of NO\textsubscript{3}\textsuperscript{−}. The combination of nitrate (NO\textsubscript{3}\textsuperscript{−}), nitrite (NO\textsubscript{2}\textsuperscript{−}), ammonia (NH\textsubscript{3}), and organic nitrogen in the soil can be form total nitrogen (TN) as the main element. Basically, nitrite in the soil occurs naturally and tend to be converted to nitrate thus making it more stable. Nitrite levels in water are generally negligible due to its low value. The present of nitrate in groundwater can affect human health if used as drinking water. The Safe Drinking Water guide can be used as a guide in controlling pollution covering surface water and groundwater due to the more sensitive limit. The lower area also shows most of the concentrations is more than safe drinking limit standard except on Run 2 in dry season and Run 1 in wet season with concentration 7.27 mg/L and 5.28 mg/L respectively. One of the factors that high concentration of nitrate is caused of peat soil is collecting directly from the field where the environment is surrounded by oil palm activity. Agriculture activity is well known by using of chemical fertilizer to increase productivity [26]. According to Zhou et al. [27], chemical fertilizer is the main source of causing the increasing used where the average fertilizer use from 169 kg / ha to 390 kg / ha with nitrogen is major based from 1983 to 2005 in northern China.

Peat soil is like a sponge that can retain of high water volume especially in the wet season. In addition, fibric peat has a large of pore size and void space ratio so it can store water between particles of soil [19]. Then, the nutrient is combine together with water and store in soil making food for plant. However, when compared between dry and wet season, the concentration is reduced of 21.1%, 21.53% and 47.47% on Run 1, Run 2 and Run 3 respectively at upper area. This could be probably of rate of concentration is high when the water volume present is low. The presence of a lot of water makes it easier for the element combined and transport to others area.

Run 1 in dry season is involved of the highest increased and decreased in percentage when compared between upper and lower area of 29.51 % and 56.58 % respectively. The effect of SP on environment or vice versa can be evaluated through concentration of element on run before and after. The highest in difference between Run 2 and Run 3 increase of 74.63 % at lower area in dry season. Although SP is present on run after, the concentration of NO\textsubscript{3}\textsuperscript{−} is increased because of the used fertilizer on run before and after as main medium. Chemical fertilizer contributes to NO\textsubscript{3}\textsuperscript{−} increase in soil where soil's capacity to hold and exchange mineral nutrients. Peat is a soil that has a high CEC as a guide to potential for greater adsorption of cations [28].

![Figure 2](image-url)  
*Figure 2. The concentration of main macronutrient in comparative of test run for upper and lower in different season.*
PO₄³⁻ shows the concentration that more than 10 mg/L is on Run 1 with concentration 14.13 mg/L. Beside that Run 2 and Run 3 occurred in wet season, with concentration 18.18 mg/L and 22.14 mg/L respectively at upper area while at lower area with same season shows the concentration are 14.49 mg/L and 24.13 mg/L respectively. According to Tomašić et al., [29], the soil with large number of negative charges can be attract, retain and hold exchangeable cations easily especially the soil that have high content of organic matter in conducting CEC process. In addition, the run that involved in physical simulation was using fertilizer as medium thus making the soil sample capable in storing additional nutrient. Therefore, not much micronutrient is leach out in Run 1 and 2 as it still retain in the soil particles.

The highest percentage in increasing concentration when compared between dry and wet is on Run 3 at lower area of 70.37 %. Basically, the element can be considered higher in dry season compare with wet season. However, beside water, soil texture can also influence the infiltration process. The permeability is active on soil with mobile pore system and move via large macro pores [30]. Boylan et al. [31] stated, the pore sizing in fibric peat generally large up to 10 μm promoting high in permeability of water through soil structure. The comparison in PO₄³⁻ between run before and after also found that Run 2 and Run 3 at lower area in wet season have the highest percentage of increment of 39.94 %.

The last element in main macronutrient is K where the concentration that more than 10 mg/L is on Run 3 in wet season and occurred both in upper and lower area. The concentration for upper is 34.23 mg/L and lower is 28.50 mg/L. K is a dominant element in supplying nutrient to soil. This does not explain that K does not important in supplying nutrient, but this could be probably related to several factors such as percentage of nutrient composition in fertilizer. Beside of fertilizer composition, concentration of potassium in soil depends on the release of K from soil minerals produced naturally [30].

The percentage between Run 2 as run before and Run 3 as run after is consider high where increased as much as 96.61 % at upper in wet season. This indicates that the presence of solidified peat can affects concentration of K in soil. However, the pollution of potassium in air dust can be spread over the soil through first rainfall and infiltrated to groundwater [32]. Besides that, microorganism activity also plays a role in the nutrient cycle. The low of pH promoting of microbe activity where they grow actively at pH less than 5.55 [33]. This is in accordance with the condition of peat soil which is generally acidic. The presence of solidified peat has less impact due to the greater peat ratio than solidified peat.

The concentration of micronutrient element in difference area generally does not exceed of standard limit where for Na⁺, Mg²⁺ and Ca²⁺ in groundwater are 150 mg/L, 30 mg/L and 250 mg/L respectively based on Environmental Quality Standards Regulations 1999. Referring to Figure 3, Run 3 at upper area in wet season and Run 1 at lower area in dry season are the run that involved of high concentration of 22.92 mg/L and 11.57 mg/L respectively.

![Figure 3](image.png)

**Figure 3.** The concentration of secondary macronutrient in comparative of test run for upper and lower in different season.
Basically, the calcium among an element that form in compound to assists in cement strength. The common compound that presence in cement is calcium oxide (CaO) where is among the major composition oxide in OPC [34]. Ca that present in solidified peat materials is able to retain more in soil. This is parallel with the result where SP is applied to the upper area and contributes to increased concentration. Usually, the dry season causes high concentrations in soil due to limited water supply. However, the presence of a lot of water in wet season helps an element move to another area. Then, water is being able to transport more concentration in every single angle of soil and leach out from soil column. The comparison at upper area in wet season between Run 2 as run before and Run 3 as run after also shows there are consider as high difference of 99.56%. This is clearly show calcium in SP contribute to high concentration.

The calcium concentration was high in wet season for Run 3 is due to more water available in weakening the cementitious product in solidified peat but it retain on upper level due to capillary effect and absorption capability of the fabric peat.

4. Conclusion
The results revealed that Ca, is a major element that exists in cement and ash has shown a positive value in increasing concentration despite being included in the micronutrients group. The higher of difference in calcium between run before and after in wet season at upper area explain the present of SP can affect concentration value. Beside SP’s position, wet season has helped transport the calcium in SP to leach out from soil column in the upper area. However, the increase of NPK in macronutrient partly is due to the use of fertilizer as an additional medium for simulation testing. This is common when it comes to the field where farmers use chemical fertilizers as the main used of nutrient supply.

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