Effect of Rainfall Patterns on Concentration Of CO₂, Soil Temperature And Matric Suction For Acidic Barren Soil

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Abstract. This study is based on field monitoring of a soil-atmosphere toward on acidic barren soil. CO₂ in the cavity are dependent on climatic parameters, mainly on the outdoor temperature during rainfall. Observations were taken over a longer period of time. Maximum CO₂ values in the barren slope are reached in the warmest months and are in accordance with soil CO₂ values. The maximum CO₂ concentration in the barren slope is 3022 ppm on average, while the minimum is 2438 ppm. To describe the field findings, CO₂ production and diffusion experiments related to the soil behavior were developed. The results showed that the soil CO₂ production increases as the soil temperature and matric suction increase. The relationship between the gas diffusion coefficient and soil water suction is necessary data (i.e. water evaporation or CO₂ evolution above the soil surface).

Keywords: matric suction, slope, CO₂, rainfall, temperature.

1.0 Introduction
The surface soil layer plays a key role in all these processes [1]. On the one hand, it is the responsible for the CO₂ production, which depends on weather conditions and soil physical, chemical and biological properties [2], such as organic matter content, the abundance of microorganisms, type and density of vegetation, etc. On the other hand, soil constitutes the primary interface through which liquid and gas pass between the outside atmosphere and the underground environment. This fluid transfer (i.e., gas and liquid movement) occurs through the soil pore network and is affected by the physical properties of soil, such as density, texture, pore network, mineral composition and organic matter content, among others. In addition, fluid transfer is also regulated by the degree of moisture in the soil, which in turn depends on the infiltration processes whereby water enters the soil and adds to the total soil moisture [3].

2.0 Materials and methods
2.1 Site description
The cut slope was located at the Research Centre for Soft Soil which is a new Research and Development (R & D) initiative by Universiti Tun Hussein Onn Malaysia. The soil sample was collected from Ayer Hitam barren acidic soil [4][5]. From that, the area of soil embankment was constructed with the length of 5 m and the width of 5 m at the bottom. Meanwhile, the small area at the top section which has 1 m length and 1 m width was built for installation of monitoring
instrument and as a working platform. The height of embankment is 1.2 m whereas the angle of the slope is 30°. The diagram of the embankment for barren soil is shown in Figure 1.

![Figure 1. Schematic diagram of scale embankment from the top view](image)

2.2 Field instrumentation monitoring program
To monitor the CO₂ and temperature changes in the slope, the Watermark Soil Moisture Sensor was installed at 20 cm depth(Figure 2). Since rain gauges were used in this study, rainfall data were monitored using a Data-Logging Rain Gauge, WatchDog 1120 (Figure 3).

![Figure 2. Watermark Soil Moisture Sensor are installed.](image)

![Figure 3. Data-Logging Rain Gauge.](image)
2.3 Soil properties
A series of laboratory tests were conducted in determining the soil properties by which the soil type and geotechnical properties can be characterized as presented in Table 1. The main physical index properties of the soil investigated in this study is soil classification. It depends on several factors such as the moisture content, permeability test, in situ density test (Core Cutter Method), specific gravity, Particle Size Distribution, and Atterberg Limit of the soil.

| Composition                  | Value     |
|------------------------------|-----------|
| Moisture content (%)         | 28        |
| Permeability (m/s)           | 7.45x10^-7|
| Bulk density, \( \rho_b \) (Mg/m³) | 1.517   |
| Dry density, \( \rho_d \) (Mg/m³) | 1.426   |
| Specific gravity, Gs         | 2.70      |
| Liquid Limit, LL             | 46        |
| Plastic Limit, PL            | 27        |
| Plasticity Index, PI         | 19        |
| Void Ratio, e                | 0.756     |
| Porosity, n                  | 0.431     |
| Dry unit weight, \( \gamma_d \) (kN/m³) | 15.08  |
| Saturated unit weight, \( \gamma_{sat} \) (kN/m³) | 19.3 |

3.0 Results and discussions
Results were analyzed and tabulated to point out brief respiration of the barren soil physically and mechanically.

3.1 Effect of rainfall intensity on the CO2 content and temperature of the soil.
Data from the barren soil were collected from August 13th to August 20th, 2017 (Figure 4). During this period, the total amount of rainfall was 36.2 mm. Immediately after the first rainfall episode, the CO2 concentration has increased (from 2637 to 2700 ppm in 17 h) in the soil. According to Pla et al., [6] when the rainfall episode started, the soil takes time to become saturated since it has already contained a considerable amount of water. Therefore, transportation of water is faster initially (Figure 4). This result was supported by Kabwe et al.[7] They showed that the CO2 gas efflux was dramatically reduced after heavy rainfall events, however, the impact was of relatively short duration.
On August 16th, in response to the rainfall episode, soil CO₂ has changed from 2458 to 2462 ppm. On the following days, the amount of water in soil was substantially higher than the mean annual value due to the continuous influx of water, which also affected the soil temperature [8]. The last and most significant rainfall event (27.5 mm) was occurred on August 19th. After the occurrence, the CO₂ concentration in the soil decreased until August 21st. Under other circumstances, i.e., without rain, the natural CO₂ trend would have decreased during this period of time [9].

Figure 5 shows a typical soil temperature plot. As depicted in this figure, the temperature fluctuates from 21°C to 31°C. Although the plot seems to show a considerable scatter but the general trend is that there is a decrease in temperature due to the rainfall [9]. Likewise, there is a decrease in soil temperature due to the rainfall.

3.2 Relationship of temperature and CO₂ on matric suction

Figure 6 below shows the relation between matric suction on CO₂ and temperature of the soil. The reading was taken after the rainy event occurs for one hour. It showed that an increase in temperature increases the matric suction. The pattern was supported by Nguyen et al., [9] where the magnitude of the temperature rise depends on the amount of water in the porous ceramic matrix, and in turn depends on the matric suction. In other words, the temperature rise is a function of matric suction with the relation of R² = 0.983. In addition, during dry seasons matric suction increases due to the net loss of water. In contrast, the soil has a net gain of water during the wet season and therefore the matric suction decreases [11]. At the temperature of 22.2°C, the measured matric suction is about 108 kPa. The suction rises to about 117.7 kPa when the temperature reached 24.5°C.

Regarding the relationship between suction and CO₂, the matrix suction is directly proportional to CO₂ as a function of R² = 0.9621. Because the soil is close to saturation point, almost all the pore space is filled with water, and thus the gas fluxes (e.g., CO₂ and O₂) are expected to be reduced significantly [7]. It should be noted that the free diffusion coefficient of CO₂ is about four orders of magnitude larger in air than in water [12]; diffusive transport in the water-filled pores is much slower than that in the air-filled voids.
Hashimoto, in 2004 [13], stated that the gas diffusion coefficient changes with air porosity and soil water content, which in turn is affected by soil water suction. The relationship between the gas diffusion coefficient and soil water suction are of necessary data for various simulations (i.e water evaporation or CO2).

3.3 Relationship of CO2 and soil temperature
Higher temperatures lead to higher levels of CO2, and vice versa as shown in Figure 7. It is predicted that the increase in the atmospheric [CO2] will lead to increases in air and soil temperatures [14]. Possible high temperature will promote soil respiration, that is to say, the release of CO2 to the atmosphere [15]. According to Hashimoto[13], soil CO2 profile depends on gas diffusivity and CO2 production within the soil. CO2 increase with increasing temperature. In addition, the increment of the CO2 gas gradient with increasing temperature is caused by the increment of CO2 production in soil. The CO2 in soil is strongly controlled by soil temperature and moisture [16].

4.0 Conclusion
In the current study, the effects of heavy rainfall events on the near surface water contents and the resultant CO2 efflux were investigated. Results showed that the CO2 gas efflux was dramatically reduced after heavy rainfall events but the impact was of relatively short duration. To quantify the total CO2 emission, all information about the underlying controls upon respiration from different soil and vegetation were important (e.g. soil disturbs and rainfall intensity). On the other hand, the main factor influencing the soil respiration is soil temperature, because the soil respiration followed the same pattern as the temperature, while rainfall only caused a brief disturbance in the soil.
respiration. Rainfall seems to contribute only by creating favorable conditions for a quick decrease in temperature and consequently the respiration followed the physical effect of soil water percolation. Soil CO₂ diffusion is also strongly linked to the soil pore space, which is responsible for the gas movement that depends on the water saturation. Soil temperature and moisture directly affect soil CO₂ production although different patterns have been found for different time scales. While daily CO₂ soil cycles are mainly controlled by the soil temperature, for the longer CO₂ time scale, the direct relationship between the soil temperature and the soil CO₂ disappears.

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