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Suction Variation of a Single Mature Tree on Top of Tropical Residual Soil

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Abstract

This paper investigates the suction variation induced by a single mature tree situated a top tropical residual soil, focusing on its impact on soil moisture content along a slope, where the tree's water uptake generates matric suction within the surrounding soil. A field monitoring program was conducted to collect matric suction data at the slope with two conditions: in the absence of a tree; and with a tree located on top of a tropical residual soil slope. The variation in both matric suction values and matric suction profiles response to the tree water uptake and rainfall are investigated. Matric suction significantly increased in the vicinity of the tree on top of the slope compared to the slope without a tree. The variations of matric suction response due to climate change occur significantly at the swallow of the slope and decrease gradually with depth. The decreases of matric suction occur after a long duration of intense rainfall. This was an initial condition before the water uptake driven by the active root tree generated the maximum matric suction (low moisture content). Analyses from matric suction profiles revealed that the majority of matric suction variation were greater near tree trunks (< 4.4 m) and at shallow depths (0.25 m). The contours of matric suction profiles are presented to reveal moisture flow due to tree water uptake. This investigation provides that the viewed contribution of a single mature tree significantly alters the matric suction or moisture variation distribution driven by transpiration in an unsaturated soil slope. It considers that preserving mature trees can improve soil properties in modern slope designs.

1. Introduction

The root system plays an important role in extracting nutrients and water for the germination of trees [1], [2]. The loss of moisture from the soil may be categorized as water used for transpiration due to metabolism in plant tissues and water evaporated to the atmosphere [3]–[5]. The total water transpiration can be assumed to be the same as the water uptake through the root zone [6]. Therefore, soil suction from water uptake by tree roots can significantly change the soil moisture near the vicinity of the tree. In this study, matric suction generated by trees was measured, and water uptake by plant roots was treated as a sink term distributed in the active root zone. The tree has developed different adaptations and strategies to acquire water to transpire and photosynthesize such as deep-water uptake, stomata closure, and water storage [3], [7]–[10]. Hence, this transpiration water uptake becomes one of the most important mechanisms influencing water availability in soils (e.g., depletion of available water from soil).

Biddle [11] conducted intensive and comprehensive studies that assuming the active root zone has extended until a depth of 2 m and a radial of 5 m both left and right. The pattern soil moisture deficit contour involves soil moisture transfer of various tree species. Also, Biddle [11] has found that the significant soil moisture contour varies by tree type and is not influenced by soil clay type. In tropical country such as Malaysia, the tropical monsoon rainfall and particularly dry season can reflect a soil moisture pattern. If these data become available, the hypothesis can be made within the result and analysis which can reveal the correlation the effects of tree with meteorological data.

This paper presents the results of matric suction monitoring for a slope located at Pahang Matriculation College. This slope exists in two conditions (with and without a tree on top of the slope) to understand the difference in soil matric suction generated at that slope. The field evidence of matric suction changes was observed at the slope with a tree on top and slope without a tree to provide reliable data. The influence of tree-induced suction was emphasized to reveal the soil suction distribution pattern around the tree.

2. Research Methodology

This section discusses the methodology for the research involving fieldwork and field monitoring procedures for the study. In the early stage, the research was initiated by reviewing the published works by previous researchers regarding the suction collected for a slope with a single mature tree located on top of the slope. Furthermore, analysis of important parameters and types of variables was also identified during the data collection stage.

2.1 The Study Area

This study was carried out at a slope with the existence of a mature tropical tree, namely Alstonia Angustiloba, situated at latitude (+3°43'12.53"N) and longitude (103° 4'31.00" E). The tree was located on top of the slope at Pahang Matriculation College, as shown in Fig. 1.

Fig. 1 *Study area at Pahang Matriculation College*

The initial condition of soil materials for the water uptake analysis was established by determining the matric suction and rainfall distribution in this study area [4], [6], [8], [9], [12]–[14]. Fig. 2 shows the cross-sectional view of the tensiometer and gypsum block installed at Pahang Matriculation College.

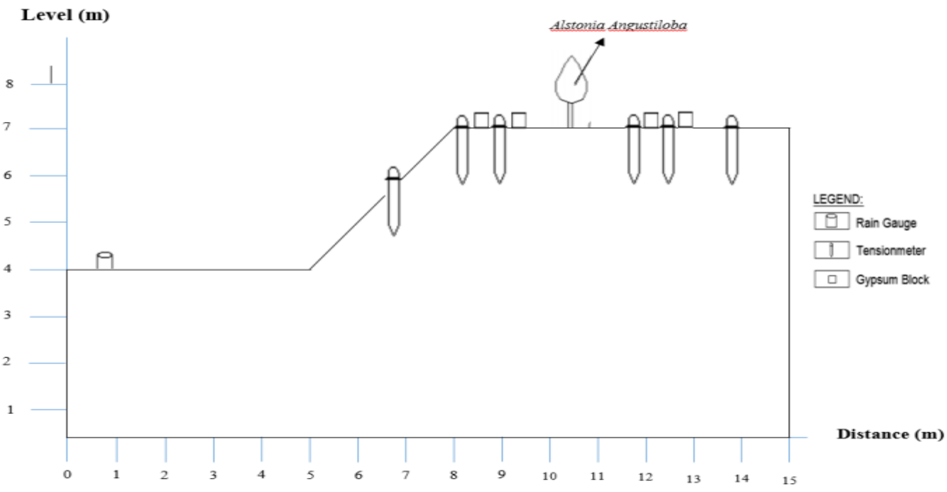


Fig. 2 *Cross-sectional view of research plot design at Pahang Matriculation College*

These field works were divided into six (6) stations, which are flat area 1 (FA 1), flat area 2 (FA 2), flat area 3 (FA 3), slope area 1 (SA 1), slope area 2 (SA 2) and slope area 3 (SA 3). Fig. 3 shows the image of the tensiometer installed at the monitored slope, which tensiometer was installed at flat area (FA) in Fig. 3(a), while the tensiometer was installed at slope area (SA) as presented in Figure 3(b). Fig. 4 shows the layout of a single mature tree (Alstonia Angustiloba) located on top of the slope with several installed monitoring equipment.

(a) **(b)**

Fig. 3 *(a) Tensiometer installed at flat area (FA); (b) Tensiometer installed at slope area (SA)*

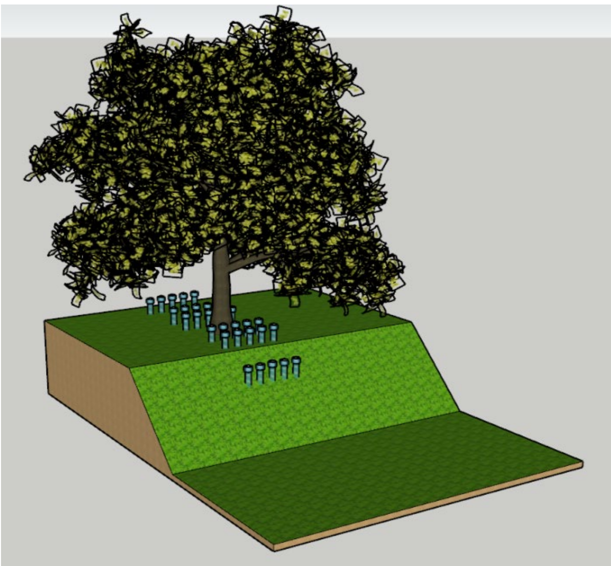


Fig. 4 *Single mature tree (Alstonia Angustiloba) located on top of the slope with several installed monitoring equipment*

Fig. 5(a) shows the image of the tensiometer, while Fig. 5(b) shows the image of a gypsum block reader. This equipment was installed into the soil close proximity the tree, which will absorb or release the moisture into the soil until the moisture approaches equilibrium with the soil's moisture. This equipment works as an instrument to measure the force by which water is trapped in the soil within the soil particles [9], [15], [16]. The measurement of how tight the water was bound in the soil and how much energy the tree's roots needed to use and remove water is known as soil suction. Tensiometers are commonly used in the field of instrumentation to measure the matric suction of soil (0-100 kPa), while gypsum blocks measure suction (0-1000 kPa). Tensiometers are the most precise and direct method when measuring suction below 100 kPa. For a gypsum block, the suction reading below 100 kPa is not as accurate as tensiometers, as shown in Table 1.

(a) **(b)**

Fig. 5 *(a) Tensiometer; (b) Gypsum block reader*

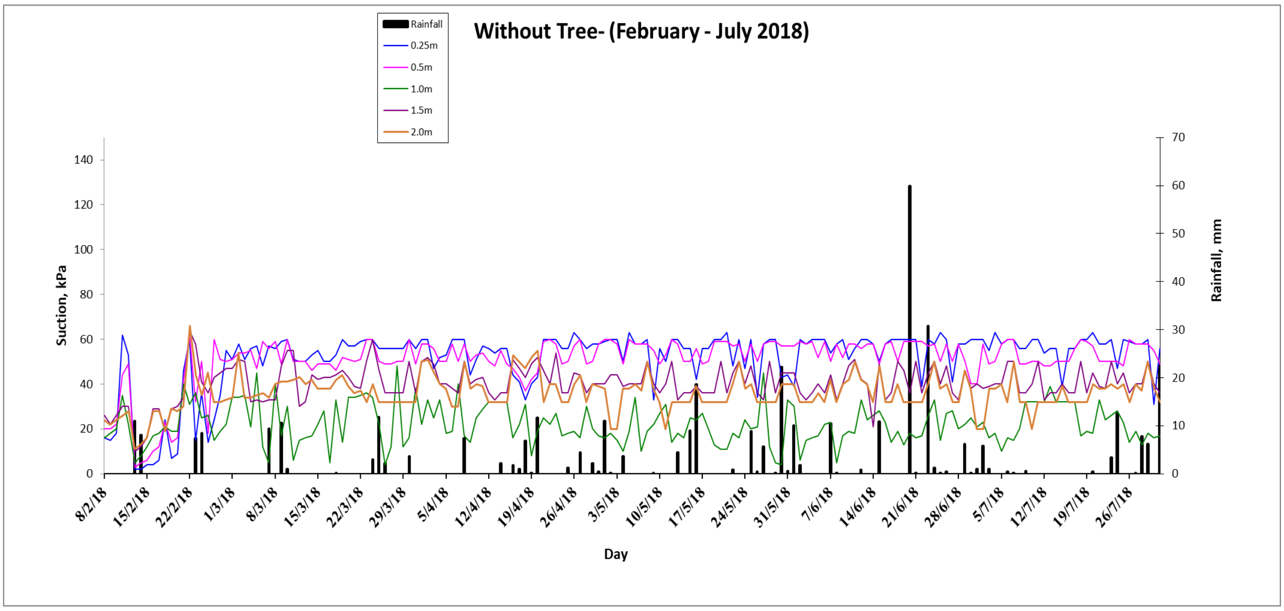
Table 1 *Technical detail of instrument at the study area*

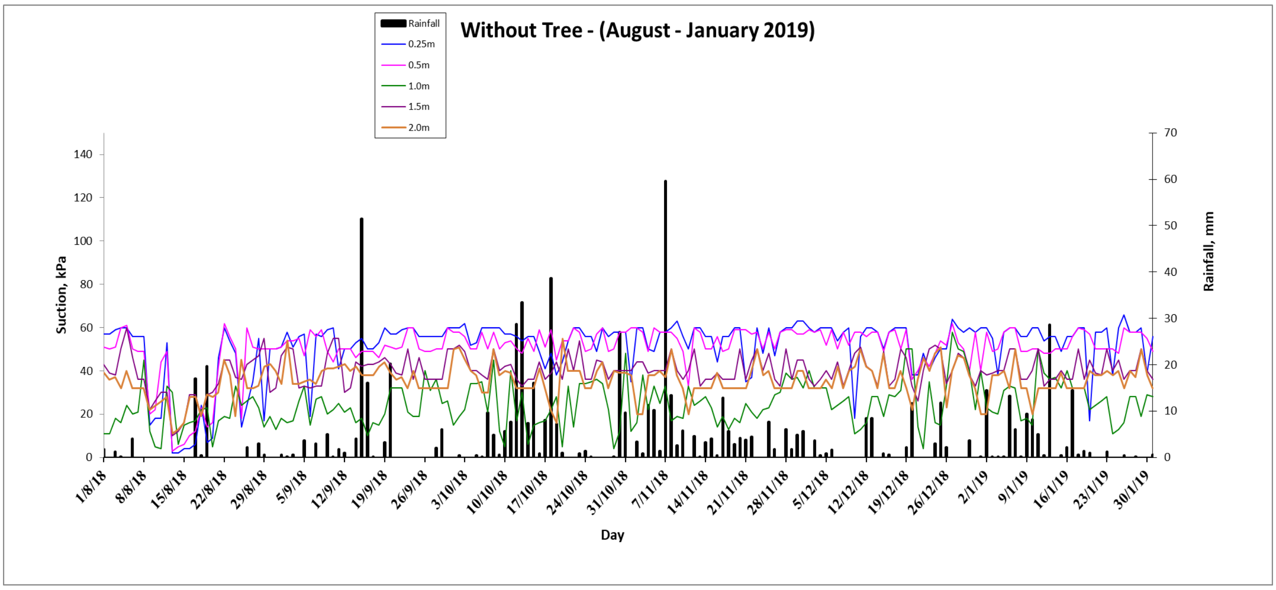
Instruments	Manufacturer	Accuracy
Field Tensiometer	Soil Moisture Equipment Corp. [17]	± 2 kPa
Gypsum Block	Delmhorst Instrument Co. Model 5KS-D1 G-Block [18]	± 5 kPa

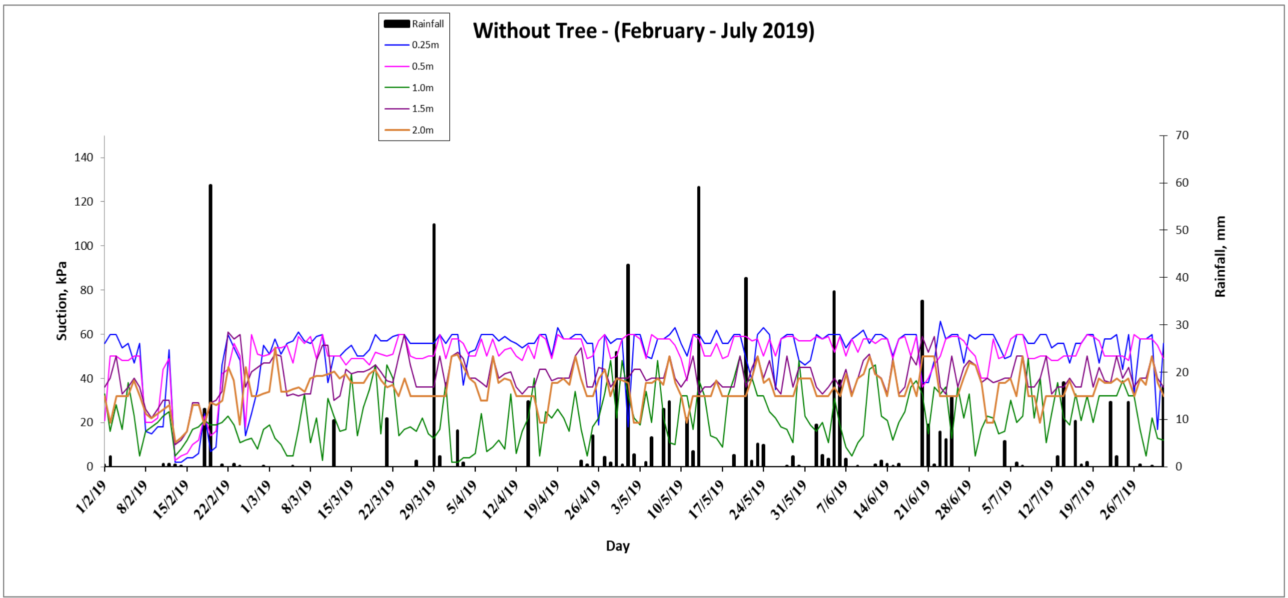
3. Result and Discussions

This section presents the results of soil suction (kPa) Vs. daily rainfall (mm) collected at the study area. This field monitoring work of 2 years, presenting the variability of daily suction at Pahang Matriculation College. Fig. 6 represents the field monitoring of matric suction in response to rainfall distribution at slope without trees during the monitoring period. The data obtained during the monitoring period containing negative pore-water pressure or matric suction, response as a result of overall annual trend of rainfall events, with the effect on water uptake from transpiration process of single tree located on top of slope at the study area.

In the accompanying graph, five (5) lines represent suction readings at various depths; the blue line corresponds to 0.25 m, the purple line to 0.5 m, the green line to 1.0 m, the dark purple line to 1.5 m, and the orange line to 2.0 m. The rainfall data is displayed as a bar graph for comparative analysis.







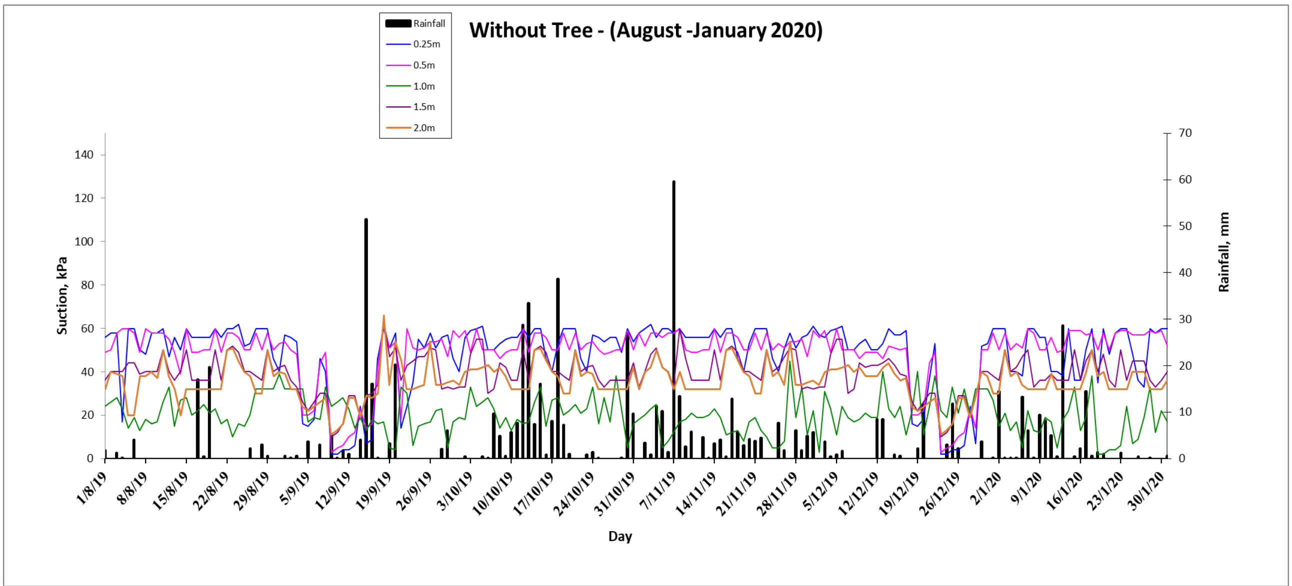
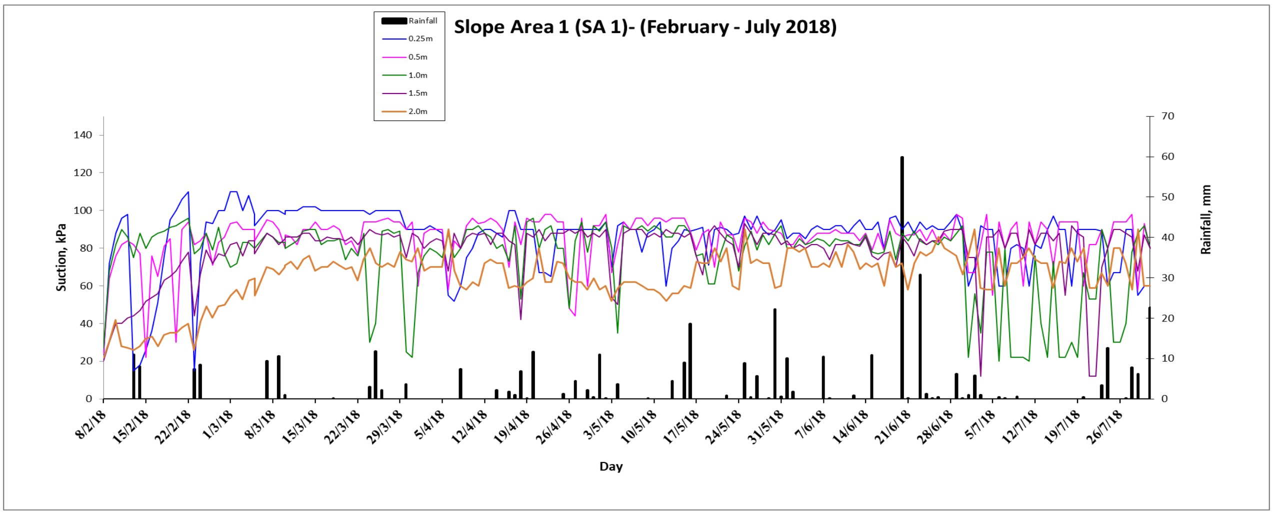


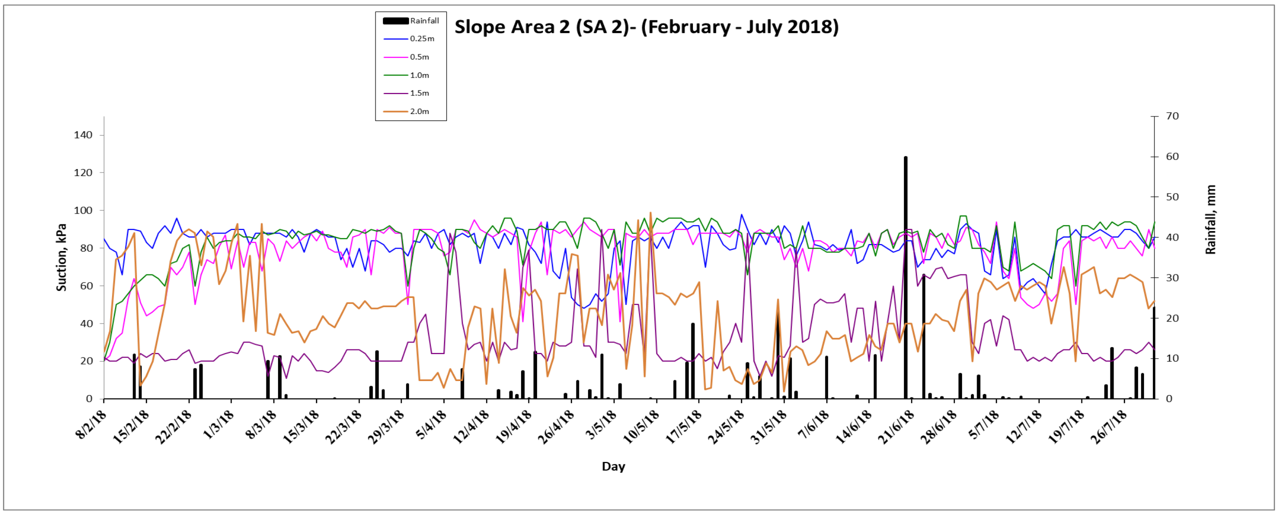
Fig. 6 *Field monitoring of matric suction with respond to rainfall distribution at slope without tree during monitoring period*

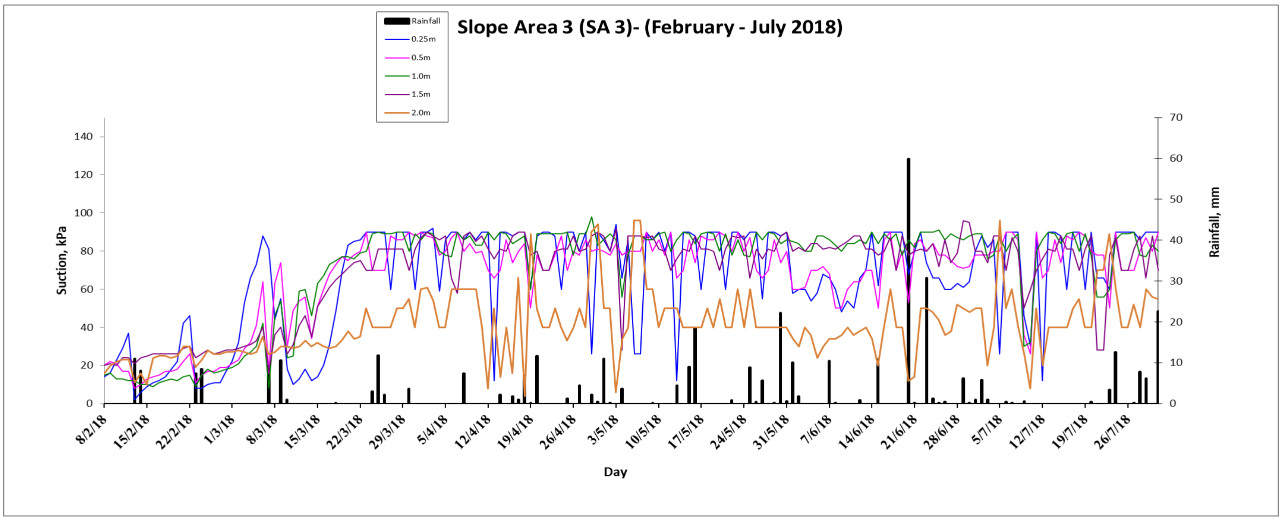
The results from field monitoring showed that daily suction is higher during the afternoon compared to data obtained early in the morning. For slope without the influence of the tree, the highest suction value recorded in this study area was 66 kPa at the depth of 2.0 m, while at 0.25 m depth, the suction recorded was 60 kPa. Two weeks (14 days) are needed for suction to increase to its maximum value without rainfall due to the evaporation process. According to Ishak [8], Lee et al. [19] and Kassim et al. [20], dry soil conditions affect the maximum matric suction for the correspondence to approximate residual water content in SWCC.

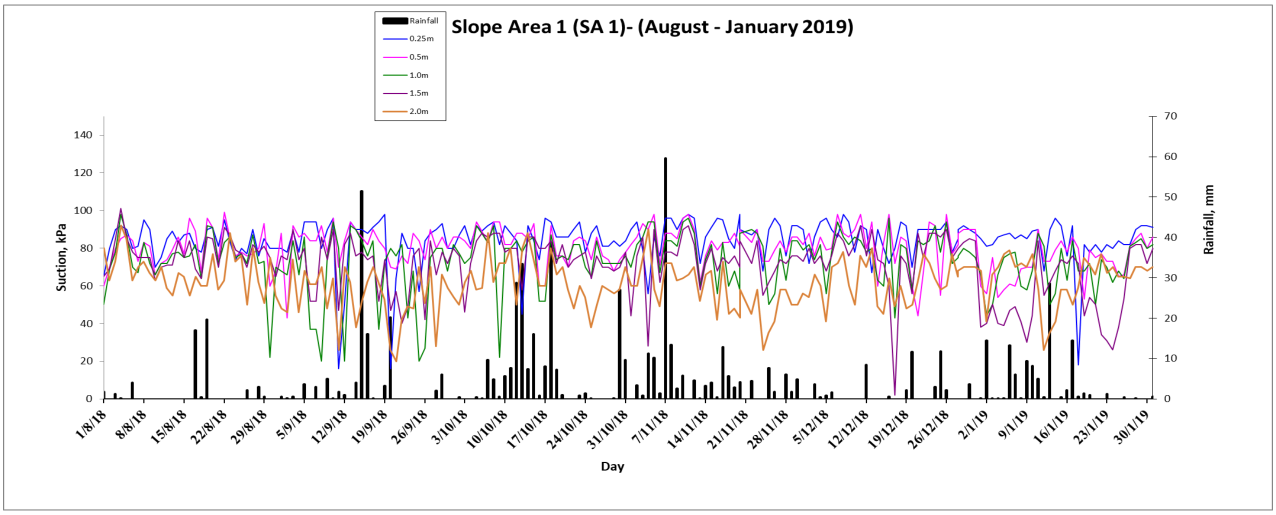
The data collected from all six stations (slope area 1 (SA 1), slope area 2 (SA 2), slope area 3 (SA 3), flat area 1 (FA 1), flat area 2 (FA 2) and flat area 3 (FA 3)) for the period of two (2) years which equivalent to 24 months were used in the analysis of this study. Fig. 7 and Fig. 8 show the matric suction for slope areas 1, 2 and 3 and flat areas 1, 2 and 3, respectively. Field monitoring results combine data from suctions (tensiometers and gypsum blocks) and rainfall data. Five (5) lines in the figure represent suction readings with different depths (0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m), while the bar graphs presented rainfall events.

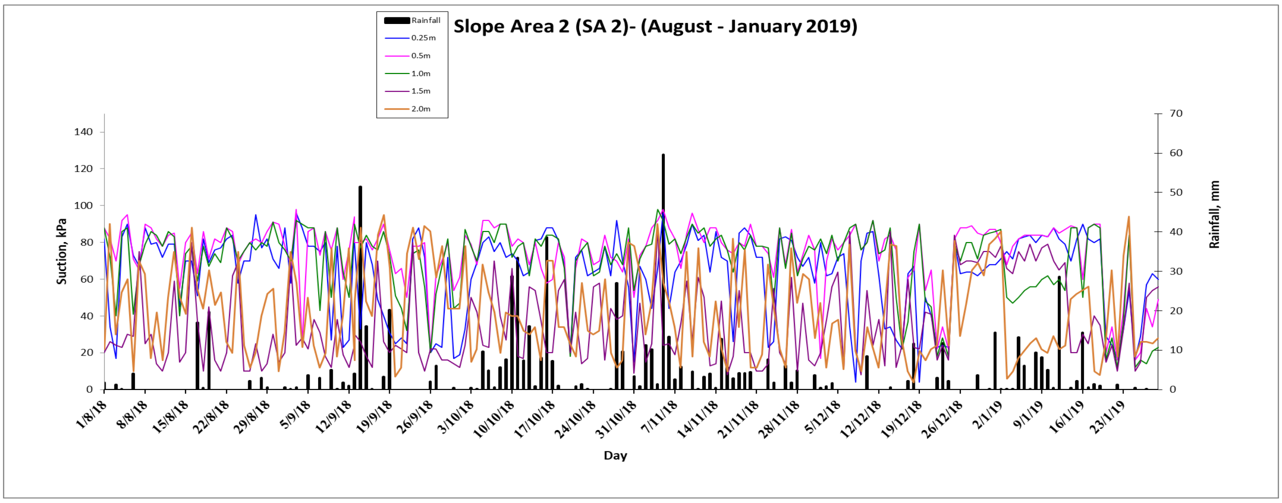
Fig. 7 presents the field monitoring of matric suction in response to rainfall distribution at slope areas 1, 2 and 3 during the same monitoring period.

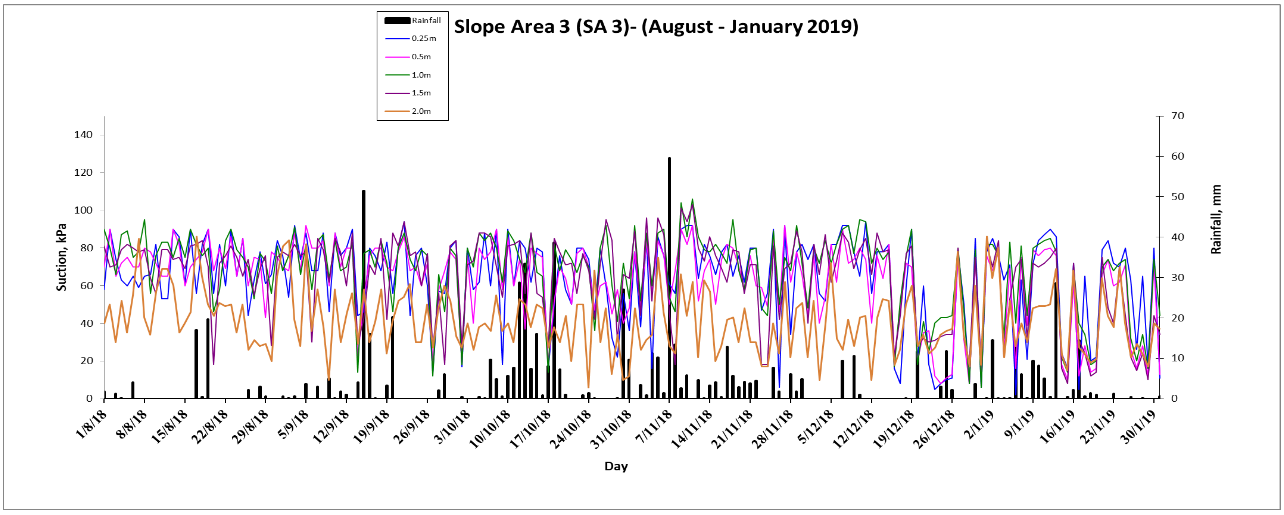

Slope Area 1 (SA 1)- (February - July 2018)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Slope Area 2 (SA 2)- (February - July 2018)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Slope Area 3 (SA 3)- (February - July 2018)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Slope Area 1 (SA 1)- (August - January 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Slope Area 2 (SA 2)- (August - January 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Slope Area 3 (SA 3)- (August - January 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day

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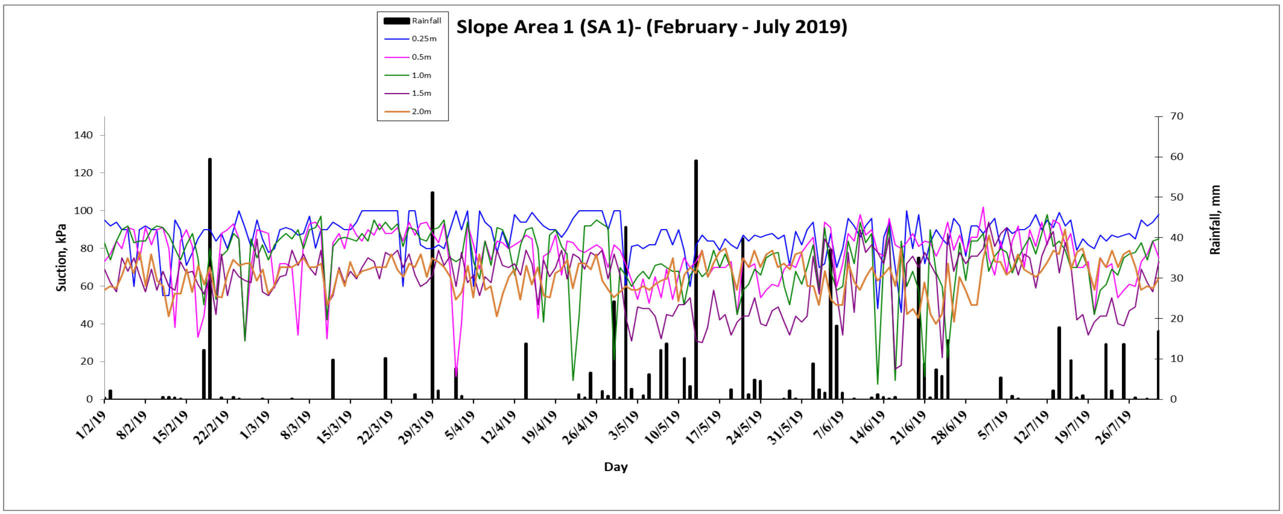
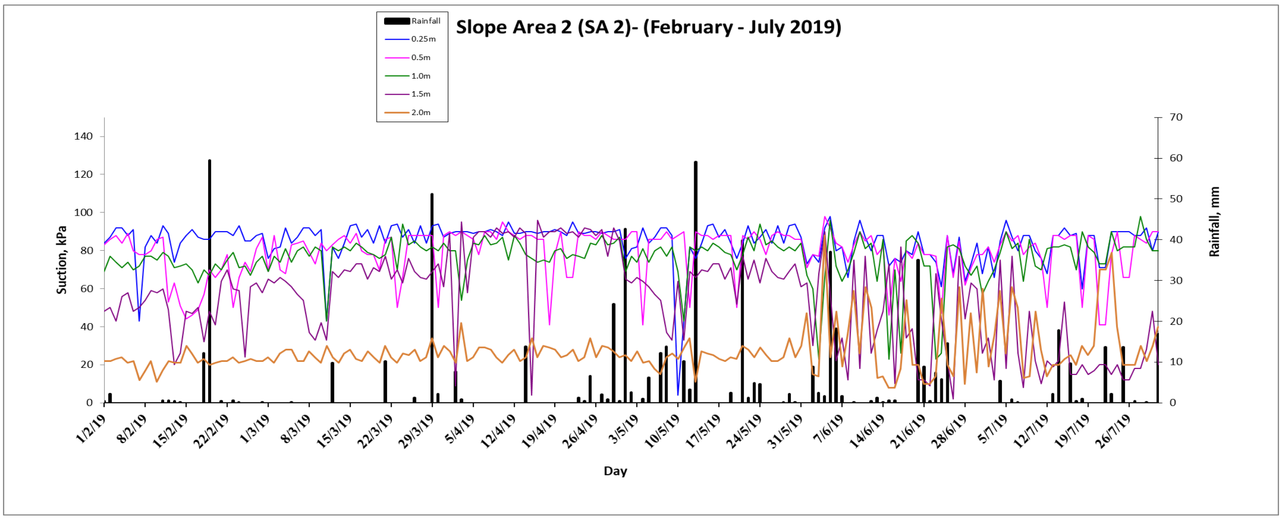
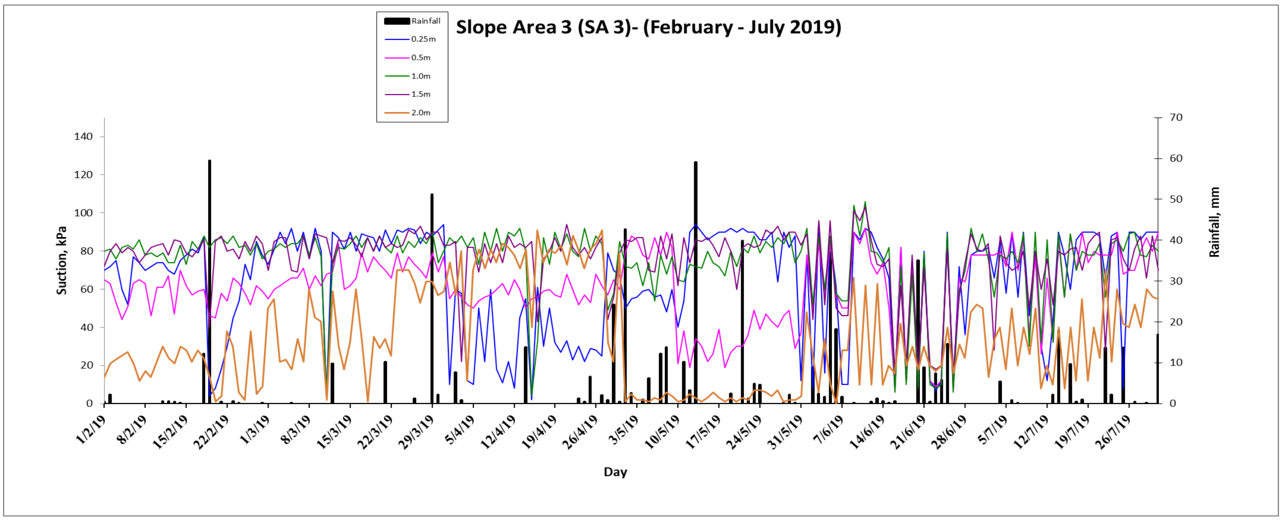
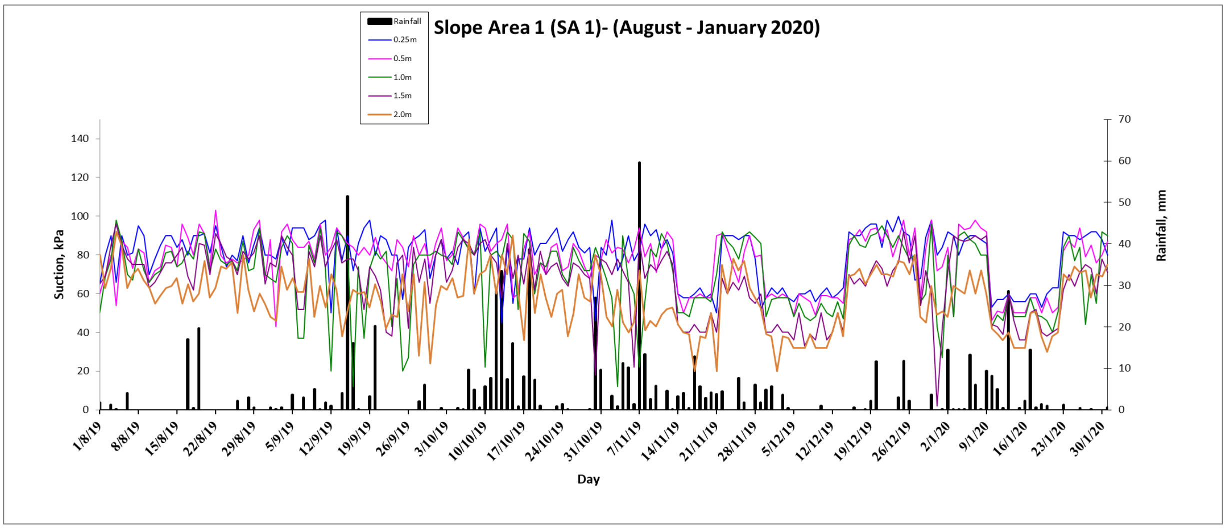








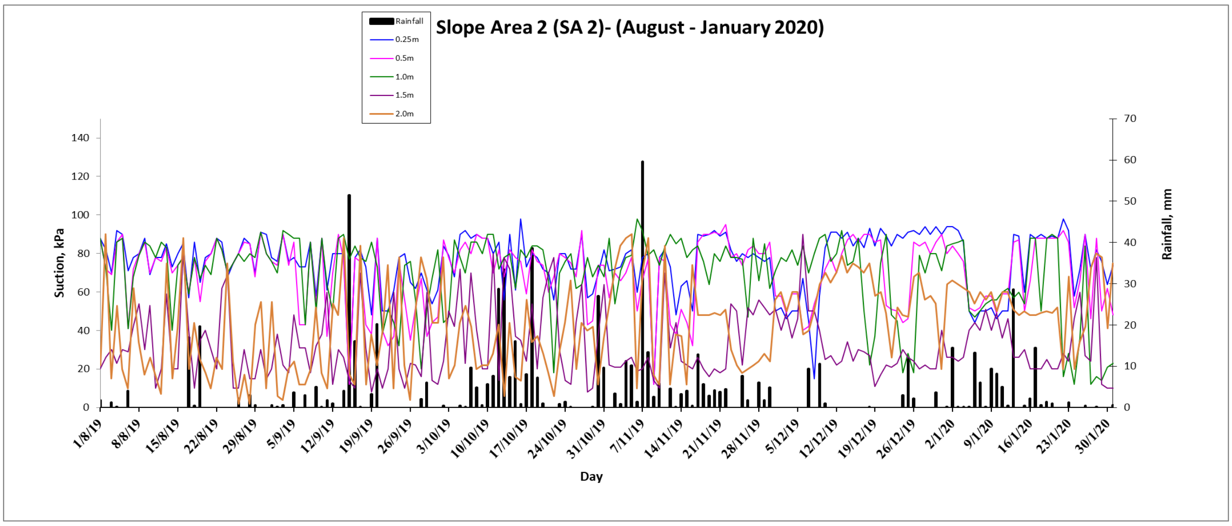
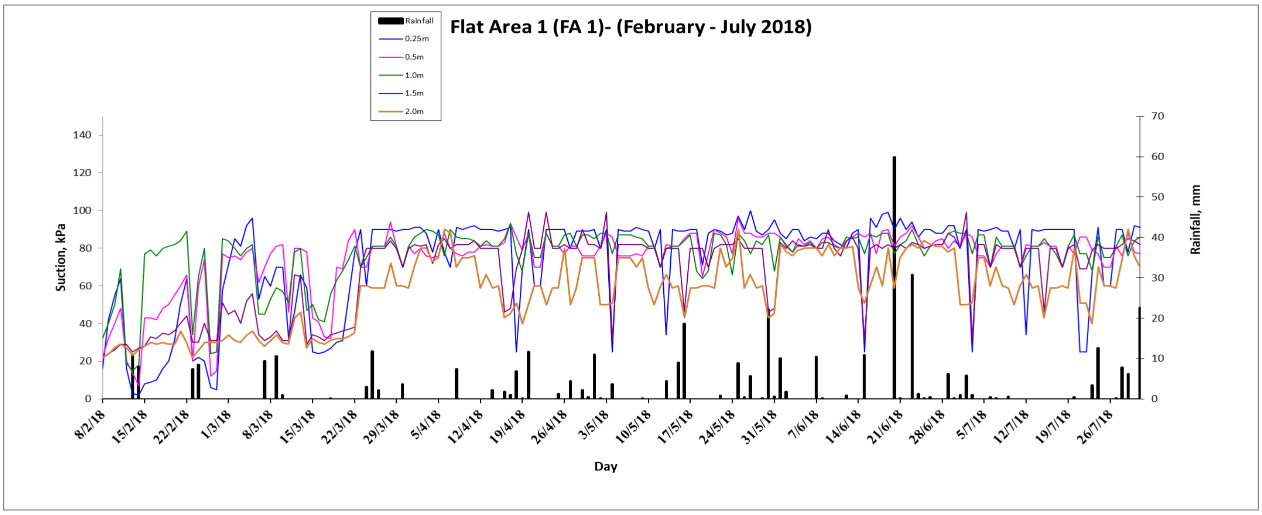


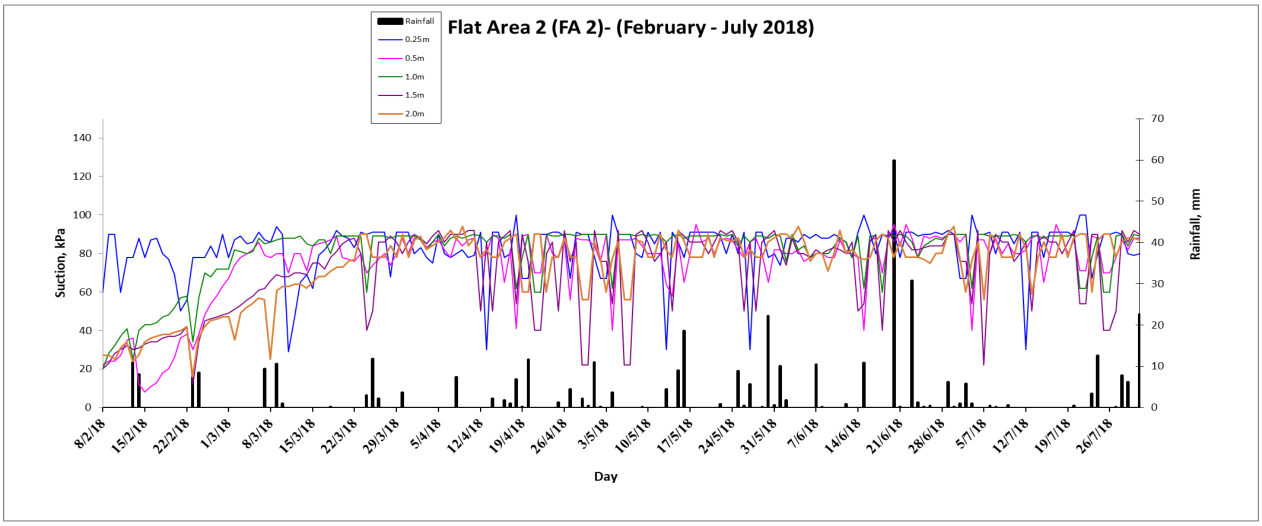
Fig. 7 *Field monitoring of matric suction with respond to rainfall distribution at slope area 1, 2 and 3 during monitoring period*

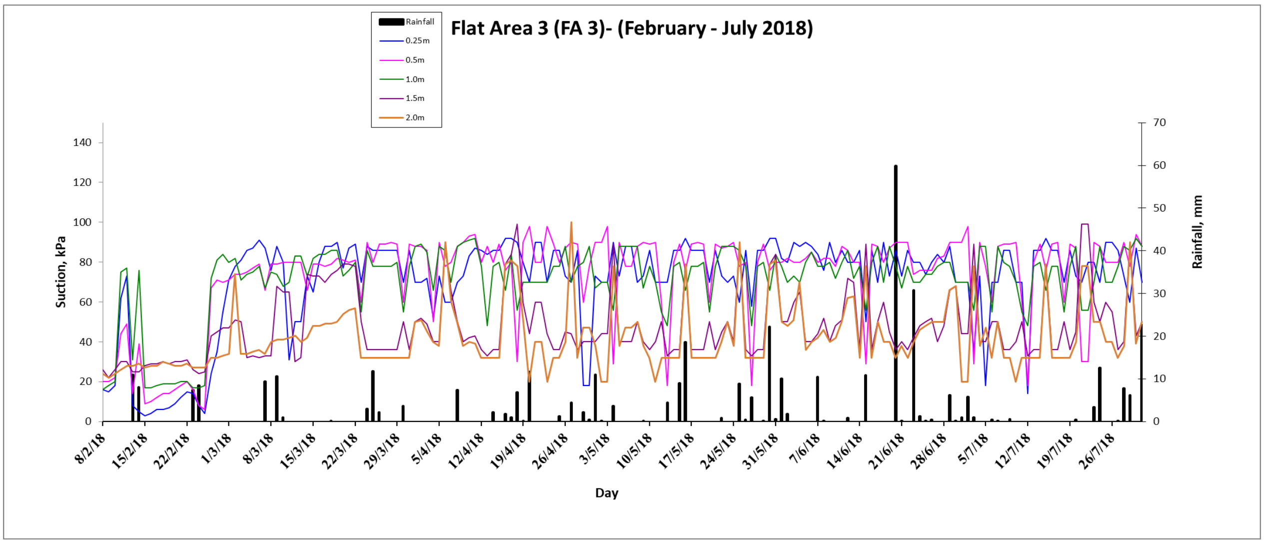
The suction variation was considerably large; on 22nd February 2018, after 10 days without rainfall, the matric suction at 0.25 m and 0.5 m at slope area 1 (SA 1) reached the value of approximately 110 kPa and 96 kPa, respectively, while the changes in the matric suction were approximately 50 kPa and 34 kPa respectively. The matric suction at 1.0 m and 1.5 m depth reached approximately 90 kPa and 84 kPa, respectively, while the changes in the matric suction were 28 kPa and 20 kPa, respectively. For flat area 1 (FA 1), the matric suction at 0.25 m and 0.5 m depth reached approximately 90 kPa and 88 kPa, respectively, while the changes in the matric suction were 30 kPa and 26 kPa, respectively. In addition, the matric suction at 1.0 m and 1.5 m reached a value of approximately 85 kPa and 83 kPa, respectively, and the changes in matric suction were 23 kPa and 19 kPa, respectively.

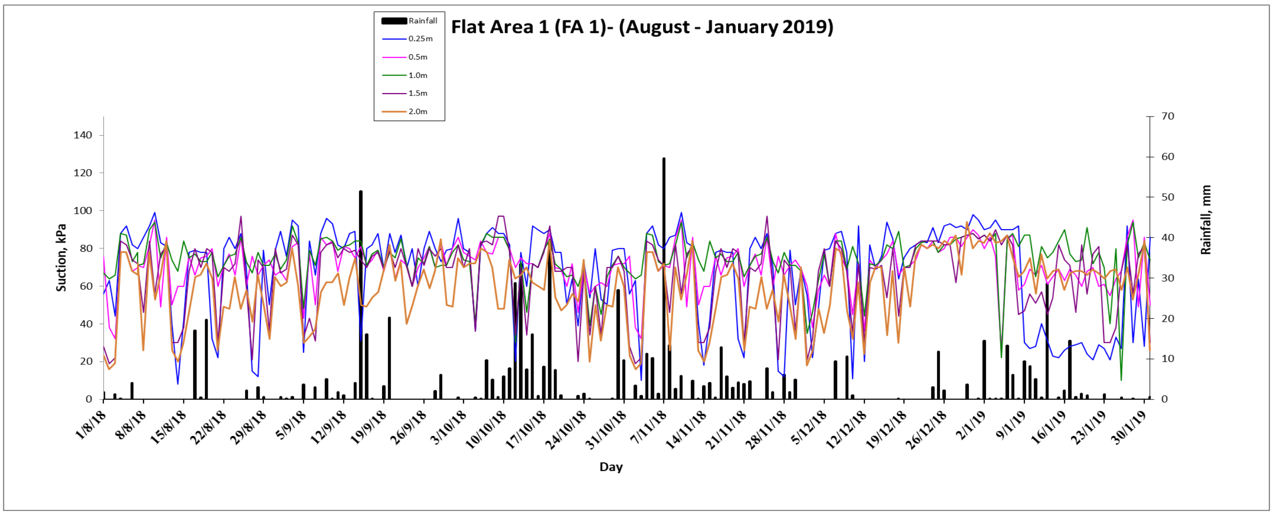
For slope area 2 (SA 2), the matric suction at 0.25 m and 0.5 m depth reached approximately 100 kPa and 86 kPa, respectively, while the changes in the matric suction were 41 kPa and 35 kPa, respectively. Moreover, the matric suction at 1.0 m and 1.5 m reached a value of approximately 80 kPa and 74 kPa, respectively, and the changes in matric suction were 40 kPa and 36 kPa, respectively, which was lower than slope area 1 (SA 1). For flat area 2 (FA 2), the matric suction at 0.25 m and 0.5 m depth reached approximately 90 kPa and 88 kPa, respectively, while the changes in the matric suction were 50 kPa for both depths. In advance, the matric suction at 1.0 m and 1.5 m reached a value of approximately 85 kPa and 83 kPa, respectively, and the changes in matric suction were 45 kPa for both depths. The minimum effect of tree-induced suction was encountered at slope area 3 (SA 3) and flat area 3 (FA 3) at a depth of 0.25 m, 0.5 m, 1.0 m and 1.5 m with the value of 58 kPa, 53 kPa, 44 kPa and 38 kPa for slope area 3 (SA 3) and with the value of 90 kPa, 76 kPa, 70 kPa and 64 kPa for flat area 3 (FA 3).

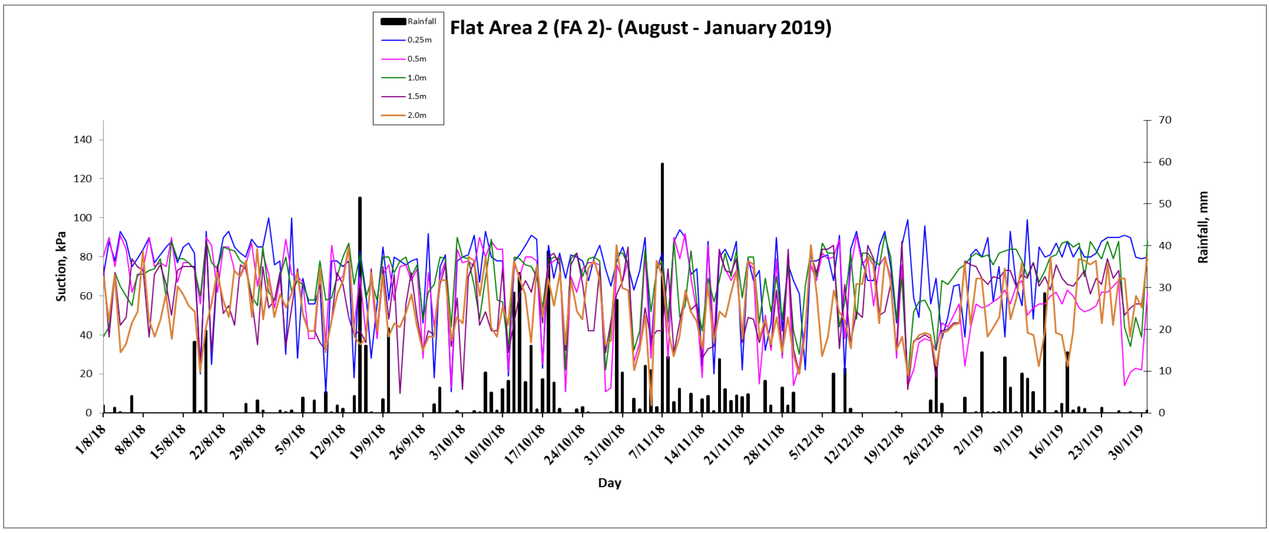
Fig. 8 presents the field monitoring of matric suction in response to rainfall distribution at flat areas 1, 2 and 3 during the monitoring period.

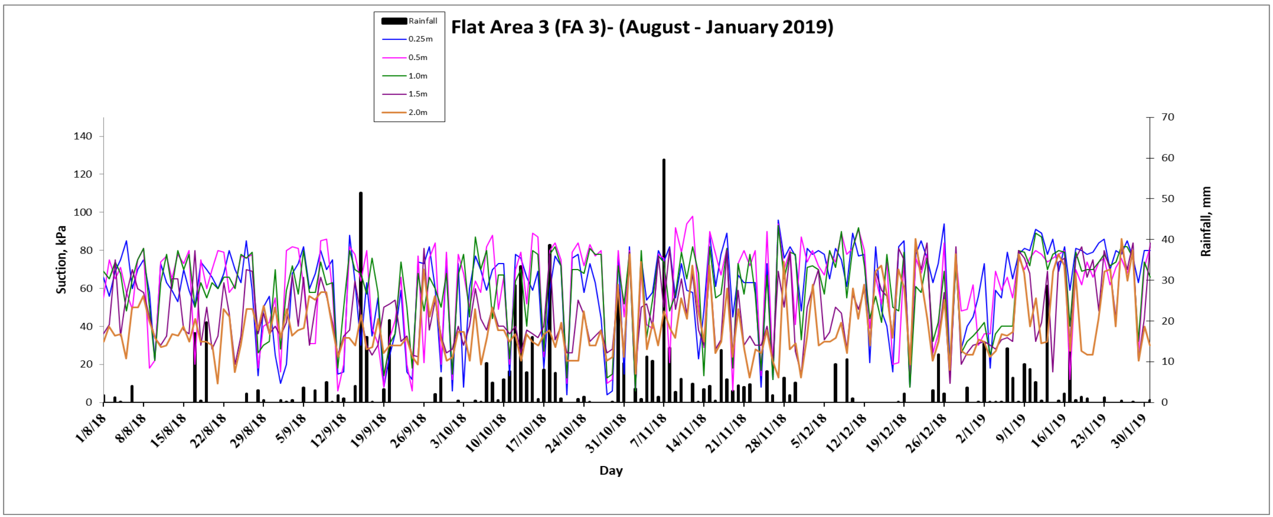

Flat Area 1 (FA 1)- (February - July 2018)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day

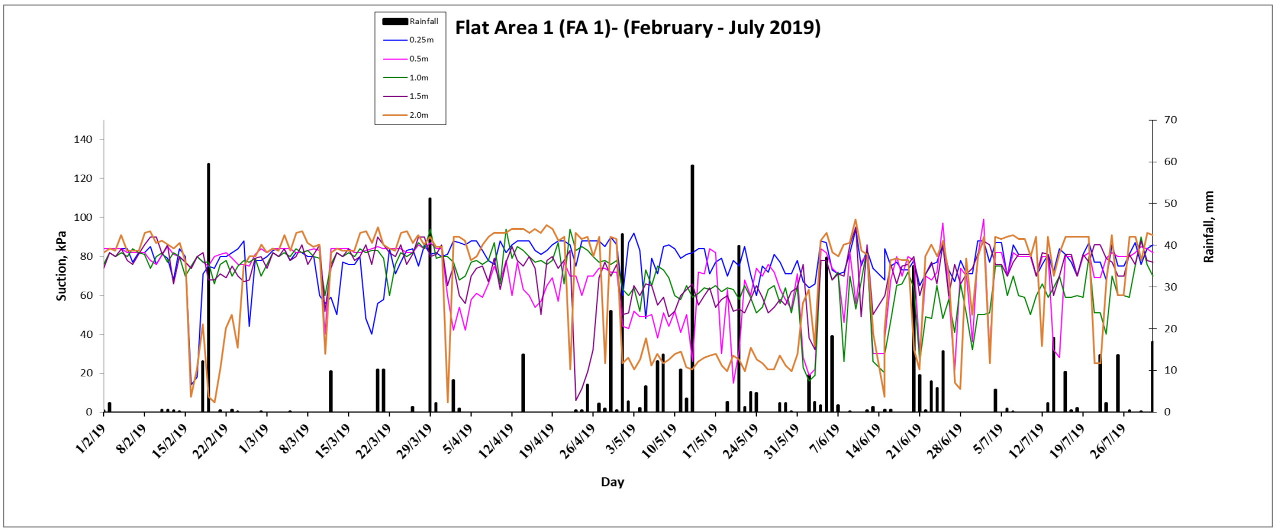

Flat Area 2 (FA 2)- (February - July 2018)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day

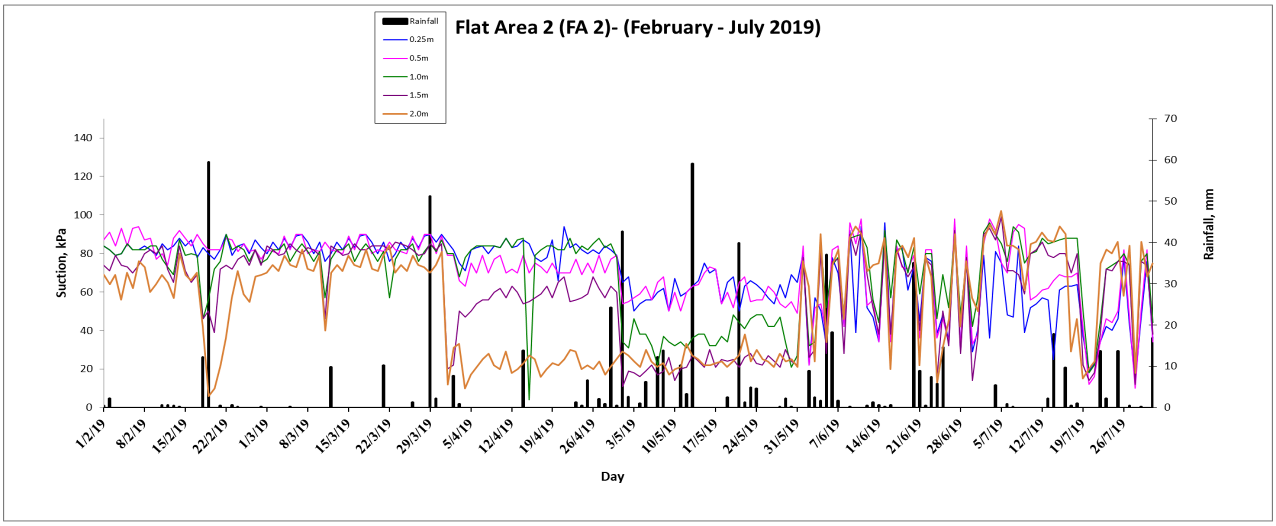

Flat Area 3 (FA 3)- (February - July 2018)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day

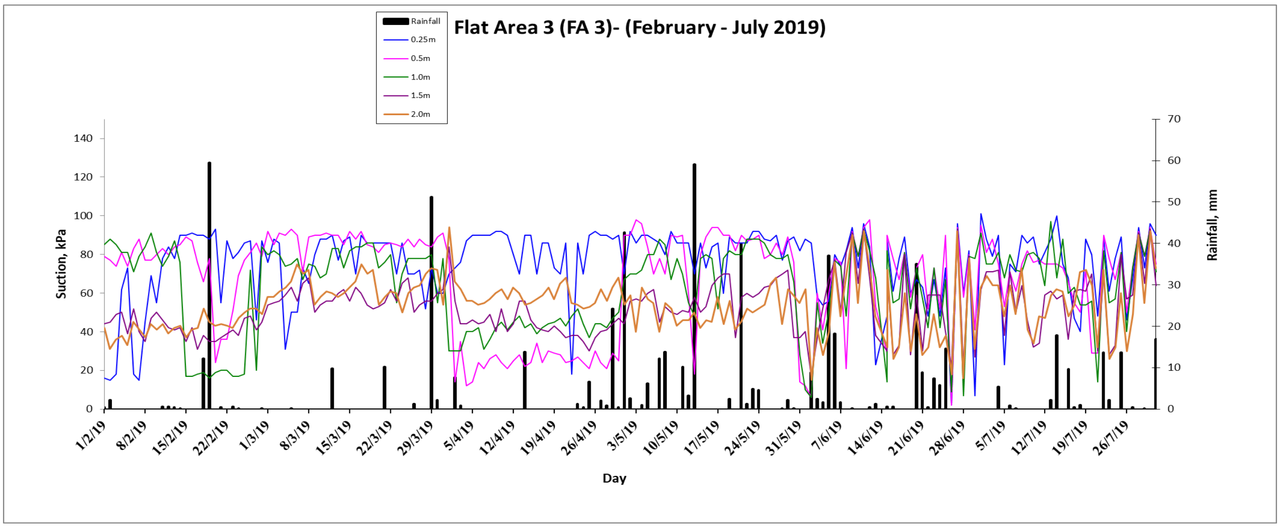

Flat Area 1 (FA 1)- (August - January 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Flat Area 2 (FA 2)- (August - January 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Flat Area 3 (FA 3)- (August - January 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Flat Area 1 (FA 1)- (February - July 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Flat Area 2 (FA 2)- (February - July 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day


Flat Area 3 (FA 3)- (February - July 2019)
Rainfall
0.25m
0.5m
1.0m
1.5m
2.0m
Suction, kPa
Rainfall, mm
Day

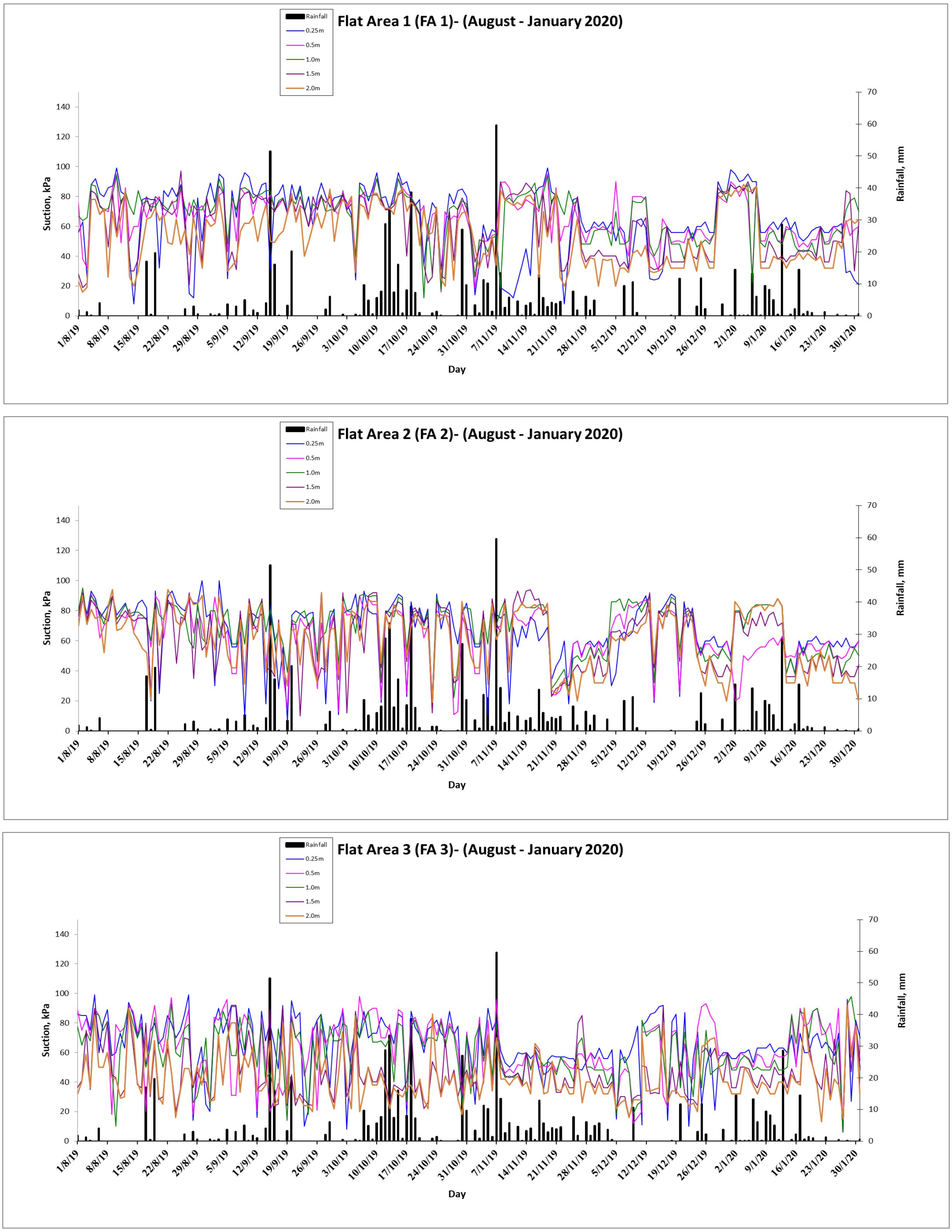


Fig. 8 *Field monitoring of matric suction with respond to rainfall distribution at flat area 1, 2 and 3 during monitoring period*

The field data in Fig. 6, Fig. 7, and Fig. 8 were the plotted matric suction concerning depth and rainfall data to allow better configuration and comparison between the field data at slope area, flat area and area without a tree. Additionally, during this field monitoring work, the suction at 0.25 m depth, 0.5 m, 1.0 m, 1.5 m and 2.0 m depth have never reached 0 kPa, or there were no suction disappearances at the slope area and flat area despite receiving several intense and long rainfall events.

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4. Conclusion

This study focusing the influence of a single mature tree (Alstonia Angustiloba) on top of the slope with matric suction distributions on tropical residual soil. The matric suction profile pattern in soil mass is subjected to decrease by rainfall and increase due to tree water uptakes. The changes in matric suction, particularly on a slope with a tree at the top, which differ from the slope without a tree. This study provides that the contribution of a single mature tree significantly alters the matric suction or moisture variation distribution in tropical residual soil slopes. The research has proven that using the tree water uptake method can increase the value of FOS of the slope up to 57%.

Acknowledgement

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *M F Ishak, M F Zolkepli;* ***data collection:*** *M F Zolkepli, S Daud;* ***analysis and interpretation of results:*** *M F Zolkepli, S Daud;* ***draft manuscript preparation:*** *M F Zolkepli, M F Ishak, S Daud. All authors reviewed the results and approved the final version of the manuscript.*

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