 https://doi.org/10.1051/e3sconf/202338224004

Field observations of soil moisture, suction and movement of cornfield in tropical highland with and without vetiver system

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Abstract. An increasing large number of cornfield have been cultivated in highland of many Southeast Asian countries. In most cases, this corn plantation is done without proper soil & water conservation such as vetiver system (VS), thus causing land degradation and shallow slide. This study is aimed at investigating the field behaviour of slopes with corn plantation with and without vetiver system in Chiang Mai, Northern Thailand. Tensiometers, soil moisture sensors, in-place inclinometers and tiltmeters were installed at a slope in two locations, with and without vetiver system from surface to 2m depth. The monitoring results show that for the vetiver treatment, the soil moisture tended to be higher and response faster to rainfall than the cornfield without vetiver. However, the pore-water pressure in the root zone (about 0.5m) was higher for the vetiver treatment than the cornfield which only has the root depth of about 0.2m. For cornfield without vetiver, the seasonal variation of the soil moisture and pore-water pressure was also larger. Tiltmeter indicates a larger surface movement in the cornfield without VS. However, the inclinometer readings suggested that for slope with VS there was some cyclic movement toward hillside at the surface. This could be an indication of non-uniform settlement of soil layers or influence of groundwater rising.

1 Introduction

Due to land scarcity and the increasing pressure for food security, cultivation of annual crops such as corn has been widespread in many steep slopes of hilly terrains in Southeast Asian countries like Thailand, Myanmar, Laos and Vietnam [1]. Oftentimes, these corn cultivations are on slopes with gradients of up to 35 degrees without proper soil & water conservation practice. This situation constantly leads to intensified erosions and ultimately to rainfall-triggered shallow landslides that not only affects the agriculture land but also the infrastructure such as highways passing through those terrains. Slash & burn practice commonly associated with corn cultivation also brings about severe air-pollution like PM2.5 that adversely causes health problems on the societal level.

In order to tackle this problem, Highland Research and Development Institute (HRDI), a Public Organization in Thailand, has initiated a programme to encourage local farmers in Northern provinces to turn to more environmentally friendly agroforestry practice and reforestation. The initial activity was to excavate a series of small reservoirs on hill tops which are interconnected to irrigate the more diverse economics plants, thus lifting the farmers out of slash & burn practice and monoculture crops. Soil & water conservation involved the use of step terrace and vetiver system (VS), i.e. planting vetiver grass as hedgerows parallel to the slope contour (Fig. 1) [2]. Very effective for reduction of runoff energy and for sediment trap, the vetiver hedgerow has a very dense fine vertical root system which is also beneficial for shallow slope stabilization [3-4]. In between the vetiver hedgerows, various economic plants are introduced, for example, mango, durian, avocado, etc, that can generate additional income to the local farmers. In addition to the socio-economic benefits of this initiatives, the geo-environmental aspect is also of interests. It is thus the objective of this study to investigate the field performance of slopes that utilize such highland agriculture practice from a geotechnical engineering point of view using unsaturated soil mechanics.

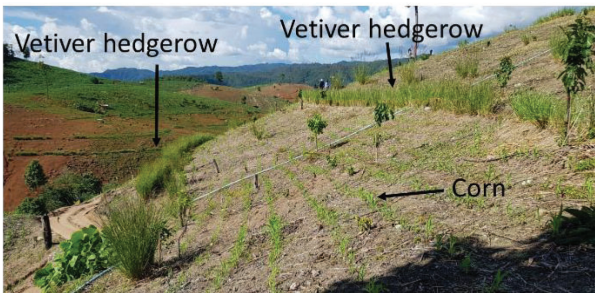

Fig. 1. Photograph of study slope (Year 2020/09)

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2 Study site

The study site is situated in a remote HRDI project area in Mae-wak village, Mae-najon sub-district, Maejam district, Chiangmai province in Northern Thailand. The elevation of the study site was between 700 to 800 above mean sea level around the foothill of Doi Intanon mountain. The annual average rainfall was 1,900 mm/year. The geology of the area was mostly granite, gneiss, and quartzite, which decomposed to residual silty sand and clayey sand. About 11% of the whole HRDI project area (212 km^2) was identified as having moderate-to-very-severe erosion problem due to the lack of soil-water conservation practice and widespread corn plantation on slope. A major rainfall-induced landslide incident took place in Year 2009 which caused debris (50m wide by 250m long) to block Mae-wak creek, luckily, with no report of casualty. Many local roads and highways in the area regularly suffered from shallow slide and erosion.

The study slope was of about 26.6 degree gradient (Fig. 1&2) which represented about 25% of the whole HRDI project area. This slope was used for corn plantation and in about half of the area, the vetiver hedgerow was recently introduced for soil & water conservation according to HRDI initiatives (Zone A with VS in Fig. 2). Four vetiver hedgerows (VS-1, VS-2, VS-3 and VS-4) were grown in half of this slope (Zone A), while in Zone B, only corn plants were grown without the vetiver system. This slope was therefore chosen for instrumentation work so that behaviour of cornfield with and without VS could be investigated.

2.1 Soil profile

Soil profile was investigated by means of light-weight dynamic cone penetration test, or so-called Kunzelstab Penetration test (KPT). This test involves dropping a 10 kg weight, from a 0.5m height, on a 90° cone with a diameter of 25 mm connected to 20 mm diameter rod. The number of blow counts was recorded for every penetration of 20 cm. Fig. 3 shows the variations of blow counts versus depth for two locations (KPT1 and KPT2, in Fig. 2). The thickness of loose soil mantle ranged between 1 to 1.8 m. The depth to hard stratum or bedrock varied between 2.2 to 2.8m.

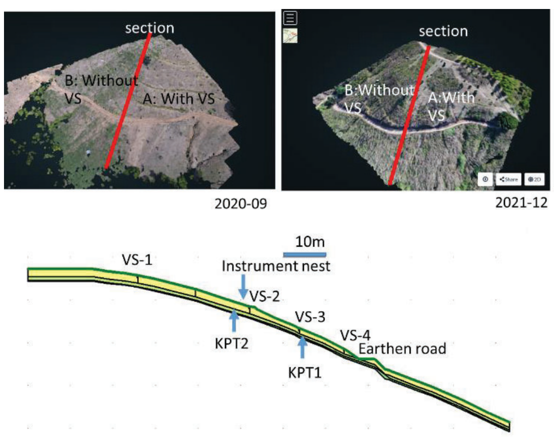

Fig. 2. 3D- model of the study slope and cross-section

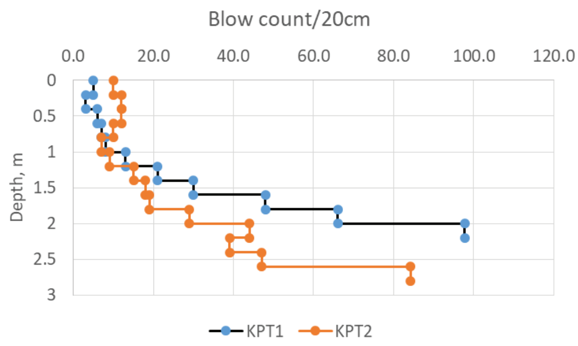

Fig. 3. Kunzelstab penetration test result

Table 1. Summary of soil properties

	%Gravel	%Sand	%Silt	%Clay	Void ratio, e	γ_t, kN/m^3	G_s
A: Vetiver	6.4	74.6	11.2	7.8	0.64	1.89	2.60
B: Cornfield	7.6	76.8	11.6	4.0	0.67	1.87	2.68

Table 1 presents the basic soil properties of undisturbed soil samples collected at about 10cm depth from near the vetiver hedgerow (Zone A) and from the middle of cornfield (Zone B). Both soils can be classified as silty sand (SM) according to the unified soil classification system (USCS). The soil near the vetiver (Zone A) was of a slightly higher clay content, a higher unit weight and a slightly smaller void ratio. This could be a result of sediment trap effect of the VS as also reported by [5].

2.2 Instrumentation

The instruments installed at the study slope are shown in Fig. 4, including 6 tensiometers (Kasetsart University or KU-type), 4 soil moisture sensors, 2 tiltmeters, 4 in-place inclinometers and a tipping bucket rain gauge. The details of the installation depth are summarized in Table 2. The monitoring results were recorded and transmitted via Narrowband Internet of Things (NB-IoT) network to the cloud platform developed in-house using Arduino telemetry datalogger (with 16bit ADU) at the interval of 5 minutes. The data can be assessed in a near-real time manner and can potentially be used as early warning system for landslide.

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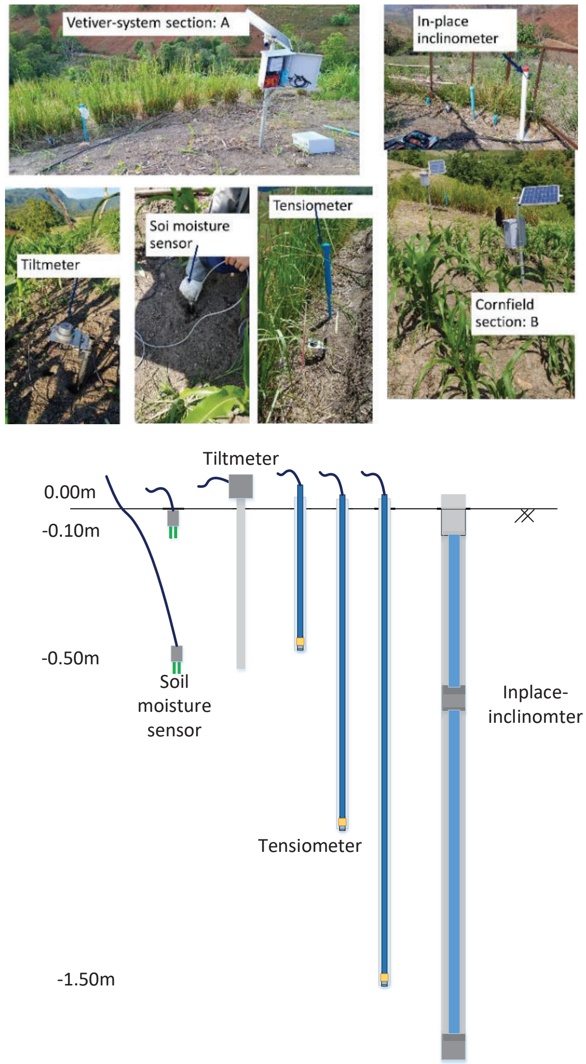

Fig. 4. Instruments installed at the study site

It is noted that the KU-tensiometers installed can be used to measure both negative and positive range of the pore-water pressure (-100 to 600 kPa). A careful saturation procedure according to [6] and suction reading check were always made to ensure no air bubble was present in the tensiometer reservoir before installation. However, two tensiometers (1.0 and 1.56m depths) from Zone A appeared to malfunction after July 2022. Their readings during this period were omitted from the analysis. It is also noteworthy that the in-place inclinometer casing pipes were installed down to the maximum depth of 1.6 to 2.2m only. This limited depth of boreholes reached the medium dense sand layer but could not be socketed into the bedrock. The borehole was actually dug using hand-auger due to the difficult accessibility of the area, as well as the limited amount of budget.

The soil moisture sensors were calibrated against the actual soil collected from the site. The tiltmeter and inclinometer sensors were based on the analogue accelerometer with the sensitivity of 70mV/deg and the maximum reading of ±15 degrees.

Table 2. Summary of instrumentation

	Instruments	Depths of installation, m
A: Vetiver	Soil moisture	0.1, 0.5
	Tensiometer	0.4, 1.0*, 1.56*
	Tiltmeter	0.5
	In-place inclinometer	0.6, 1.6
B: Cornfield	Soil moisture	0.1, 0.5
	Tensiometer	0.4, 1.0, 1.5
	Tiltmeter	0.5
	In-place inclinometer	1.2, 2.2

*Malfunctioned after July 2022

3 Monitoring results

The instrument installation was complete in February 2022 which was in middle of the dry season. The first rain that followed the dry period came about in April 2022. Fig. 5 shows the variation of soil moisture, tiltmeter reading and pore-water pressure. It can be seen that the soil moisture (Fig. 5a) above the vetiver hedgerow responded faster to the rainfall than the cornfield soil moisture without VS. As runoff was slowed down by the vetiver row, more water could infiltrate into the soil. Nevertheless, despite a higher water content near the vetiver row, the soil surface movement as shown in Fig. 5b was negligible due to the root reinforcement effect of the VS. For cornfield without VS, the surface movement was clearly greater. Interestingly, the pore-water pressure (Fig. 5c) behind the vetiver row was also greater than that in the middle of cornfield. The pore-water pressure at 0.4m for plot with VS (No. 3) appeared to not respond to this first rain, possibly due to the high water holding capacity of the rooted soil mantle above 0.4m, implying that soil-water retention curve is steep in this zone. In general, the variation of pore-water pressure with depth in Fig. 6 suggests there was more infiltration along the vetiver grass. It is notable that the pore-water pressure at 0.4m depth in the cornfield without VS fluctuated to a greater extent than that with VS. This result shows the effectiveness of the VS for conserving soil & water within the slope, which is definitely favourable for agricultural practice.

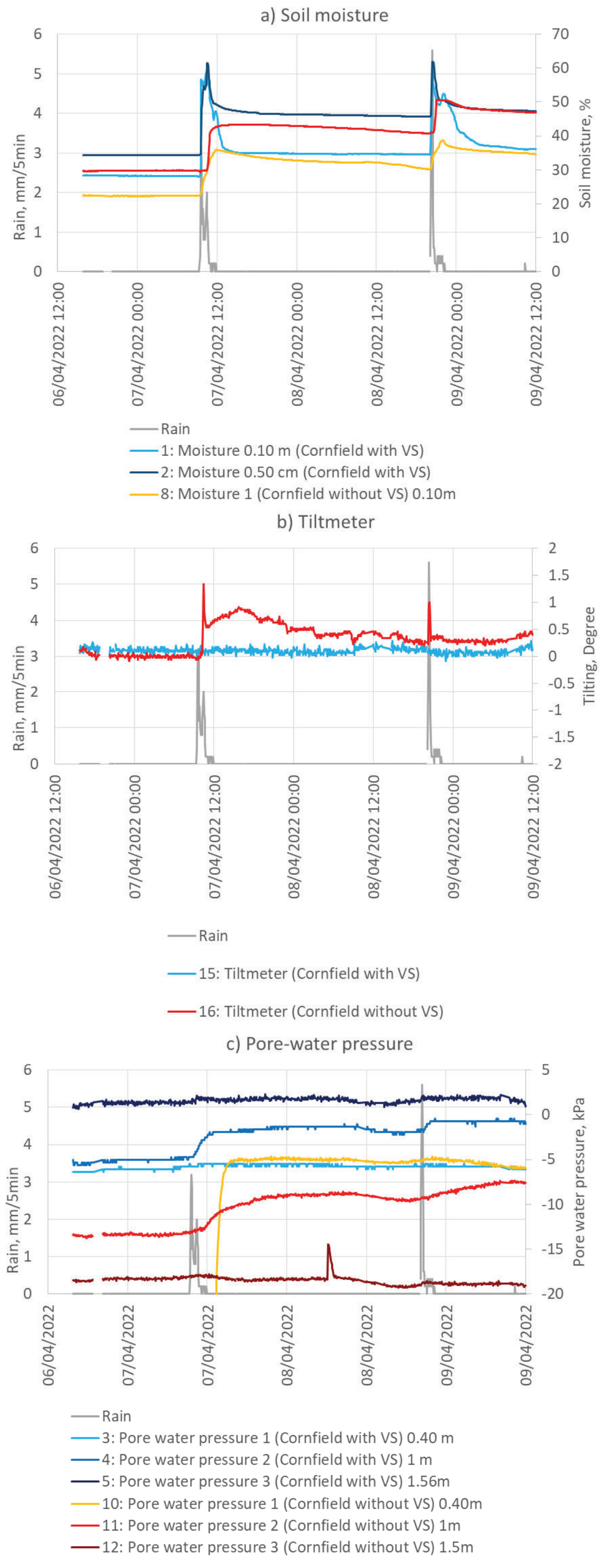

Fig. 5. Slope surface movement, soil moisture and pore-water pressure of the study slope subjected to the first rainfall event after dry period

The behaviour of soil surface movement as measured using the tiltmeters in the long term are shown in Fig. 7. Interestingly, a significant movement (measured as tilting degree) was observed in the cornfield during July until August and reached the maximum value of 7.3 degree once the accumulated rainfall was 763mm (measured from January 2022). Again the surface movement behind the vetiver hedge was mostly negligible. The variation of soil moisture with time is shown in Fig. 8. Similarly, the soil moisture near the VS was higher than that in the middle of cornfield. This observation applies for both soil moistures at 0.1 and 0.5m depths which are well within the root zone of the vetiver.

The slope response during the rainy season in the months of July to September 2022 is shown in Fig. 9 to 12. The pore-water pressures at 0.4m depths from the VS zone and non-VS zone were compared in Fig. 9a. The pore-water pressures in both zones were of negative value indicating the unsaturated condition was still maintained at this depth. In the VS zone, the pore-water pressure was slight lower than that outside by 1kPa. This additional suction in the VS zone could be a result of transpiration of the VS.

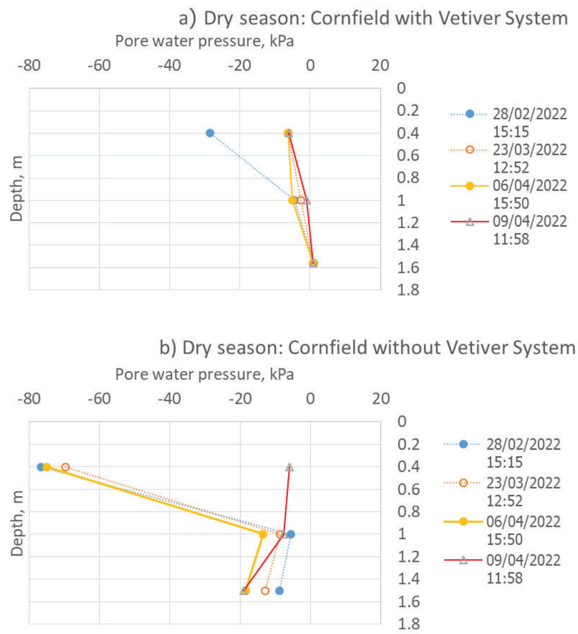

Fig. 6. Variation of pore-water pressure with depth of the study slope from February until April 2022

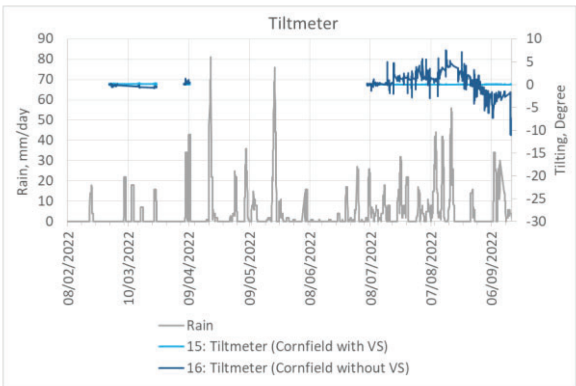

Fig. 7. Slope surface movement as measured using tiltmeters plotted with daily rainfall

Fig. 9b compares the pore-water pressures in the cornfield without VS at the depths of 1 and 1.5m. Interestingly, the pore-water pressure was close to zero at 1m depth while becoming negative at 1.5m depth. This suggested a kind of perched ground water table at about 1m depth above the unsaturated zone, which could potentially correspond to the location of the most critical slip plane.

Fig. 10 shows the variation of inclinometer readings in terms of tilting angle together with daily rainfall. As expected, the inclinometers nearer the top were more tilting than the ones nearer the base for both VS and non-VS zones. However, the top inclinometer for VS zone appeared to oscillate and even exhibited some tilting towards the hill (negative value) during some rainfall event (Fig. 11). This kind of towards-hill tilting has been observed in a previous study by [7]. The explanations for this towards-hill tilt were provided by [7] as follows, namely unequal settlement due to the layer structure of the slope, the non-uniformity of the engineering properties and the tendency of groundwater to rise. Apparently, the tendency of groundwater rising seems to be a plausible one given the trend of pore-water pressure near VS shown in Fig. 6a, though more field evidence was needed to confirm this statement.

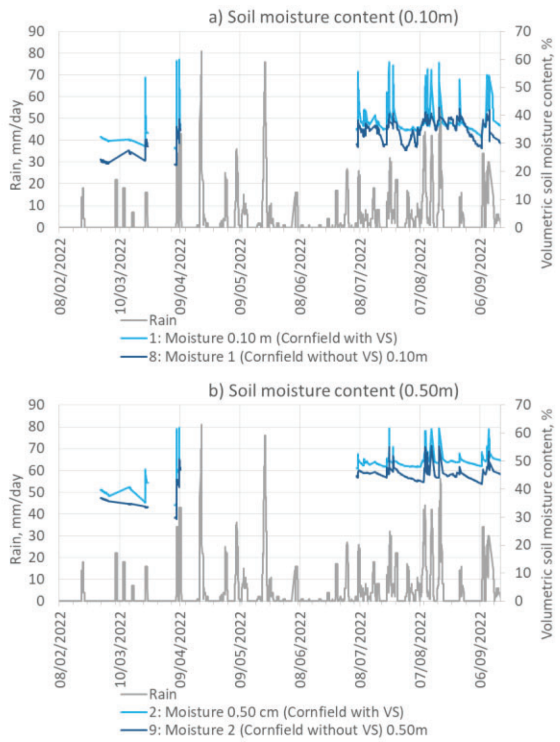

Fig. 8. Variation of volumetric soil moisture content along the vetiver hedge row and at the middle of cornfield with daily rainfall

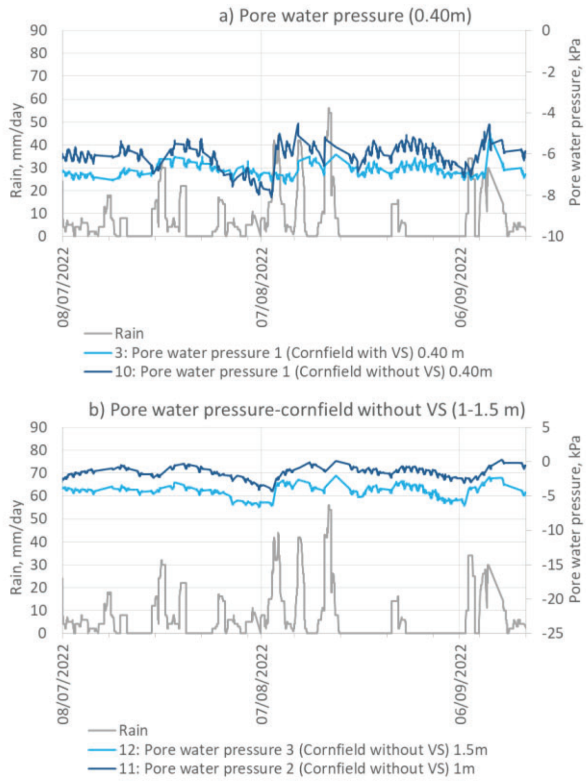

Fig. 9. Variation of pore-water pressure during rainy season along the vetiver hedge row and at the middle of cornfield with daily rainfall

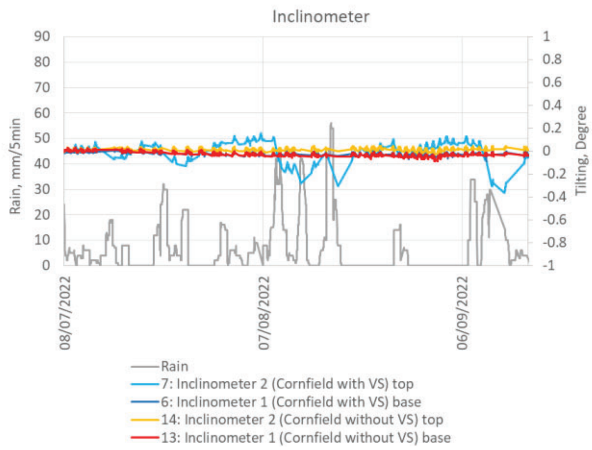

Fig. 10. Variation of inclinometer reading and rainfall with time during rainy season

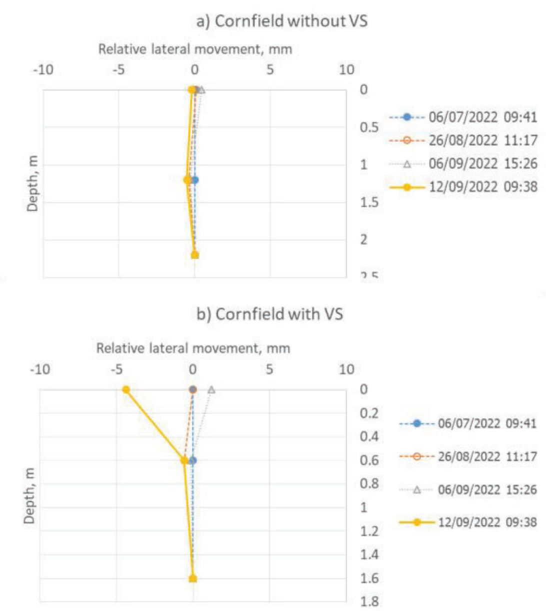

Fig. 11. Variation of calculated relative lateral movement at soil surface and rainfall with time <u>during rainy season</u>

Based on field evidence during excavation for undisturbed samples, the roots of vetiver grass appeared to reach about 0.5m depth while those of corn were less than 0.2m deep. This root trait agrees with earlier observations. For example, the soil moisture from 0.1 to 0.5m near the root zones of the VS were greater than those without VS (Fig. 8). This increase in water content nearer the root zone could be due to root exudates and influence of roots on hydraulic properties as explained by [5, 8]. Nevertheless, the pore-water pressure near the root zones of VS at 0.4m was slightly lower than those without VS (Fig. 9a). The additional suction was likely due to transpiration of the vetiver grass. This observation was also in line with a previous study by [9] In general, it appears that for slope with VS system, the soil moisture retention capacity and suction was improved near the root zone. However, at a greater depth beyond the root zone, the pore-water pressure may increase due to infiltration, but this still needs further field evidence to confirm this statement.

4 Conclusions

This study investigated the field behaviour of slopes with corn plantation with and without vetiver system (VS) in Chiang Mai, Northern Thailand using tensiometers, soil moisture sensors, in-place inclinometers and tiltmeters. The instrumentation period was about 1 year. The following conclusions can be drawn.

- For the vetiver treatment, the soil moisture tended to be higher near the root zone and response faster to rainfall than the cornfield without vetiver.
- The pore-water pressure in the root zone of vetiver treatment (about 0.5m) was slightly higher than the cornfield which only has the root depth of about 0.2m. This is expected to be due to transpiration.
- For cornfield without VS, the seasonal variation of the soil moisture and pore-water pressure was larger due to the lack of soil & water conservation.
- Tiltmeter indicates a larger surface movement in the cornfield without VS especially during the first rain events following the dry season.
- The inclinometer readings nevertheless suggested that for slope with vetiver hedgerow there was some toward-hill tilting movement at the surface. This could be a results of higher groundwater rise below the root zone of VS. This observation warrants further study in this field.

The authors acknowledge the funding provided by Highland Research and Development Institute and Hydro-Informatics Institute of Thailand.

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