Vetiver system with engineering enhancement for slope and coastal stabilization

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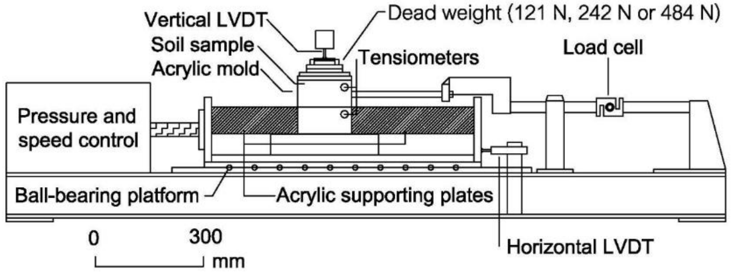
Outline

- **Introduction:** extreme weathers and needs for vetiver system enhancement
- **Fundamental research**: shear and water retention behaviour of vetiver-root reinforced soil: optimum moisture level for vetiver reinforcement
- **Irrigation and new growing techniques** for VS during drought
- A case study of rural road
- A case study of coastal area stabilization
- **Conclusions**



Introduction: extreme weathers and needs for vetiver system enhancement

- Extreme climate conditions: prolonged drought, forest fire, intensive rainfall, strong typhoon leads to more severe erosion and landslide problems
- Along the coastlines, the rise in sea levels, frequent tidal surges as well as human activities contributes to coastal erosion problems.

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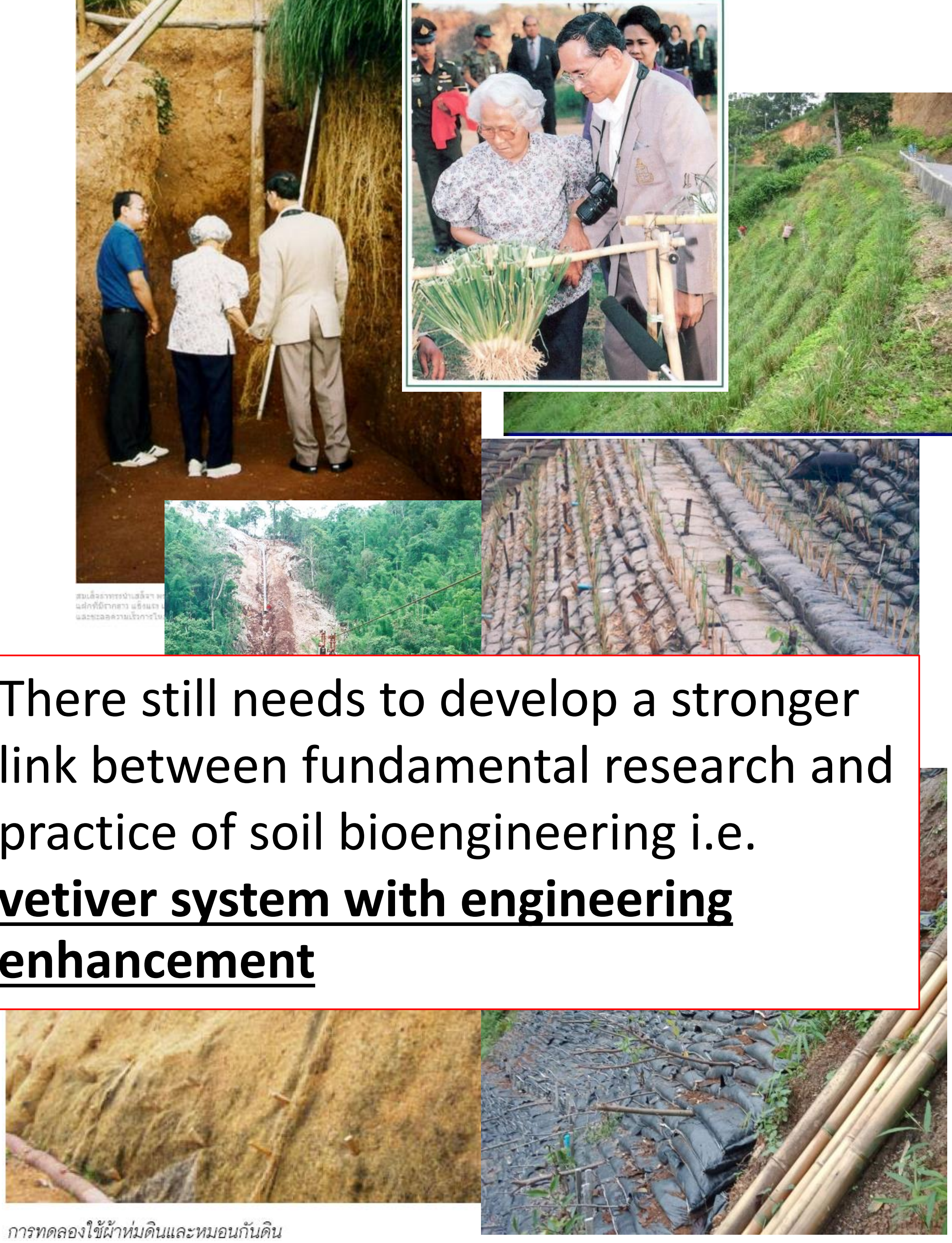
The changing and **hard-to-predict rainfall pattern, higher erosive energy, and drought** resulted in much difficulties in growing and maintaining the vetiver especially for construction projects in which **time and budget constraint** is a crucial issue.

Modern soil-bioengineering in Thailand

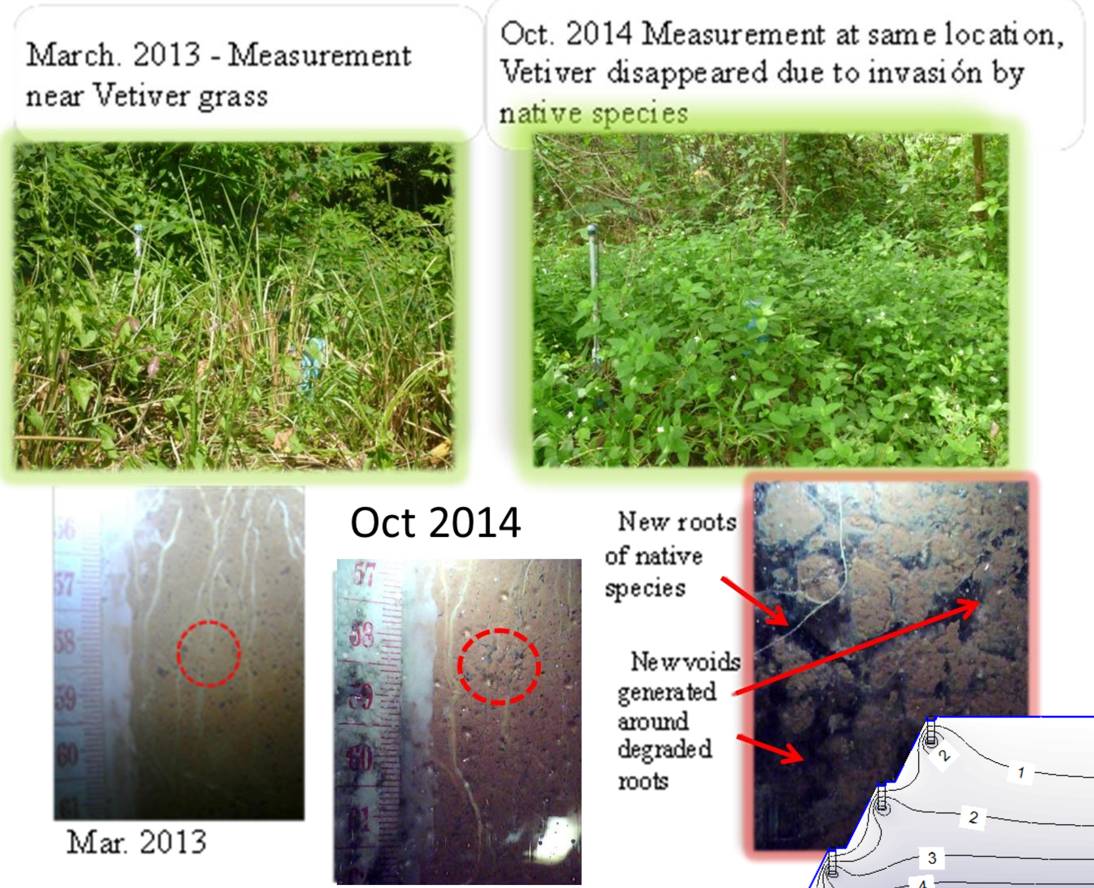
- Vetiver grass system introduced by **World Bank** into Thailand through **Royal development projects by King Rama 9** in 1991
- First technical paper on **vetiver engineering properties** by Diti Hengchaovanich (1998)
- Many fundamental research and application on vetiver grass (DoH, LDD, many universities)
- PTT gas pipe-line project (use of vetiver grass + jute soil bag + live stake) 1997
- Introduction of **erosion control blanket** and **erosion control logs** products (around 2005)
- Development of **flapped soil bag** (2007)
- Incorporation of plants into geosynthetics products and development of new innovations like vegetated soil bags with micropiles etc.

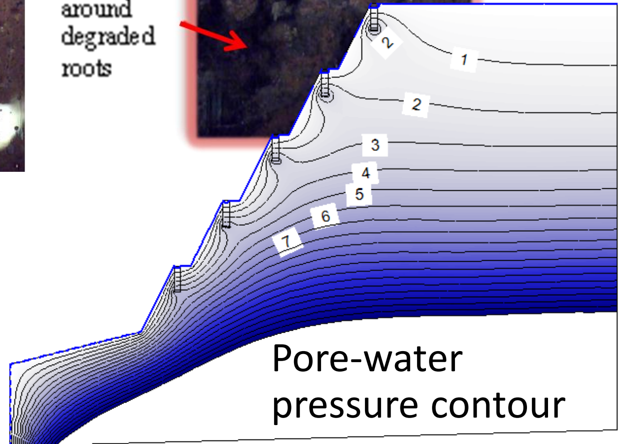


There still needs to develop a stronger link between fundamental research and practice of soil bioengineering i.e. **vetiver system with engineering enhancement**

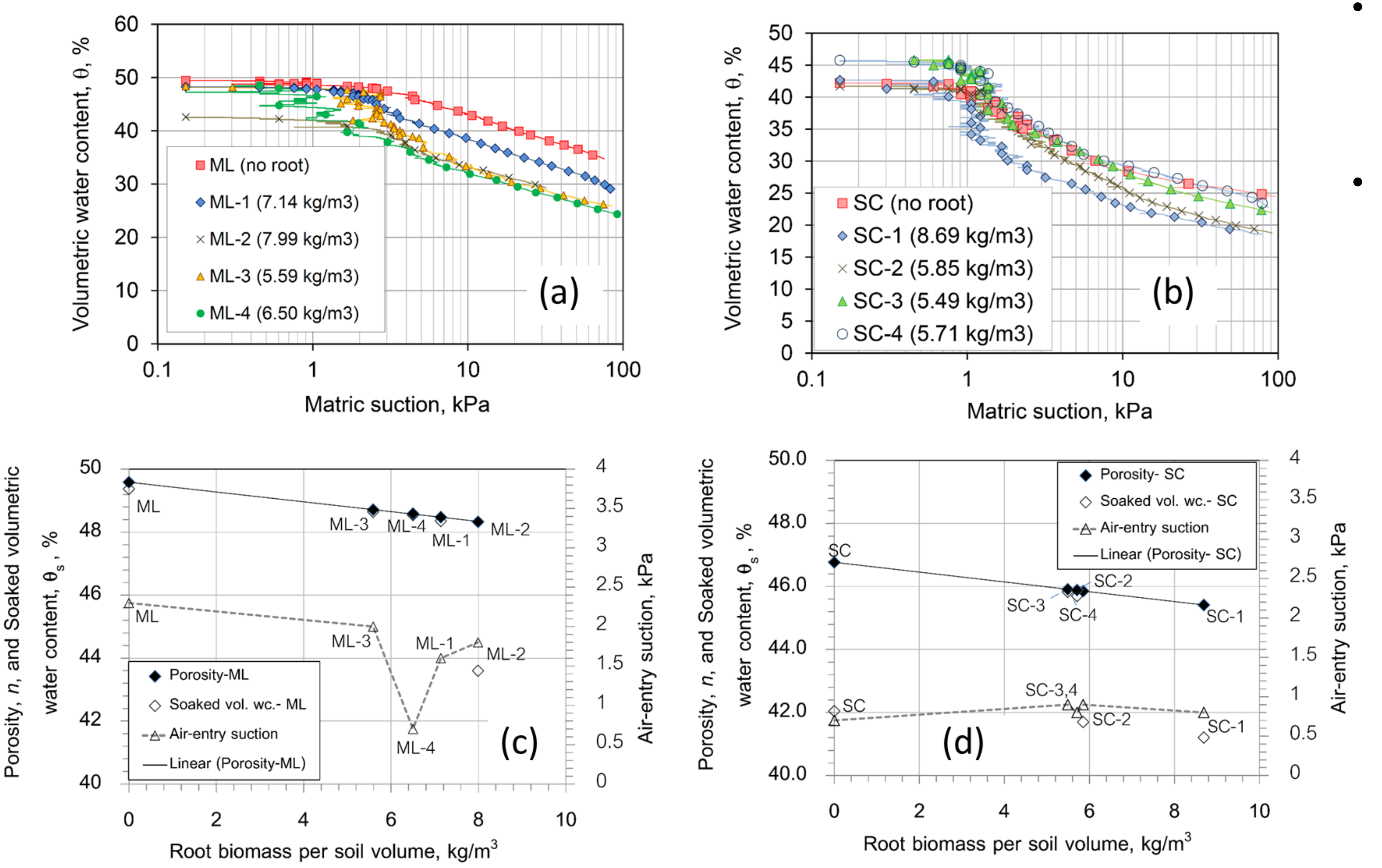
Shear and water retention behaviour of vetiver-root reinforced soil with varying root concentrations and moisture conditions

- During severe drought, the VS without proper irrigation will be subject to considerable stress and roots may decay, causing loss of reinforcement and increased deep infiltration after subsequent rain
- Jotisankasa et al. (2014, 2015) showed that for steep slope (>60^o) increase in water permeability could cause deep-seated **instability**, especially if root reinforcement is reduced due to root decay
- **Need to quantify the effects of changing root contents and moisture on slope stability**





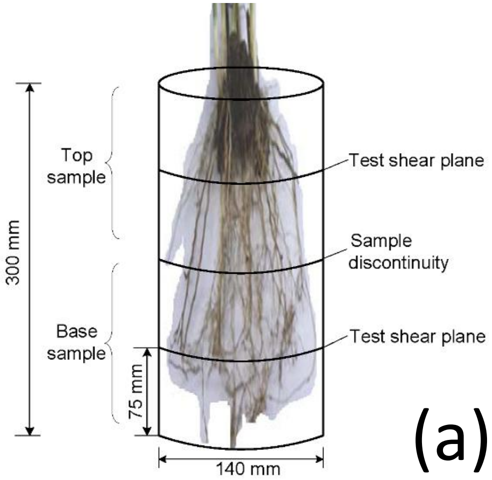
Soil water retention curve (SWRC) of vetiver-root reinforced soil



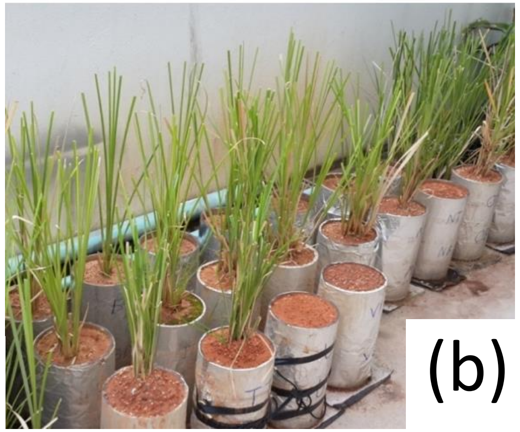
- The slope of SWRC represents the change of water content per unit change of suction or the specific water capacity
- As root biomass increased up to 6.5 kg/m3, the air-entry suction of ML soils (Figure 2a & 2c) appeared to decrease slightly (from 2.3 to 0.7 kPa), and the SWRC becomes steeper (i.e. higher specific water capacity) due to the presence of roots, surrounding gaps and micro-cracks induced by wetting & drying cycle and more aggregated.

The higher specific water capacity of rooted means the root-reinforced soil can take up more water due to their aggregated structure and this is beneficial both for erosion control and stability.

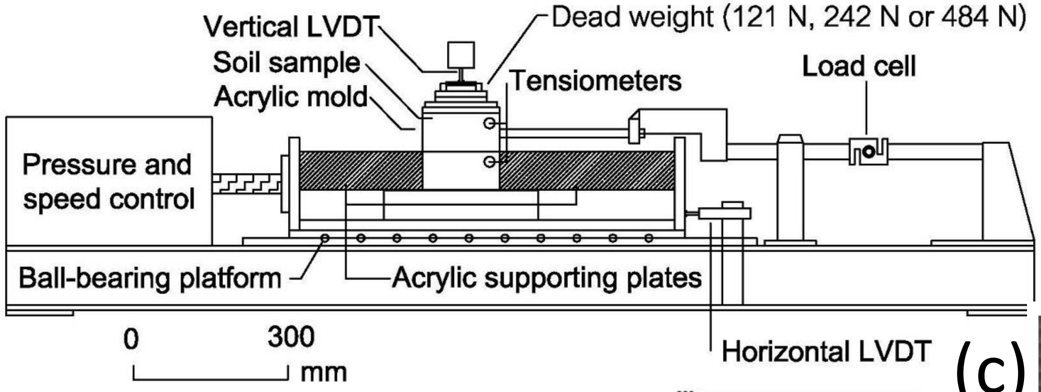
Shear behaviour of vetiver-root reinforced soil with varying root concentrations and moisture conditions



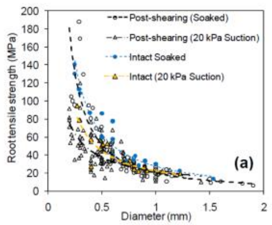
(a)



(b)

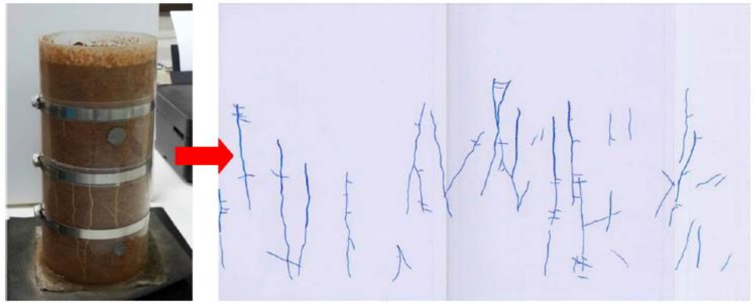


(c)

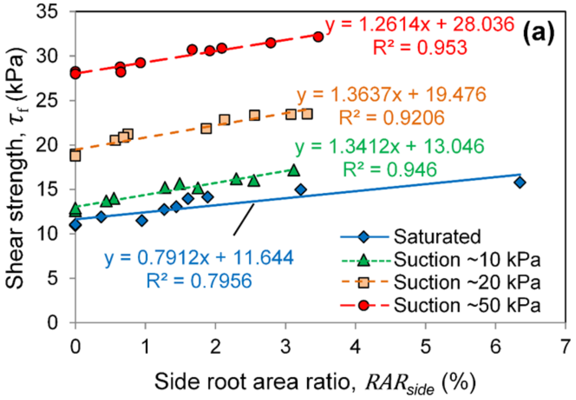


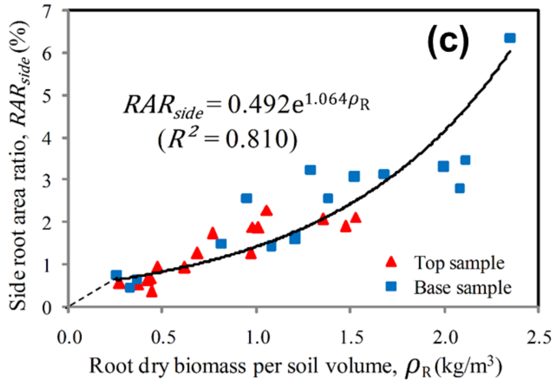
- Mahannopkul and Jotisankasa (2019) performed experimental studies using large direct shear tests and tensile strength tests on root reinforced soils.
- Moisture condition or soil suction was measured using miniature tensiometers in the large direct shear and the root concentration measured as root area ratio and root biomass per soil total volume.

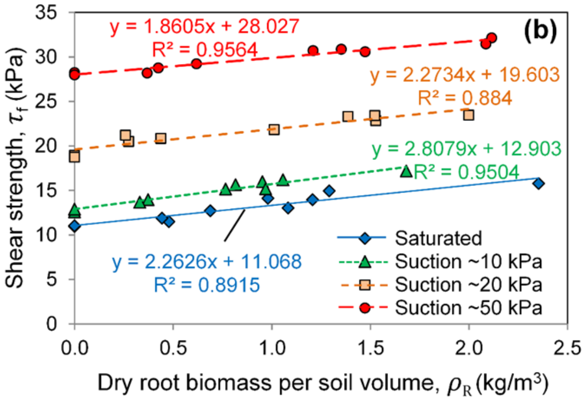
$$RAR_{side} = \frac{A_R}{A} = \frac{Number\ of\ Root\ Pixels}{Total\ Number\ of\ Pixels} \quad (28)$$

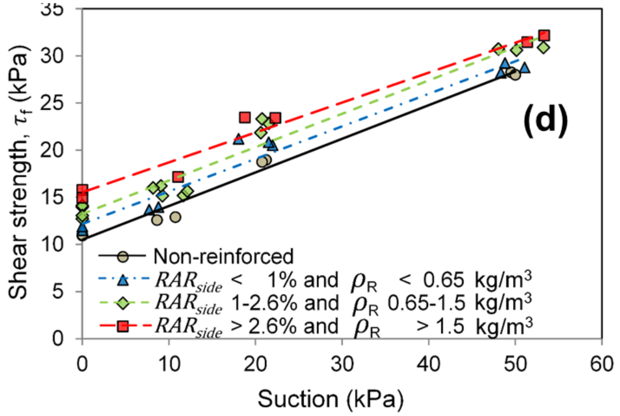


Shear behaviour of vetiver-root reinforced soil with varying root concentrations and moisture conditions

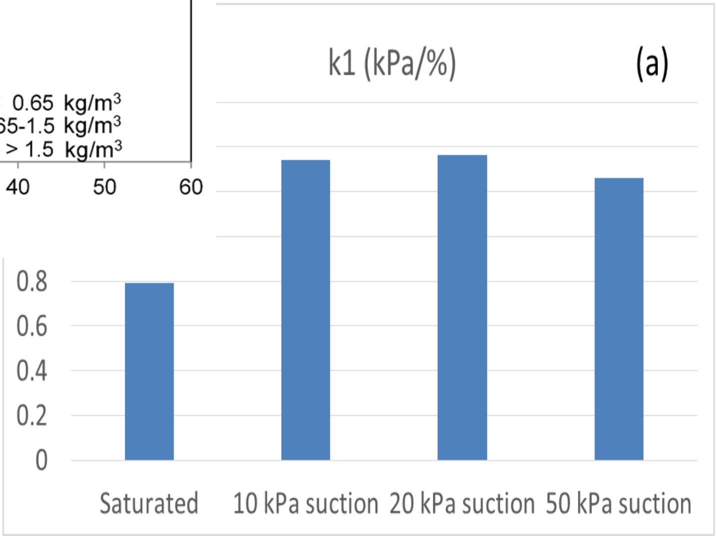


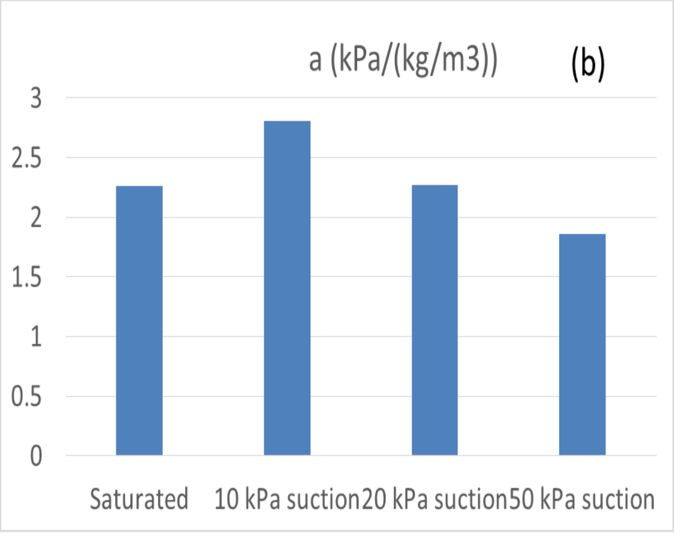






- Relationships between shear strength, root concentrations and suction of the root-reinforced soil are proposed
- The rate which the root cohesion increases with root concentration, is an indication of how well the roots could reinforce the soil.



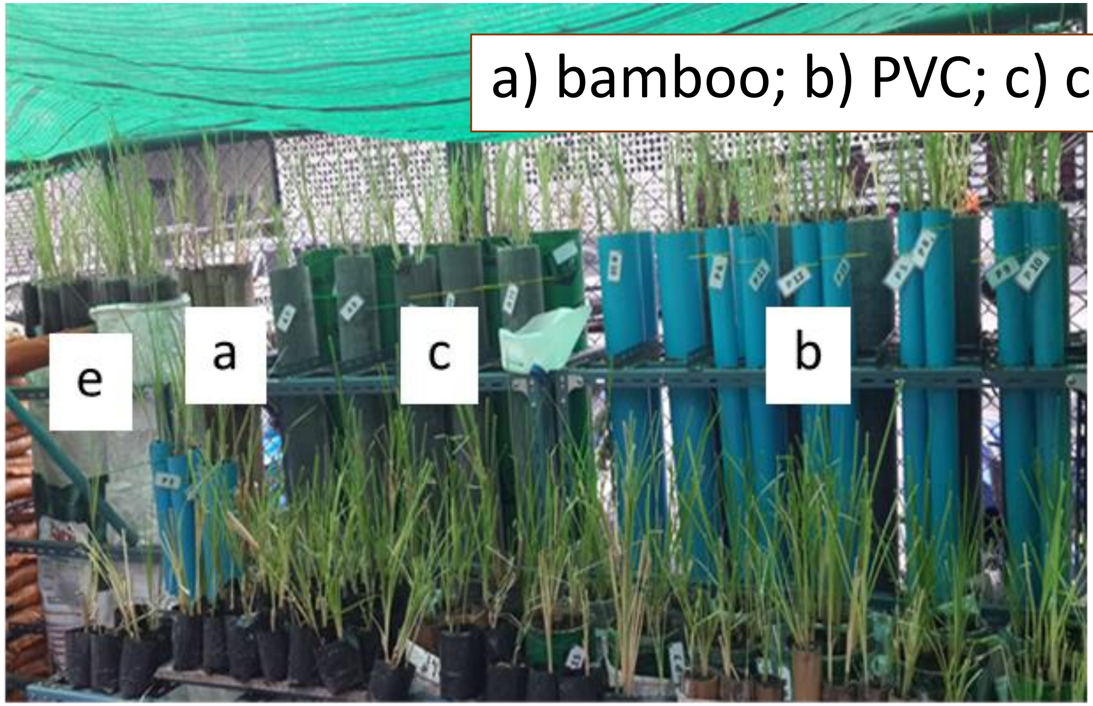


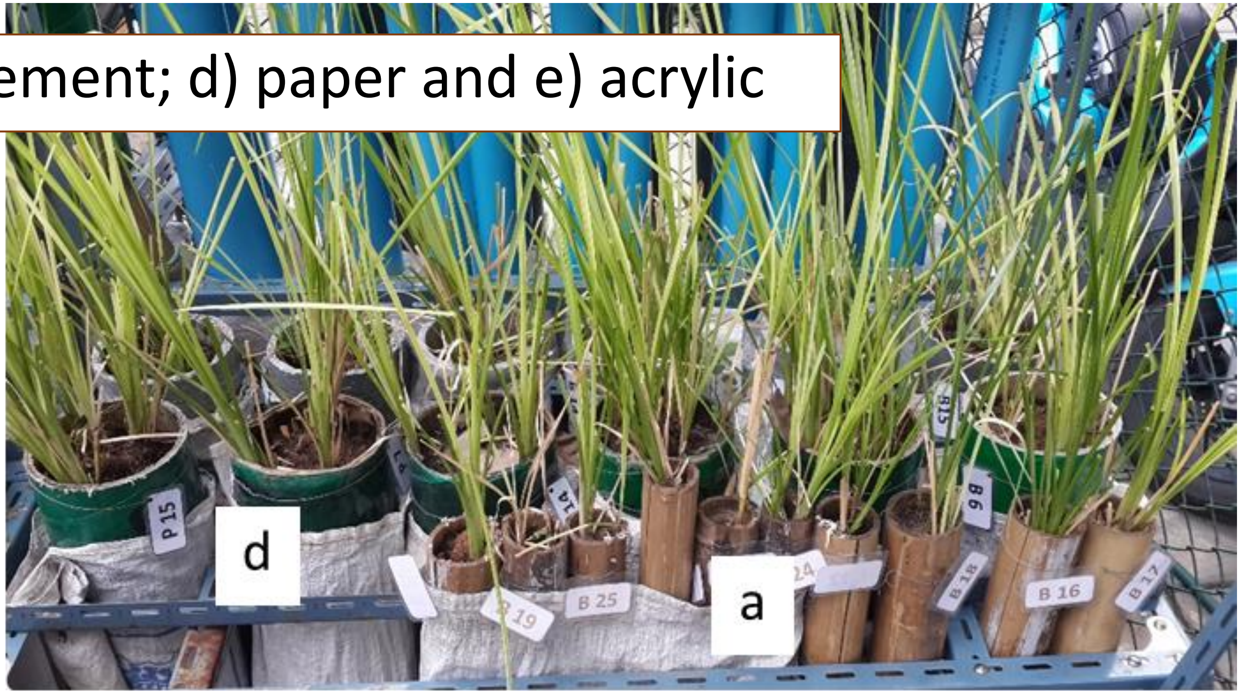
The optimum level of soil moisture at **suction around 10-20 kPa** at which the reinforcement of vetiver roots on shear strength became greatest. This suction level can be used as a threshold for automatic irrigation to maximize VS benefit in soil bioengineering.

Vetiver tube plant

- Tube plant or “tall pot” stock types first proposed by Steinfeld et al. (2007) for FHWA in United States to ensure that plants become established in highly disturbed sites.
- In this study, five kinds of tube materials, namely, bamboo, PVC, cement, paper and acrylic, were used in the experiments. (the growth material was silty-clayey sand mixed with rice husk biochar and earthworm fertilizer.)

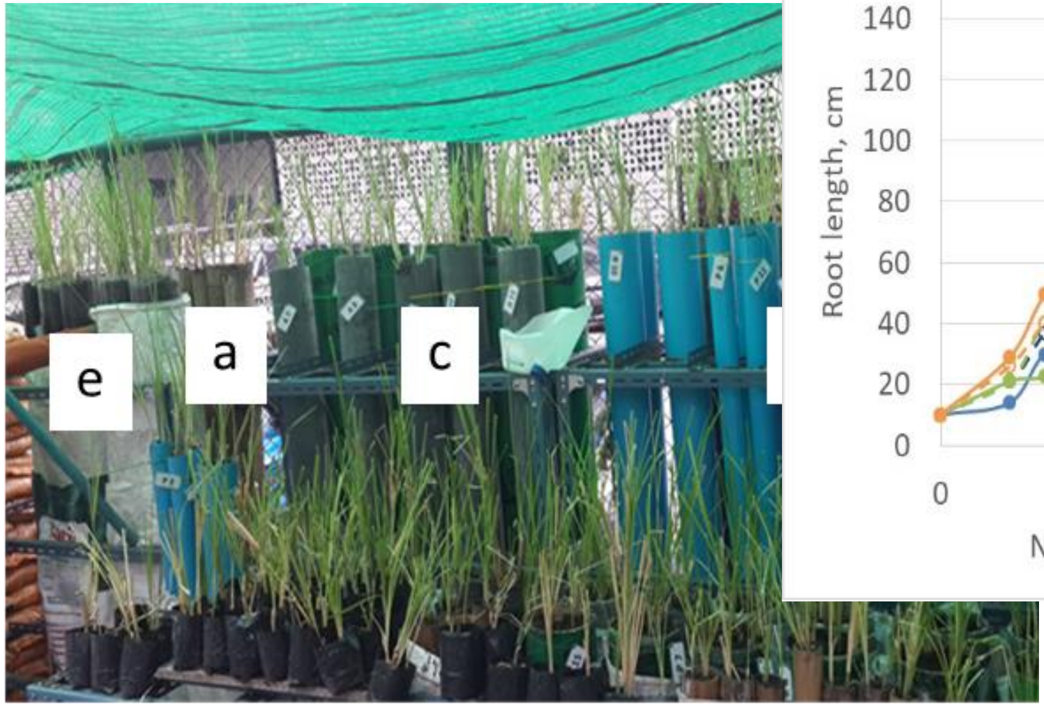
a) bamboo; b) PVC; c) cement; d) paper and e) acrylic

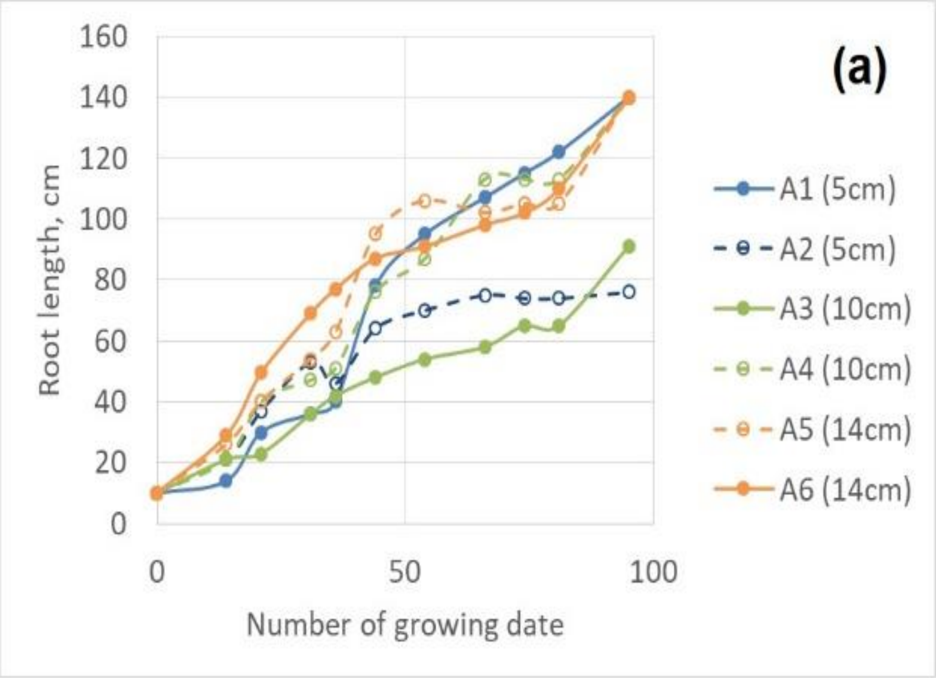


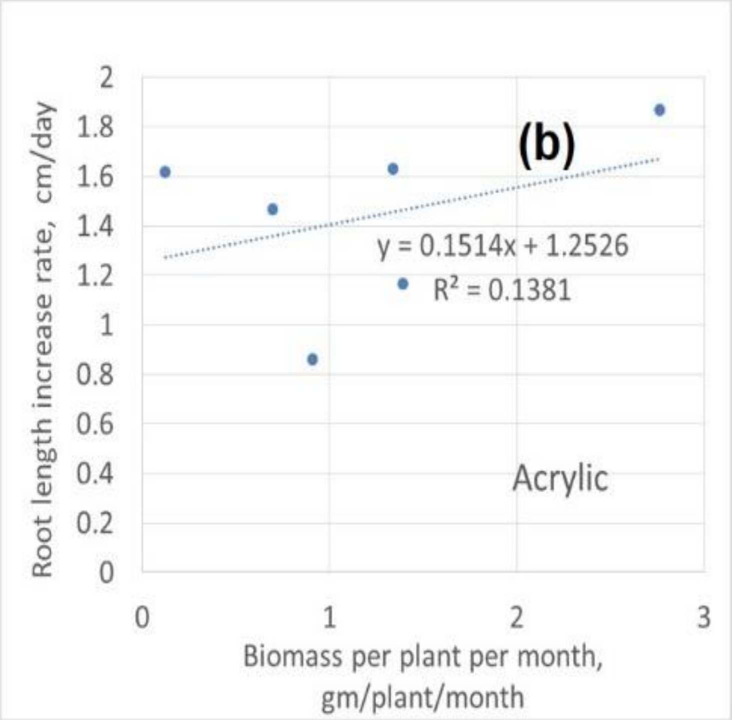


Vetiver tube plant: lab results

- It was observed that the bigger tube size tended to yield higher rate of root length increase especially during first month of growth. Yet after 3 months of growing period, the tube size did not seem to have as much influence on root length as in the earlier period.



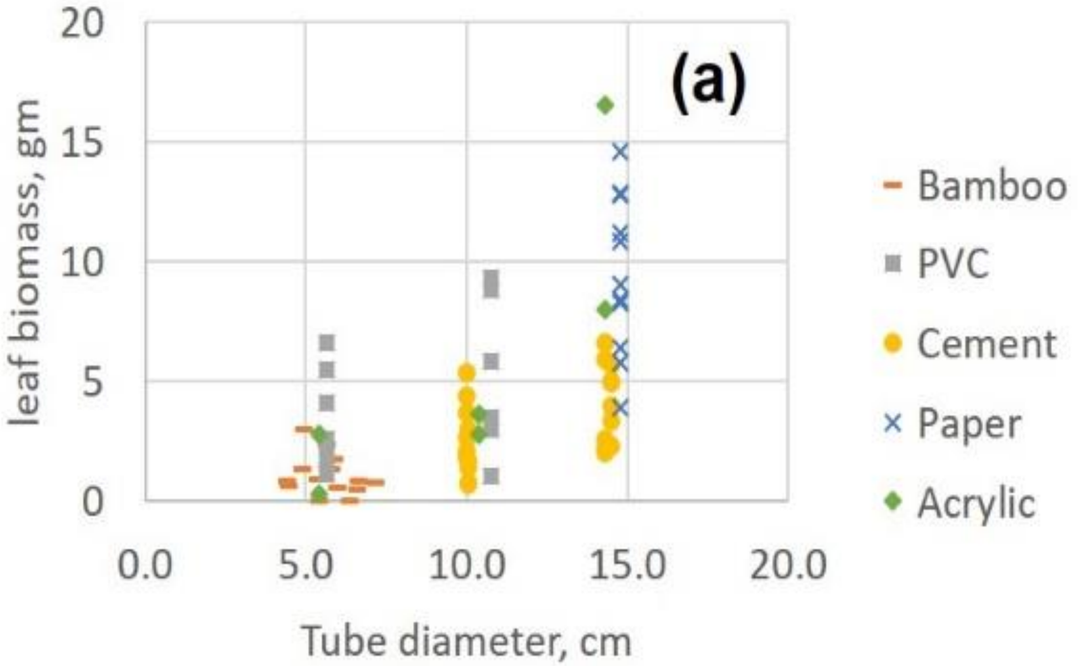


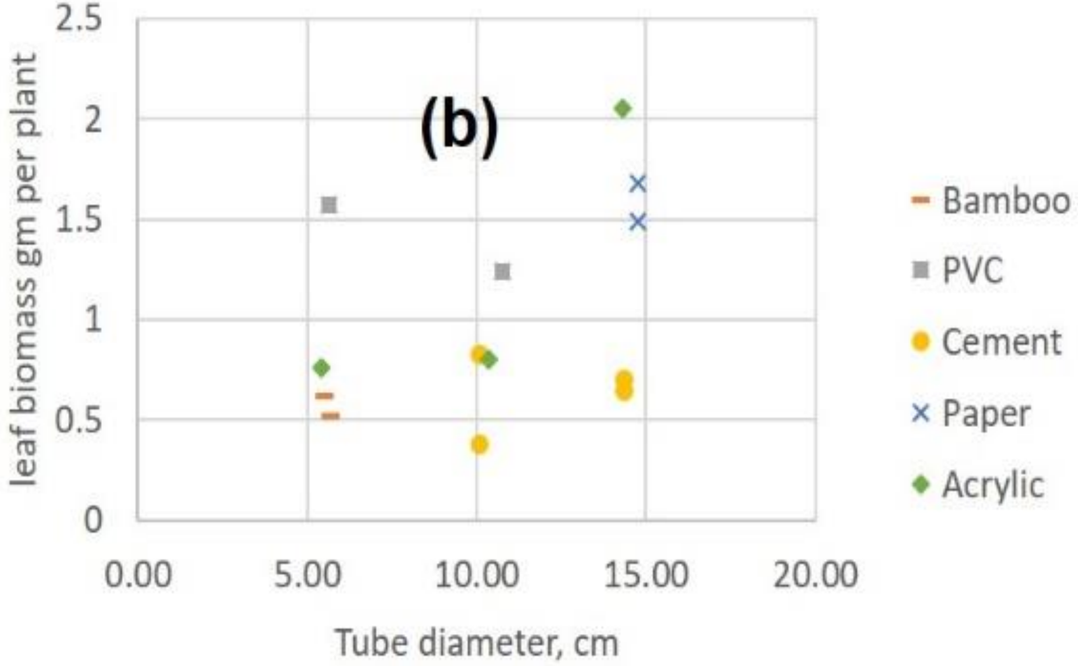


Leaf biomass of the vetiver measured after 40 days of growing period.

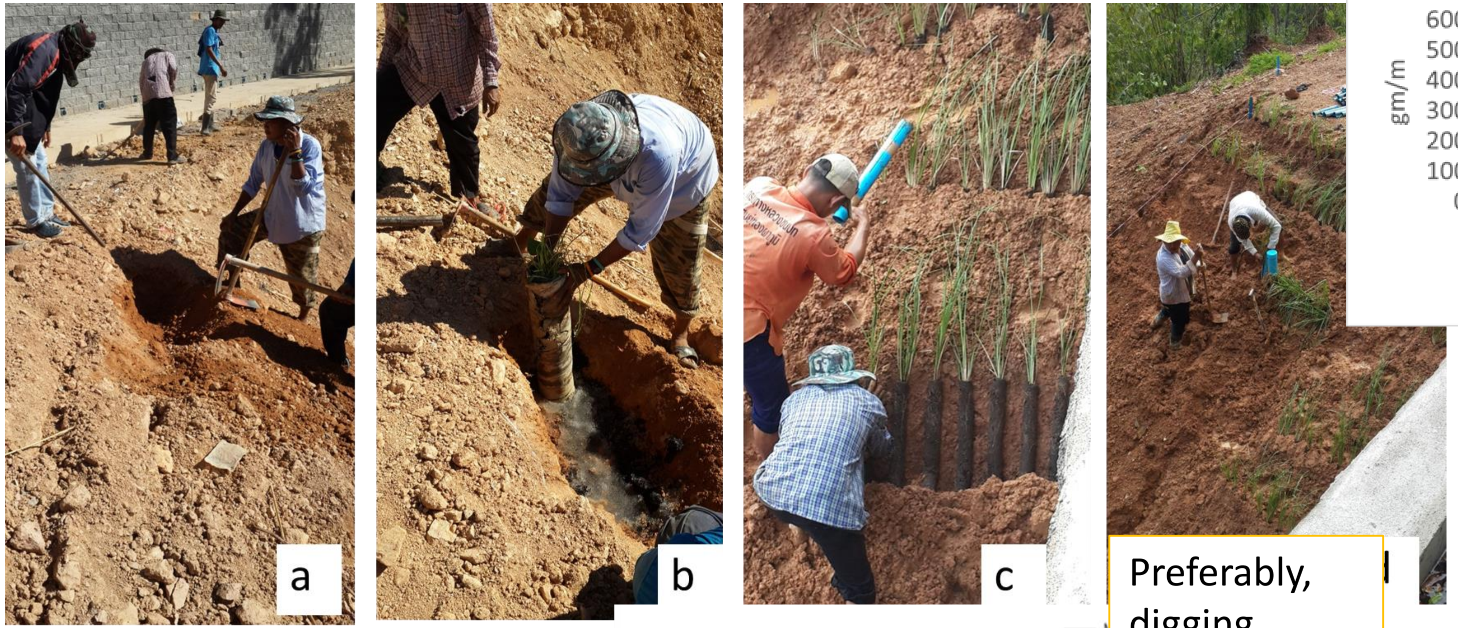
Vetiver tube plant: lab results

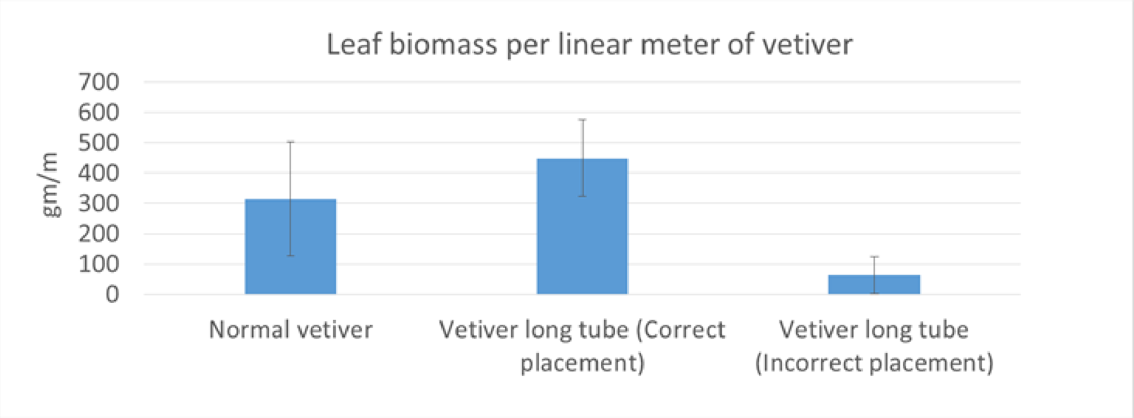
- In terms of the leaf biomass, PVC and paper tubes tended to yield the higher growth per plant, while the cement and bamboo tubes did not have as good result.
- Possibly, the inner tubular space inside the bamboo were irregular making it hard for soil to fill up inside the space, thus more difficult for root to penetrate. Fungi in some of the bamboo tubes may damage the plants. For the cement tube, the moisture may evaporate easily during growing.
- PVC pipe was thus considered to be most feasible, since the pipes can be reused afterwards. Also considering the ease of transportation to the site, PVC pipes with 50m diameter and 0.5m length are selected for field trial as presented thereafter.





Vetiver tube plant: Field trial

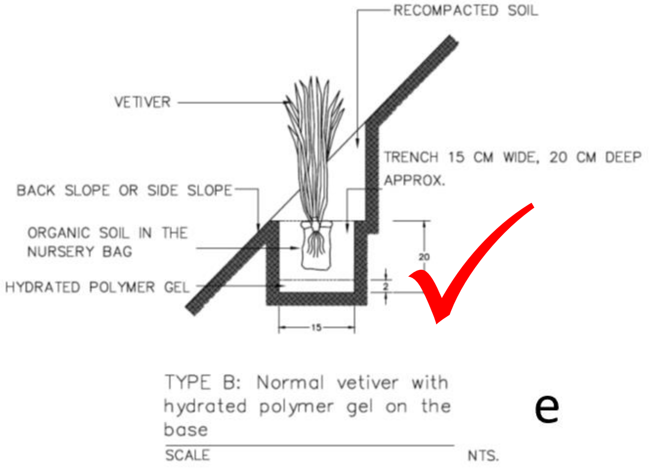




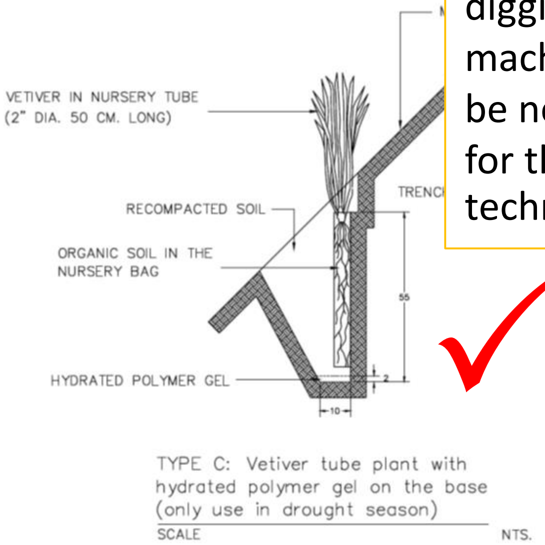
any rain or watering)

- Vetiver long tube yielded a better result than normal vetiver if done correctly (f), while may have adverse effect if applied inappropriately (g).

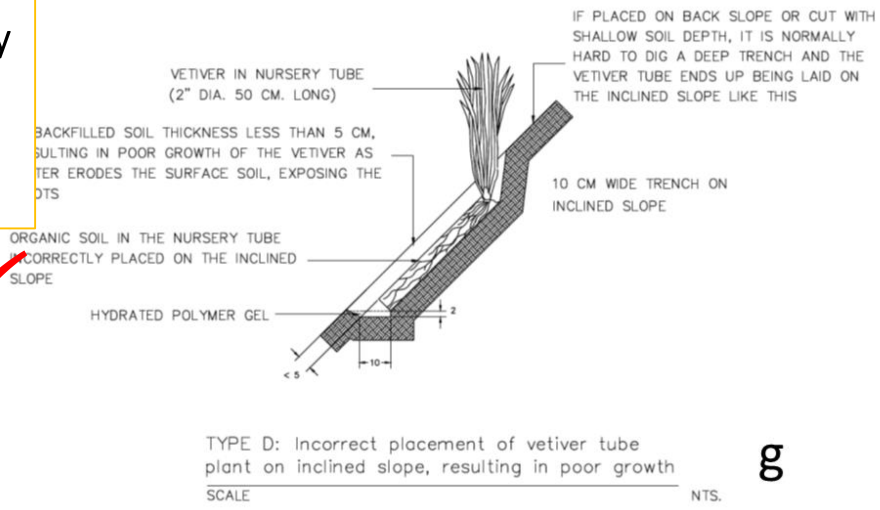
Preferably, digging machine may be needed for this technique



e



f



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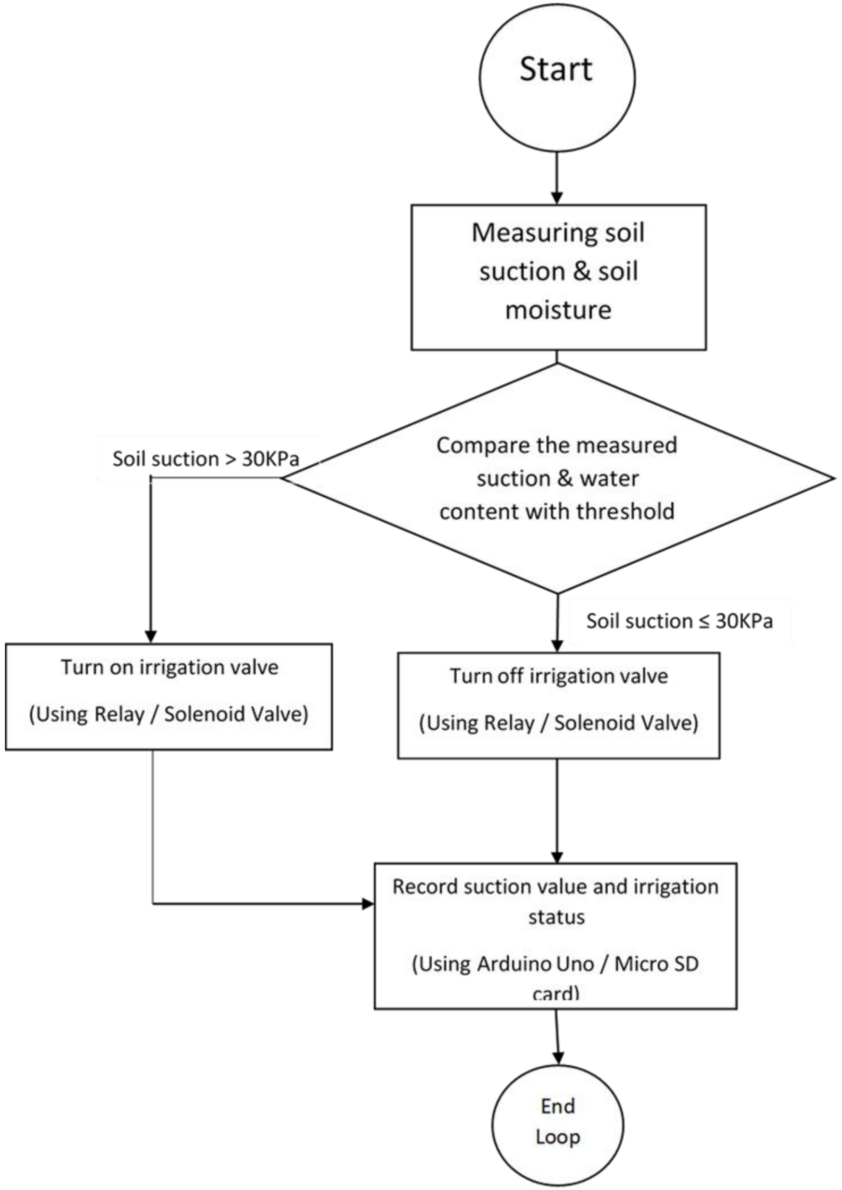
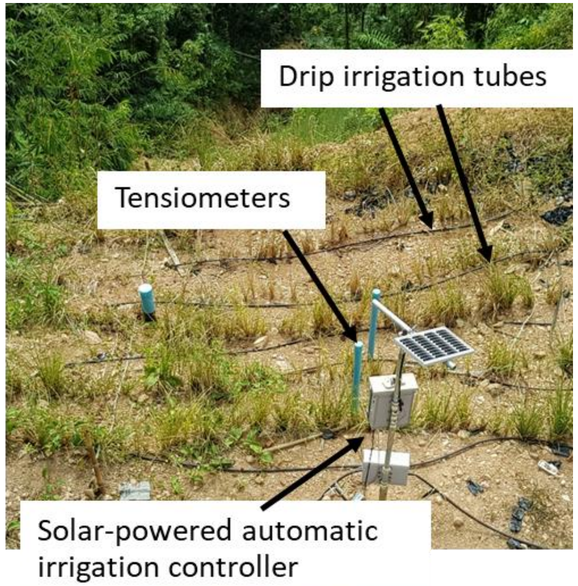
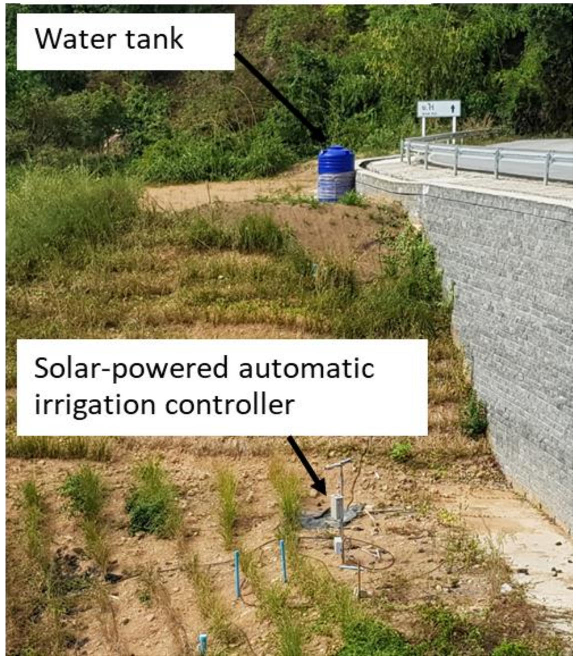






- Maneechote (2003) amongst the first who systematically developed the drip tape irrigation system for vetiver grass for highway side slope protection.
- This current study further develop the irrigation control system based on moisture sensor and suction measurement using tensiometer.
- The optimum suction and moisture level was based on Mahannopkul and Jotisankasa (2019) to be **10-20 kPa of suction and 20-30% of** volumetric water content depending on the soil types, root contents, and SWRC as shown

Rural road-4088 Kanchanaburi case study

- Soil slopes below GRS wall often suffered from continuous erosion lead to global wall failure
- Erosion rills first appeared in March 2018 next to the wall, and the wall movement then began.
- In May 2018, a beginning of rainy season, vetiver tube plant and normal vetiver were planted along the contour. The movement of the wall was at its peak in June 2018 (Figure 10c), after which a small earth bund was made above the vetiver hedgerow as level spreader to divert surface water away from the slope.
- Vetiver system appeared to be progressively established and the wall movement appeared to stop as witnessed by no further crack widening.

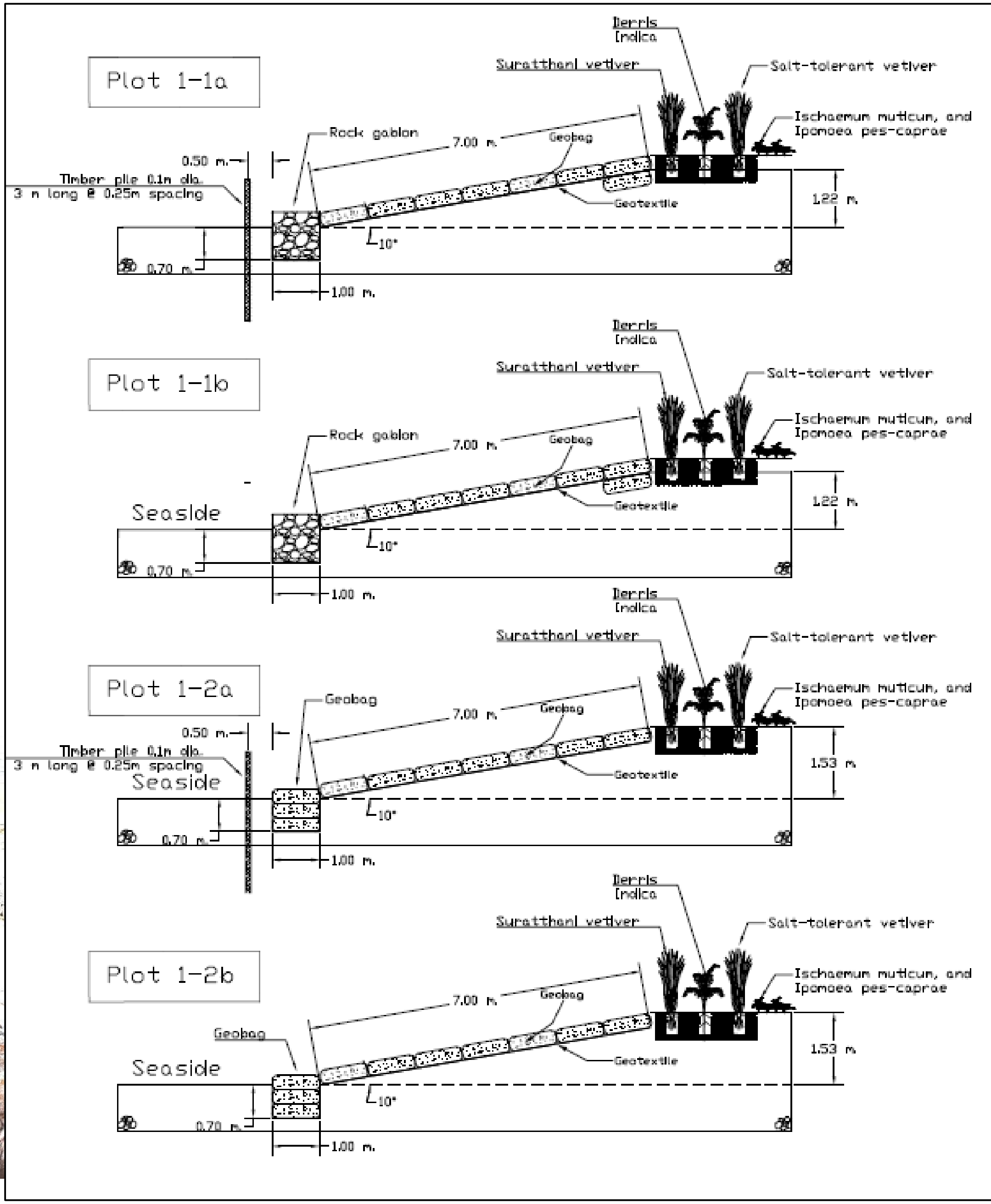
Erosion of the slope below was stopped at the vetiver front. The efficiency of the VS was demonstrated at this site

A case study of coastal area stabilization

- Located at the Beach front of Sittiporn Kriddakorn Research Station of Kasetsart University, Prachuap Khiri Khan. The studied area divided into two zones. Zone 1 at the beach front and Zone 2 along the Klong Tha-si-nuan canal. The beach front suffered from coastal erosion.
- In Zone 1, 6 treatment plots namely, 1-1a, 1-1b, 1-2a, 1-2b, 1-3 (only plants) and 1-4 (control).
- Prior to this study, only vetiver system alone had been used at this beach front in year 2014 and was severely eroded by wave attack, and thus other solution using VS in combination with tree, other grasses and structural component was then sought after.

A case study of coastal area stabilization

- Different combinations of engineering techniques were used as beach revetment for plots (1-1a&b and 1-2a&b) i.e. driven timber pile (3m long with 0.1m diameter at 0.25m spacing); gabion toe wall (1m high and 1 wide); geotextile bag (1*1.5 m2 size) and geotextile sheet
- Behind the structural component, vetiver system and tree are used to further stabilize the coast to maximize the anchor effect or tree tap roots and vetiver dense fibrous roots

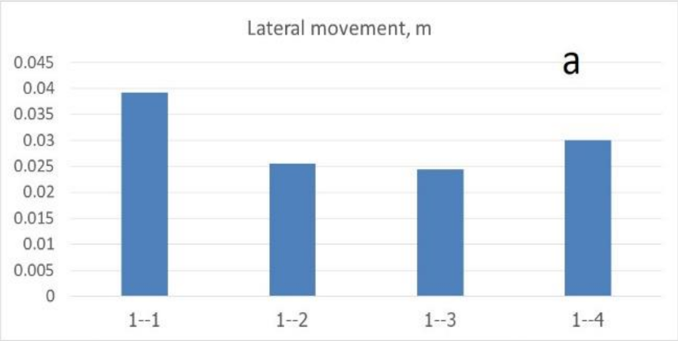


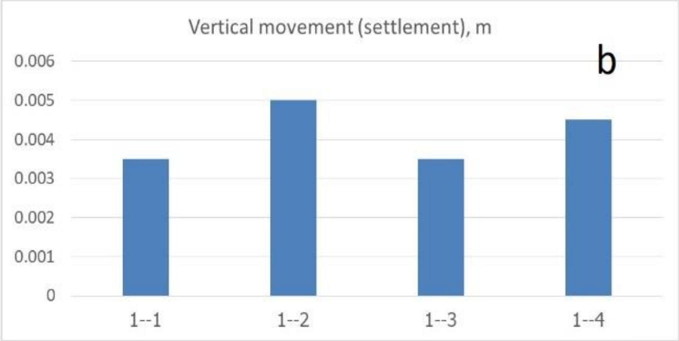
- Two types of vetiver were used, namely, Surathani ecotype and salt-tolerant type developed using in-vitro tetraploid induction technique (Nanakorn, 2015, Maikami et al., 2017).
- Also planted are *Derris indica (Lamk.)* Benn, locally known as Yee-Talae tree, and local beach front grasses, i.e. *Ischaemum muticum*, and *Ipomoea pes-caprae* (L.) R.br.
- Due to the severe saline environment at the beach front, mini-sprinkler irrigation, hydrated polymer gel and amended fertilized soil had to be used to assist the plant growth.
- Tree species, *Derris indica,* locally found in the beach environment in Southern Thailand (also potential for bio-diesel production) was planted with 1.5 m spacing, two types of which were used, namely, layerings and seedlings

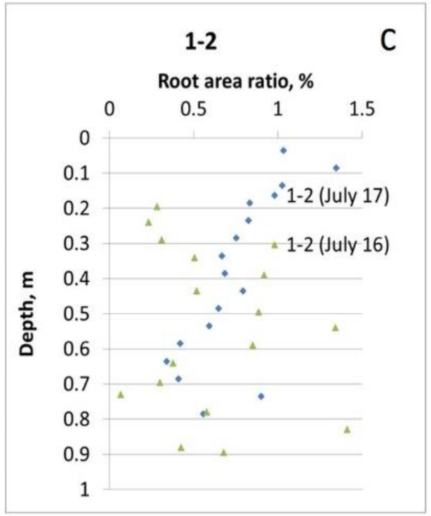
after the stabilization work, sand was deposited behind the timber piles and fully covered the geotextile bag. (there were times when sand was washed away during the high tide (c) but once vetiver hedgerow was established, *Ischaemum muticum*, and *Ipomoea pes-caprae* (L.) R.br. crept over the geotextile bags (d &c), the sand beach behind the piles were fully vegetated and stable as shown in e.

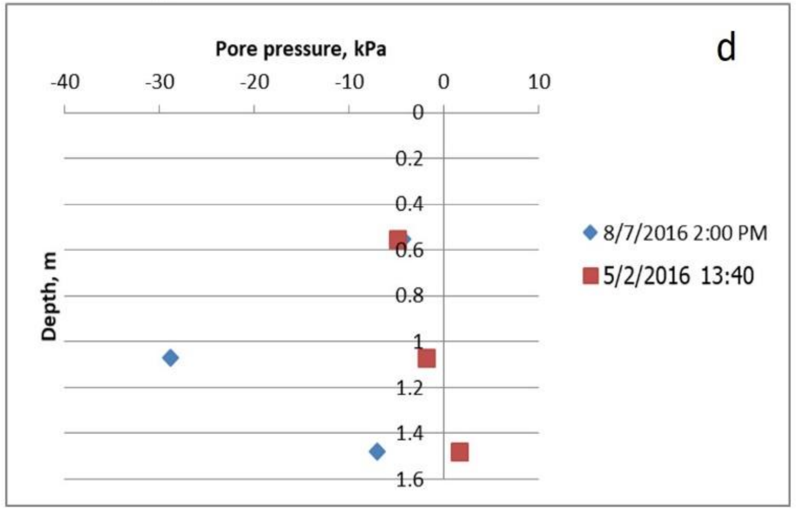
Monitoring results

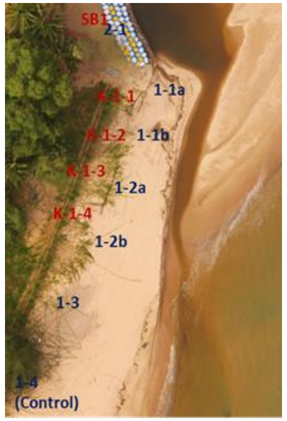
- Surface movement using total station survey
- Soil moisture potential using tensiometer
- Root concentration using minirhizotron

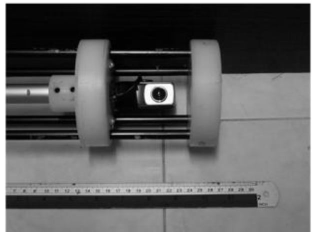


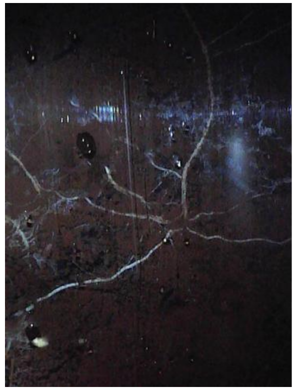






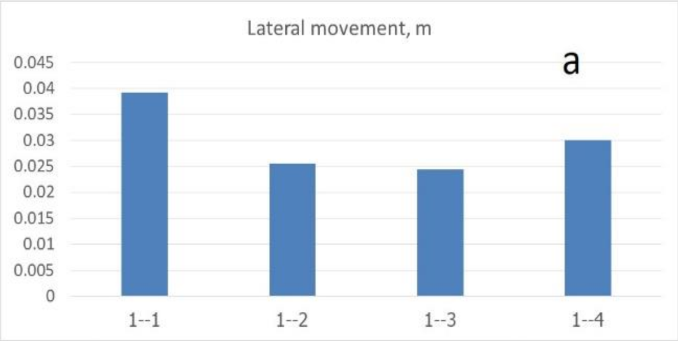


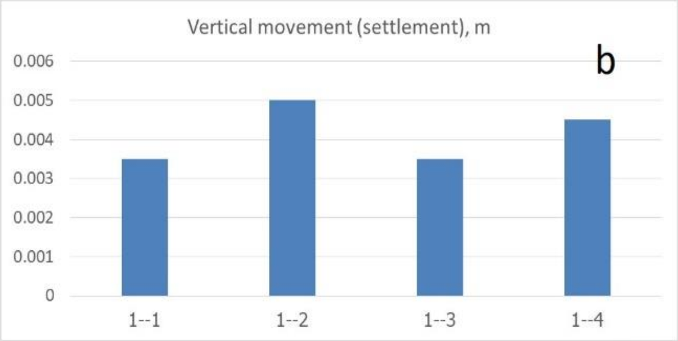


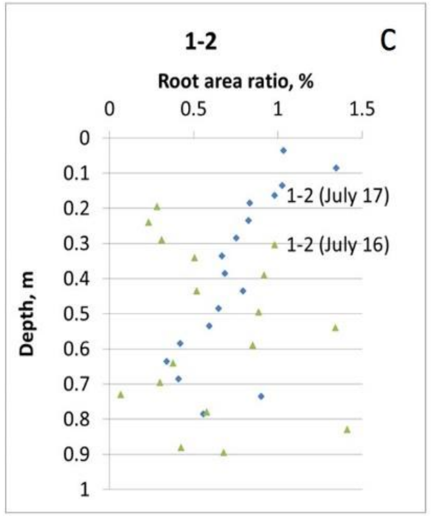


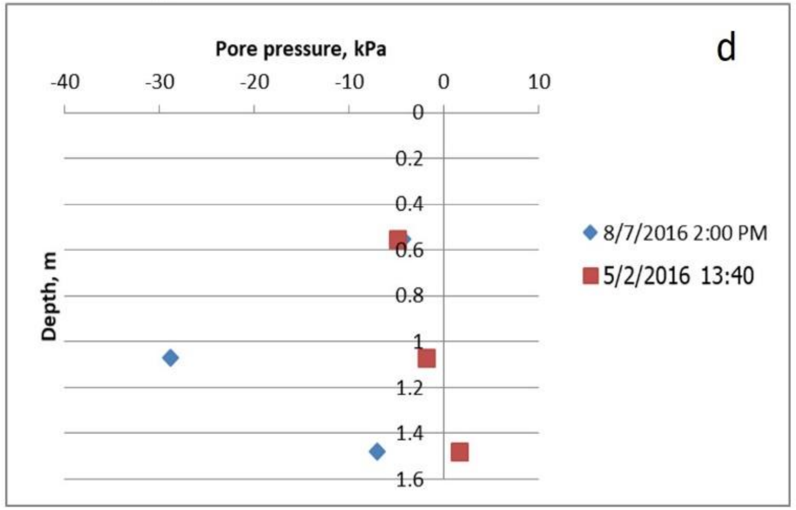
Monitoring results

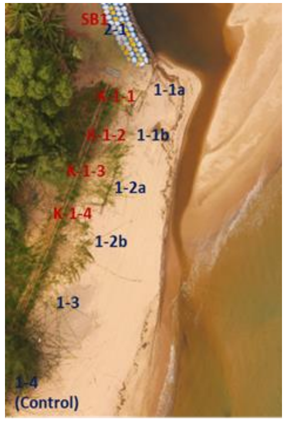
- Vertical movements for all treatments were only 3-5 mm and the lateral movement was highest in plot1-1 being about 4cm as it is closer to the cannal mouth, while the others were about 2.5-3cm.

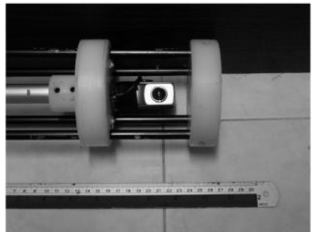


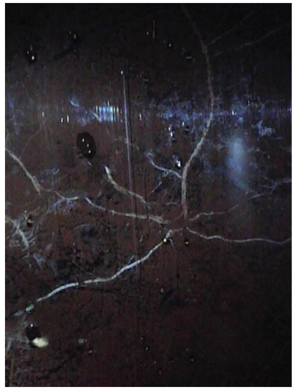






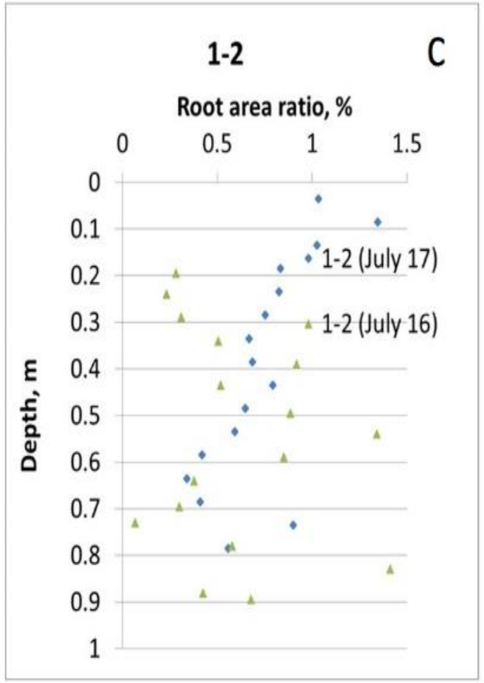


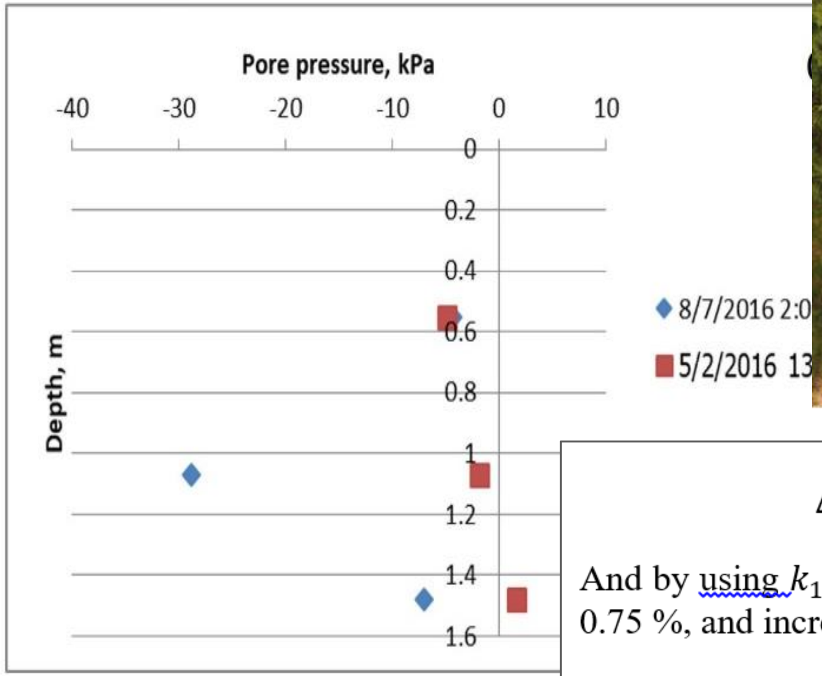


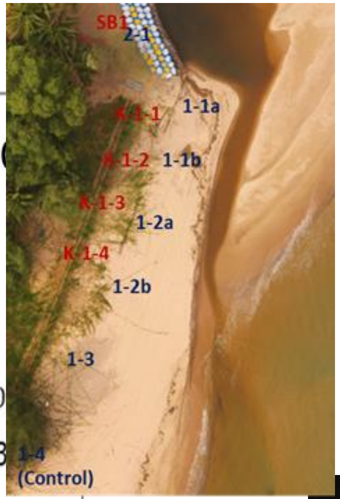


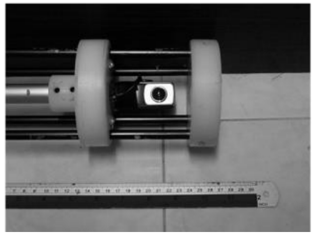
Monitoring results

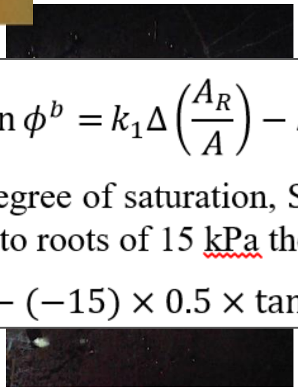
- The typical root area ratio as monitored using mini-rhizotron located near the vetiver grass, which suggested the root zone with area ratio of 0.5 to 1% down to depth of 0.8 m (average of 0.75%).
- The value of suction in the root zone as measured using tensiometer was shown to vary from 2 to 30 kPa (d). This suction was expected to be cause by plant evapotranspiration.
- This increase in shear strength of the vegetated soil at the beach surface provided additional resistance to erosive force

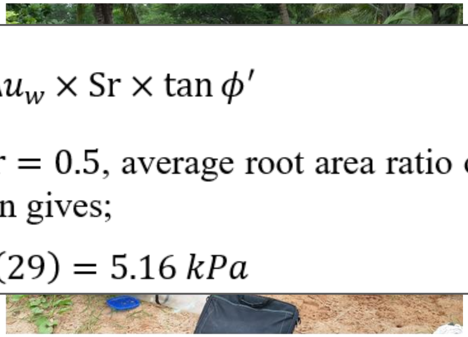












$$\Delta\tau = \Delta c^r - \Delta u_w \tan\phi^b = k_1 \Delta\left(\frac{A_R}{A}\right) - \Delta u_w \times Sr \times \tan\phi'$$

And by using $k_1 = 1.34\ kPa/\%$, degree of saturation, Sr = 0.5, average root area ratio of 0.75 %, and increase of suction due to roots of 15 kPa then gives;

$$\Delta\tau = 1.34 \times 0.75 - (-15) \times 0.5 \times \tan(29) = 5.16\ kPa$$

Observations on plant growth at the beach front

- Both types of vetivers, i.e. Surathani ecotype and salt tolerant type equally survived the highly saline condition at the beach (Kittiwatsopon, 2018). Its survival depended very much on the provided irrigation and soil amendment.
- *Ischaemum muticum*, and *Ipomoea pes-caprae* (L.) grass cover over the geotextile bags were effective in preventing the erosion on the beach in front of vetiver hedgerow.
- *Derris indica* obtained layerings showed a faster growth rate than those from seedlings during the first 2 years, while in the 3rd year, those from seedlings grew faster. This was expected to be caused by difference in the root systems of the two types.

Conclusions

- Recent research at Kasetsart University both in laboratory and field trials incorporated several engineering techniques to enhance the VS performance in highly erosive environment.
- According to tests on shear and water retention behaviour of vetiver-root reinforced soil with varying root concentrations and moisture conditions, a higher specific water capacity was observed for rooted soils and there was an optimum level of soil moisture at suction around 10-20 kPa at which the reinforcement of vetiver roots on shear strength became greatest. This suction can be used as a threshold for automatic irrigation system.
- Various materials for vetiver nursery tube were tried. PVC pipe was considered to be most feasible in this study, since the pipes can be reused afterwards and the growth rate was one of the highest types. This technique is effective if used with hydrated polymer gel for growing vetiver during drought.
- For coastal protection, VS was used with local plants such as *Derris indica* (Lamk.) Benn, locally known as Yee-Talae tree, and local beach front grasses, i.e. *Ischaemum muticum*, and *Ipomoea pes-caprae* (L.) R.br, showing good results. The plants were supplemented by various engineering techniques such as driven timber pile, gabion toe wall and geotextile bag. Irrigation and soil amendment are also a key to the success of VS along the beach.

Acknowledgements

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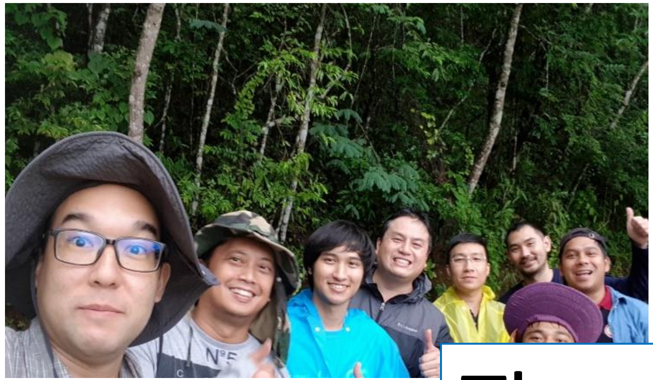
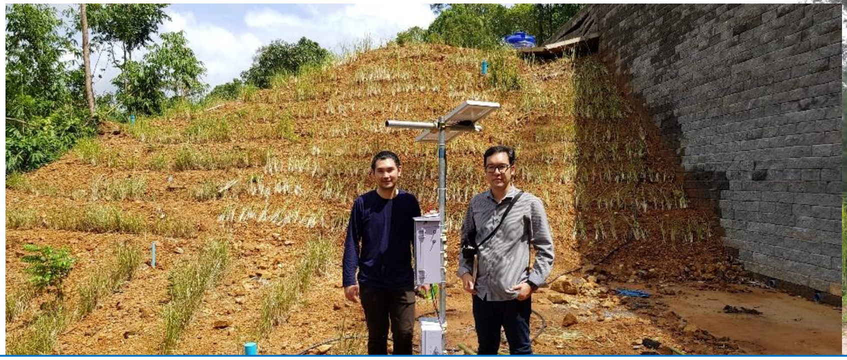


Thank you very much ขอบคุณครับ