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Do Vegetation Root Systems Affect Landslide Mobility?

– A Flume Experiment –

Rozaqqa NOVIANDI[1*], Takashi GOMI[2], Roy C. SIDLE[3], Rasis P. RITONGA[1], and Yuko HASUNUMA[4]

[1] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Japan
[2] Graduate School of Agriculture, Tokyo University of Agriculture and Technology, Japan
[3] Mountain Societies Research Institute, University of Central Asia, Tajikistan
[4] Nippon Steel Metal Products, Co., Ltd., Japan

What is a Landslide?

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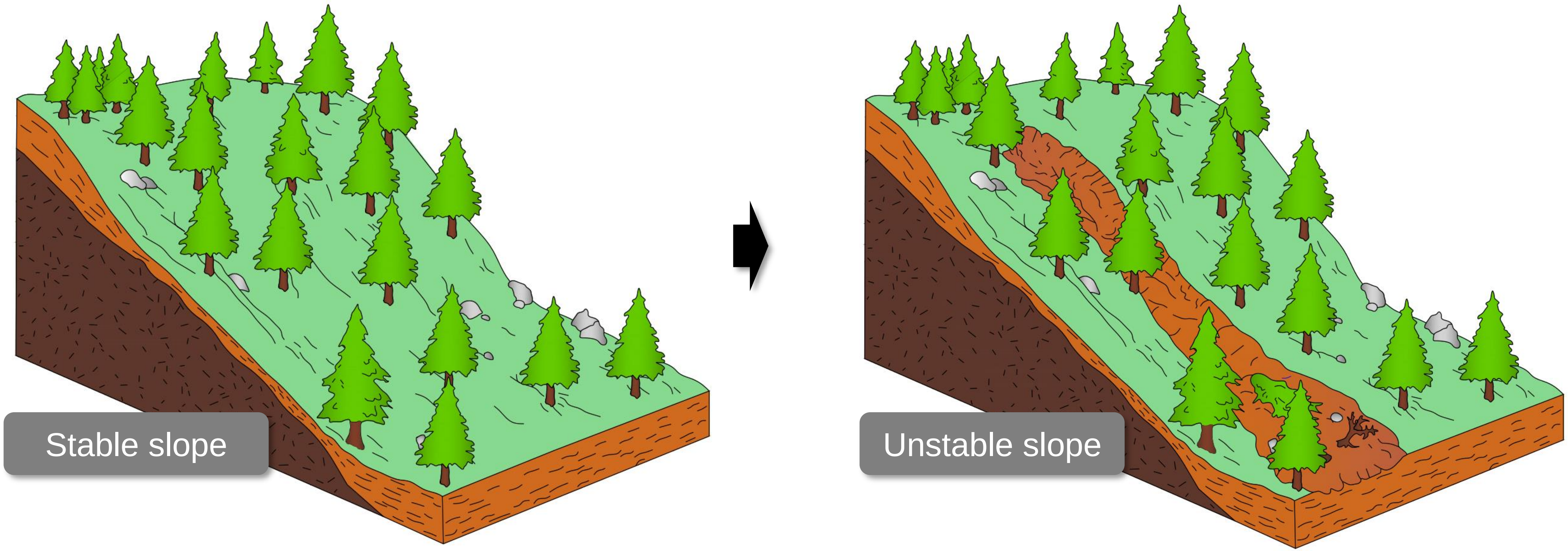
- Landslide is a **down-slope movement** of slope materials under gravitational actions (*USGS, 2008*).
- In general, landslides can be found in **hilly** and **mountainous areas** due to extreme rainfall and earthquake (*Sidle, 2013*).



Rising population due to economic development in mountainous areas may escalate landslide impacts worldwide (*Leuven, 2021*).

Landslide mobility

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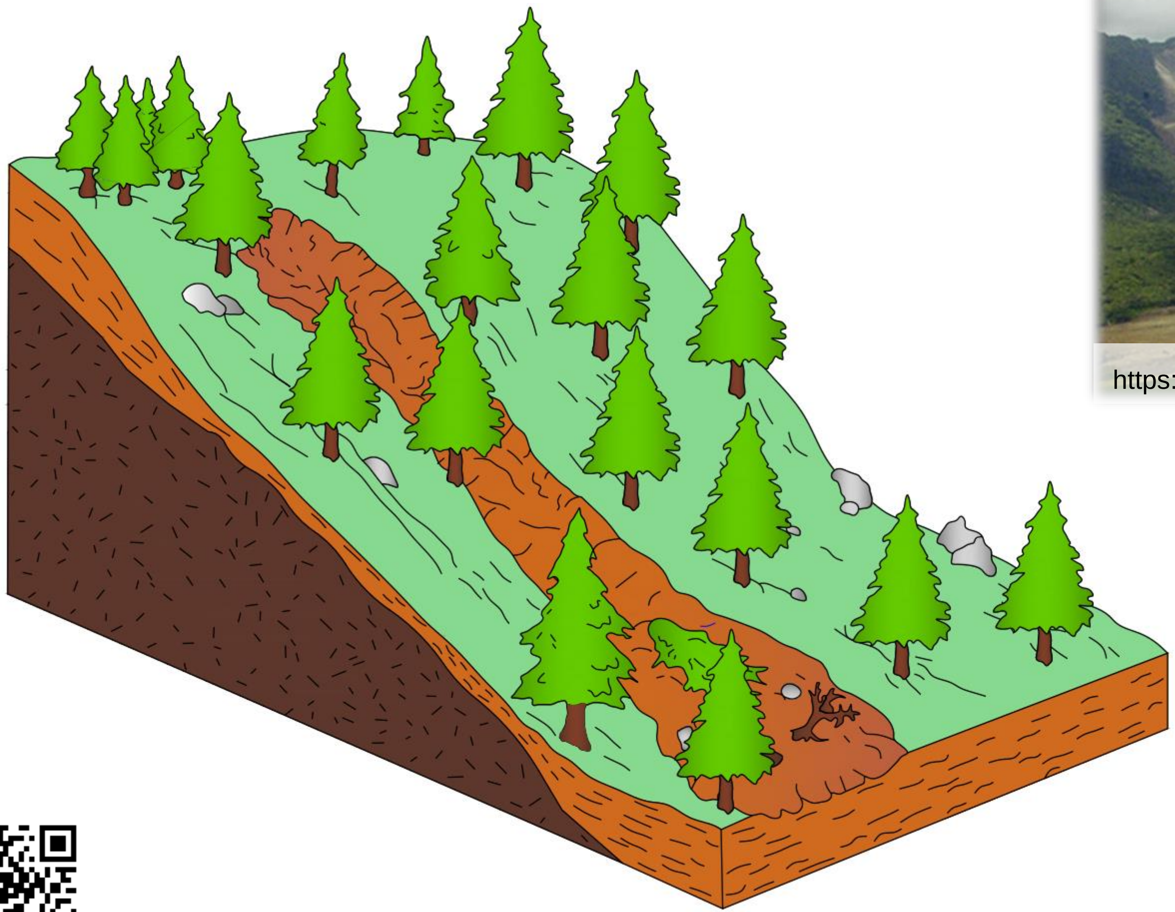
- The magnitude of **landslide impacts** depends strongly on how far landslide sediments travel, widely known as **landslide mobility** (*Iverson et al., 2015*).



https://alchetron.com/2006-Southern-Leyte-mudslide

The 2006 Leyte landslide, Phillipines

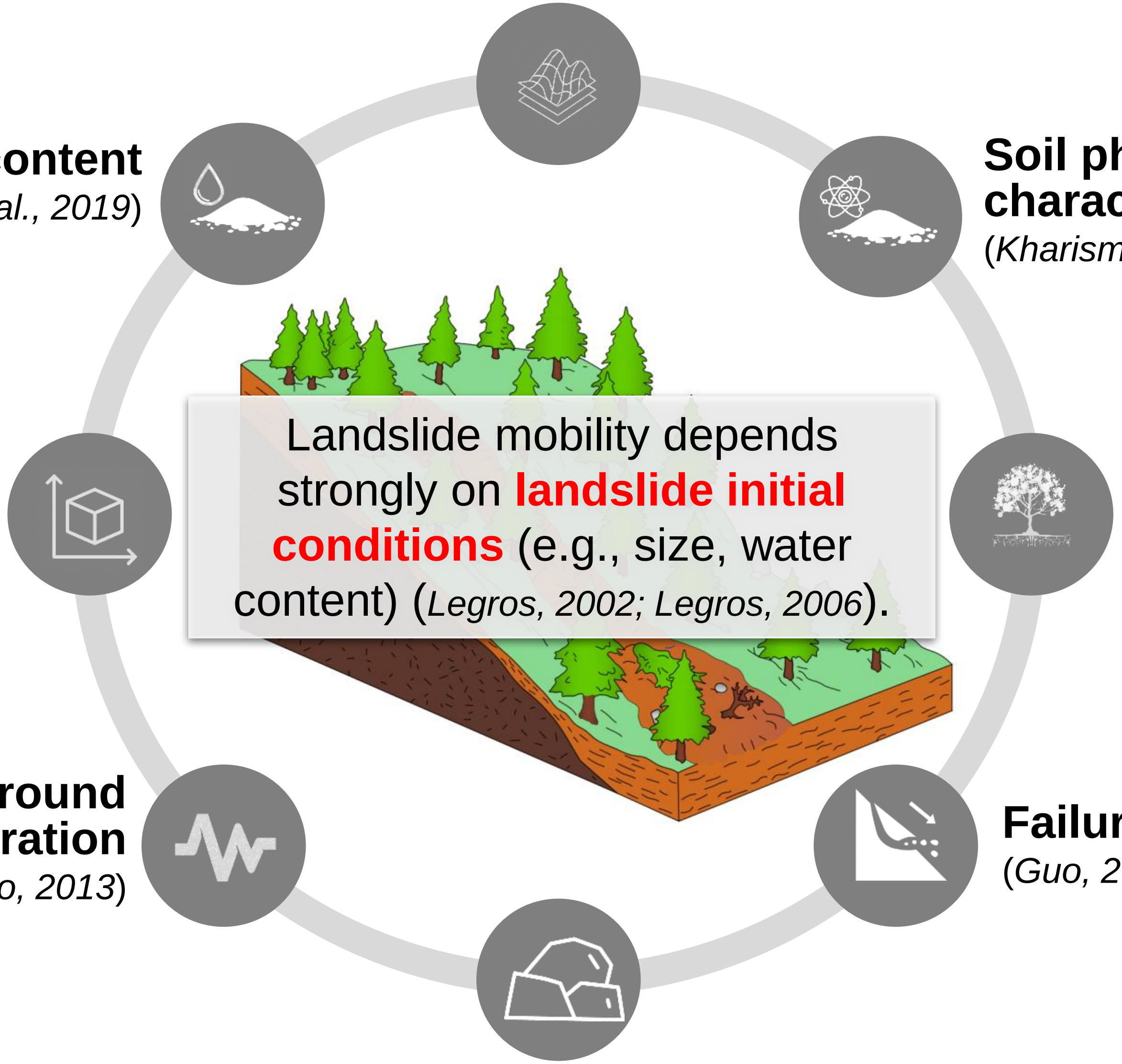
Traveled on **3 km** distance, causing **>500 fatalities** (*Evans et al., 2007*).

The 2014 Oso landslide, USA

Crossed **1-km-wide** floodplain, causing **42 fatalities** (*Iverson et al,, 2015*).

https://en.wikipedia.org/wiki/2014_Oso_mudslide

Factors that control landslide mobility



Landslide mobility depends strongly on **landslide initial conditions** (e.g., size, water content) (*Legros, 2002; Legros, 2006*).

Topography (*Kharismalatri et al., 2017*)

Soil physical characteristics (*Kharismalatri et al., 2019*)

Land cover and root reinforcement (*Ritonga et al., 2020*; *Koyanagi et al., 2020*)

Failure mechanism (*Guo, 2013*)

Bedrock type (*Aydan and Hamada, 2009*)

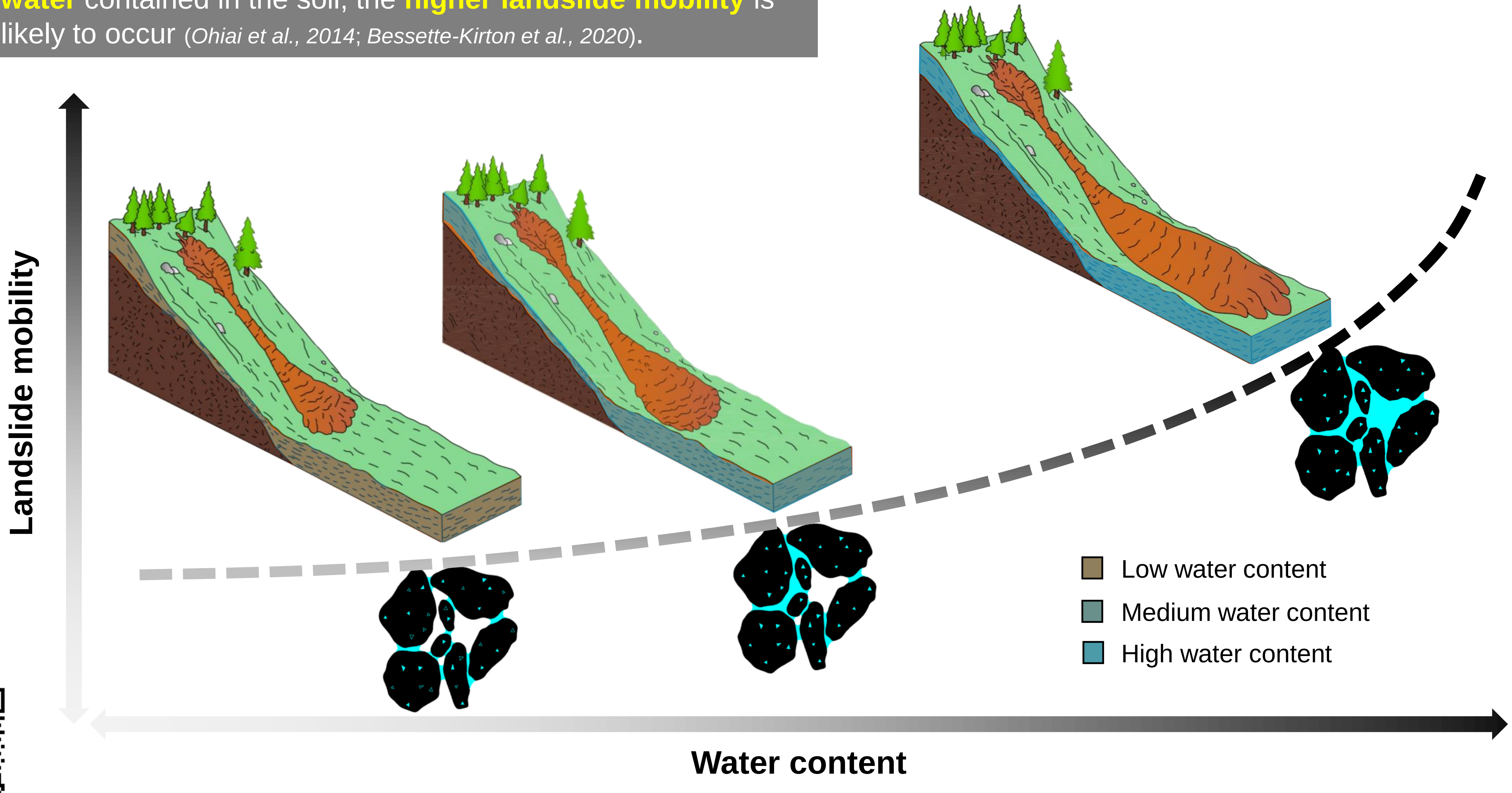
Peak ground acceleration (*Guo, 2013*)

Volume (*Guo et al., 2014*)

Water content (*Zhou et al., 2019*)

The effect of water content on landslide mobility

Water **fluidizes** landslide mass to move downslope. The **more water** contained in the soil; the **higher landslide mobility** is likely to occur (*Ohiai et al., 2014*; *Bessette-Kirton et al., 2020*).



The effect of size on landslide mobility

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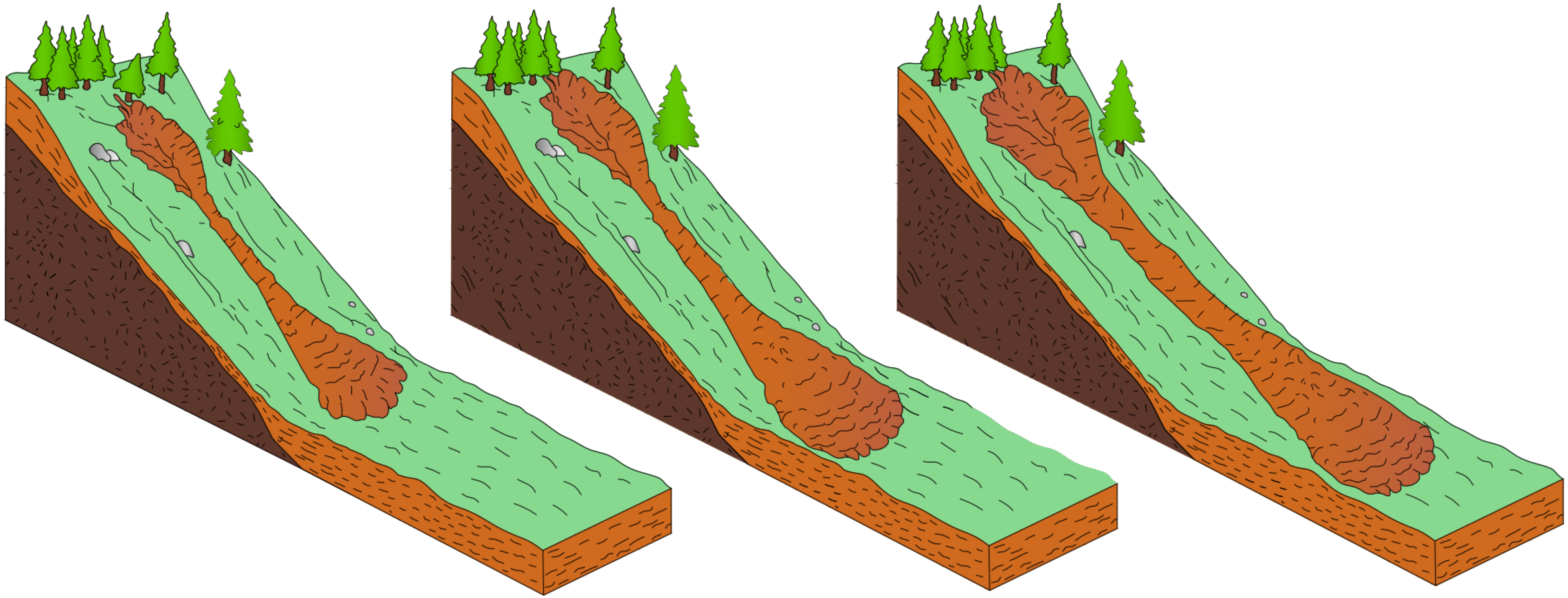
Previous studies suggested **size-dependent mobility**, which became the key mechanisms for landslide sediment movement in the Earth and other planetary bodies (e.g., *Legros, 2002*).

Larger **size** → Larger **mass**
→ Greater **momentum**



Landslide size

Low ← → **High**

Mobility

Vegetation root systems affect landslide initial condition

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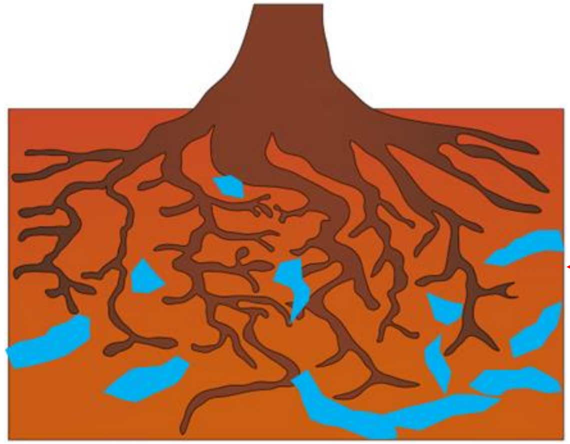
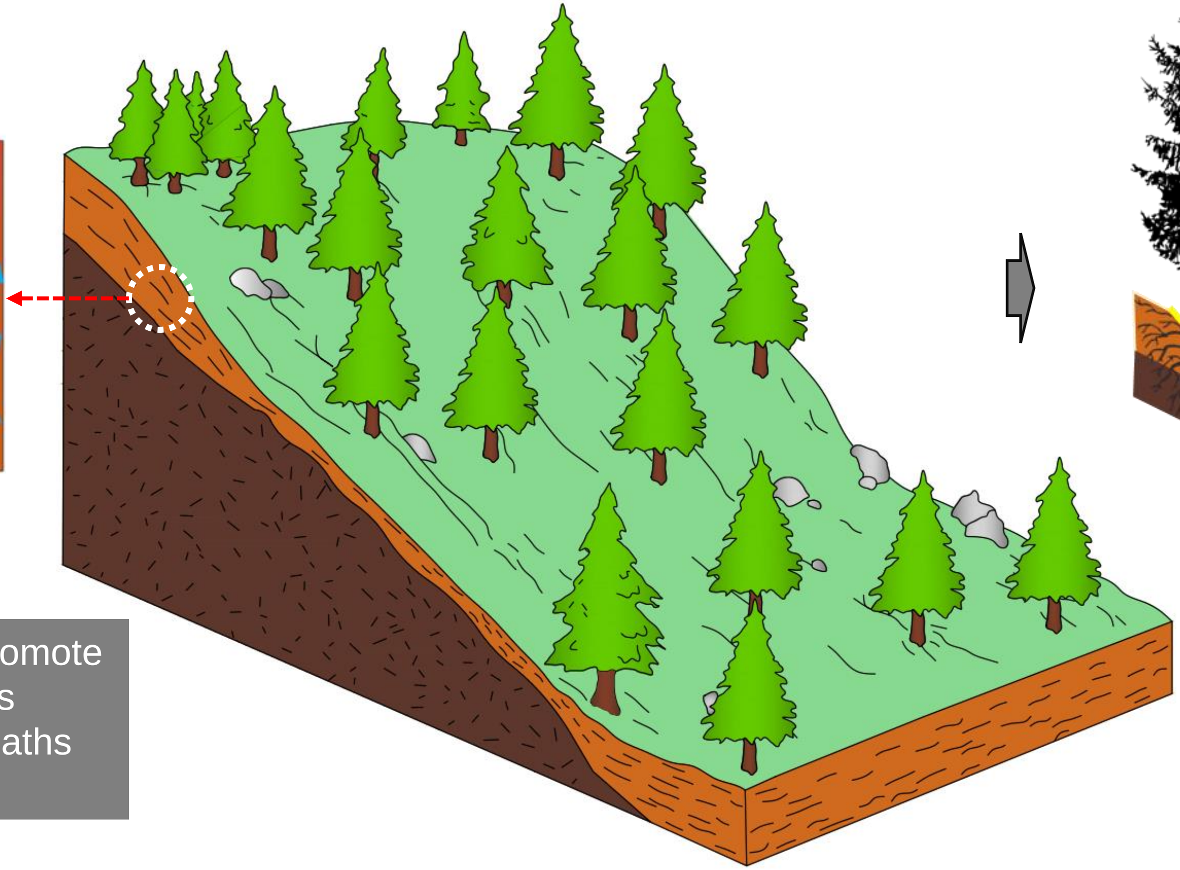
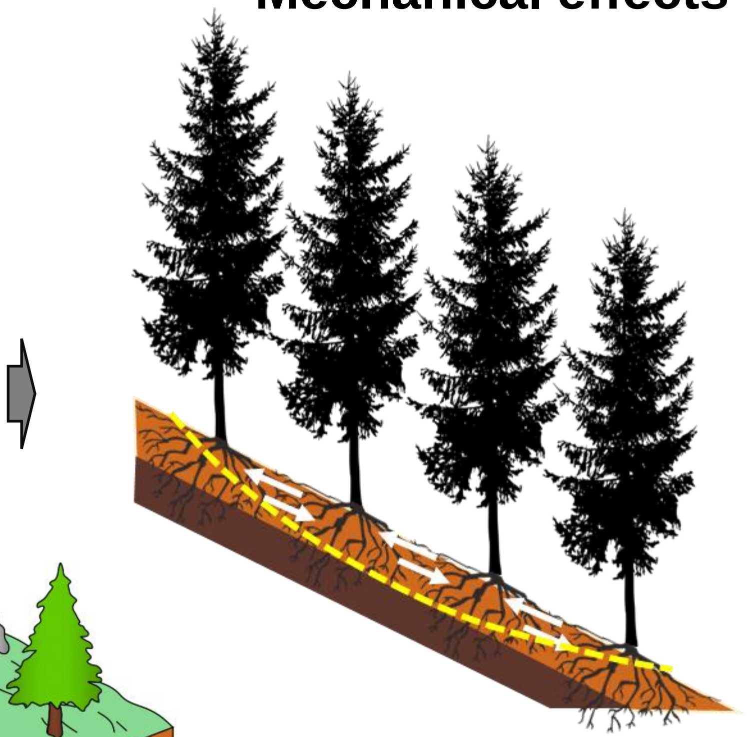
Hydrological effects

Mechanical effects





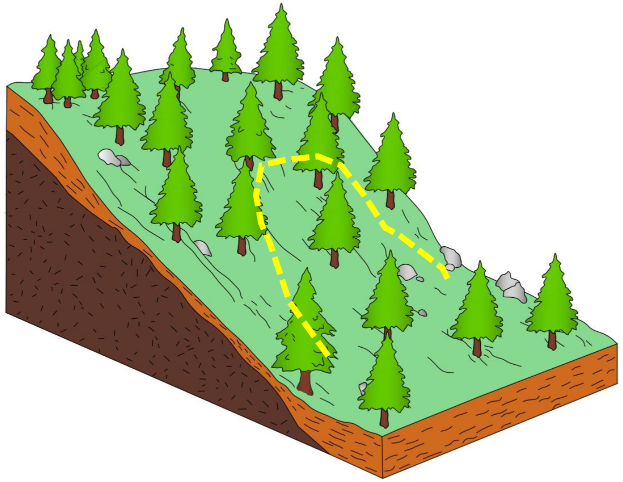


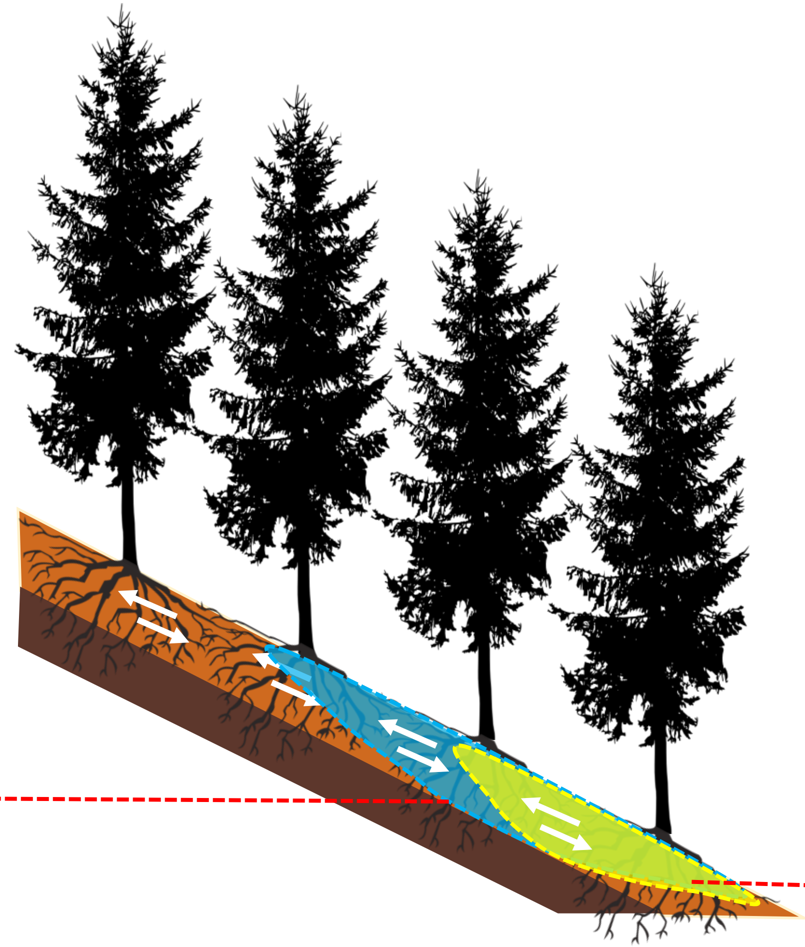
Plant roots, alive or dead, can promote **slope drainage** by functioning as hillslope-scale preferential flow paths (*Ghestem et al., 2011*).

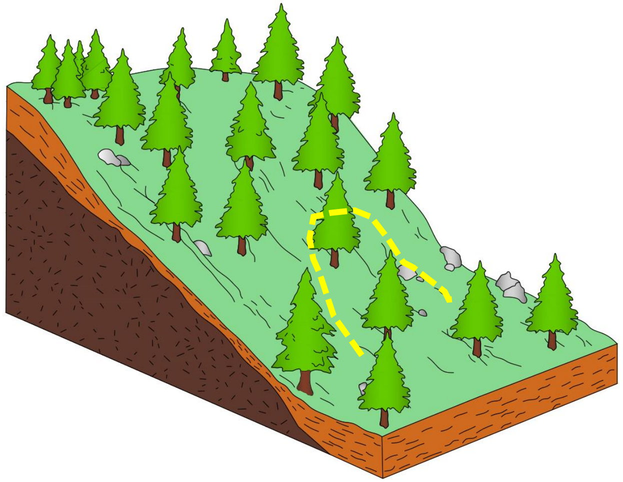
Lateral root reinforcement potentially alters landslide size (*Schwarz et al., 2010; Ritonga et al., 2021*).

Vegetation root systems, **mechanically and hydrologically**, may affect landslide **initial conditions**.

Does root reinforcement affect landslide size?





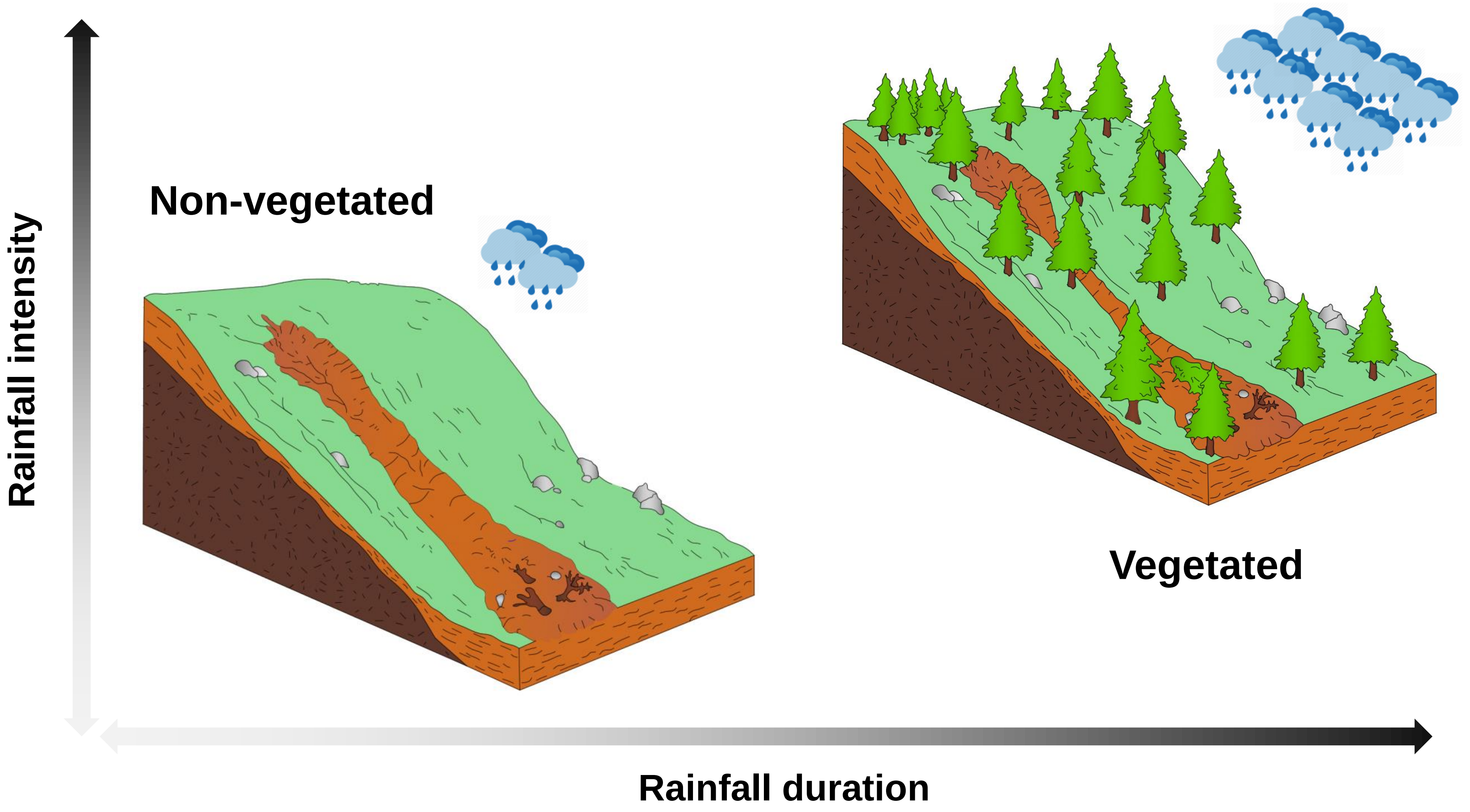


Greater landslide size (gravitational force) is needed to destabilize the slope because of additional reinforcement by lateral roots network (*Schwarz et al., 2010*).

Extended lateral tree root networks provide more cohesion, which may consequently **moderate landslide area** (*Ritonga et al., 2021*).

The effect of root reinforcement on landslide size is still **unclear** and becomes a matter of **debate**.

Does root reinforcement affect initial soil water content?



The presence of root systems increase the **threshold** for landslide initiation (*Wang et al., 2020*), which may alter initial water content.

Knowledge gap and objective

Even though numerous studies have investigated root related landslides, **however:**

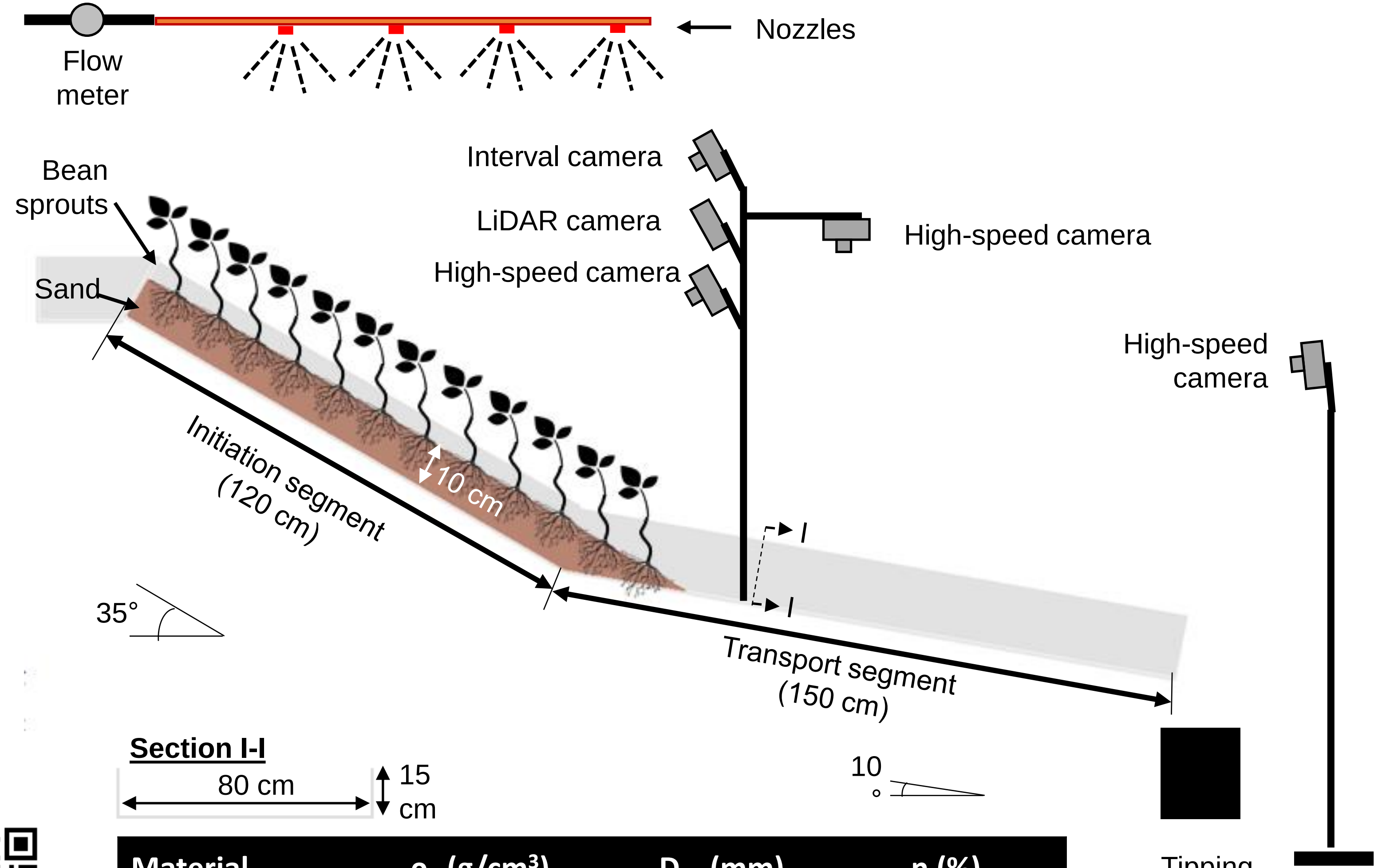
- The effect of vegetation root systems on landslide initial conditions (water content and size) remain **unclear**.
- Studies on root related landslides mainly focused on landslide initiation. Thus, the effect of vegetation root systems on landslide mobility is **not fully understood**.

Objective

- Evaluate the effect of vegetation root systems on **landslide initial conditions**.
- Examine the effect of changes in initial landslide conditions due to vegetation root systems on **landslide mobility**.

Flume apparatus

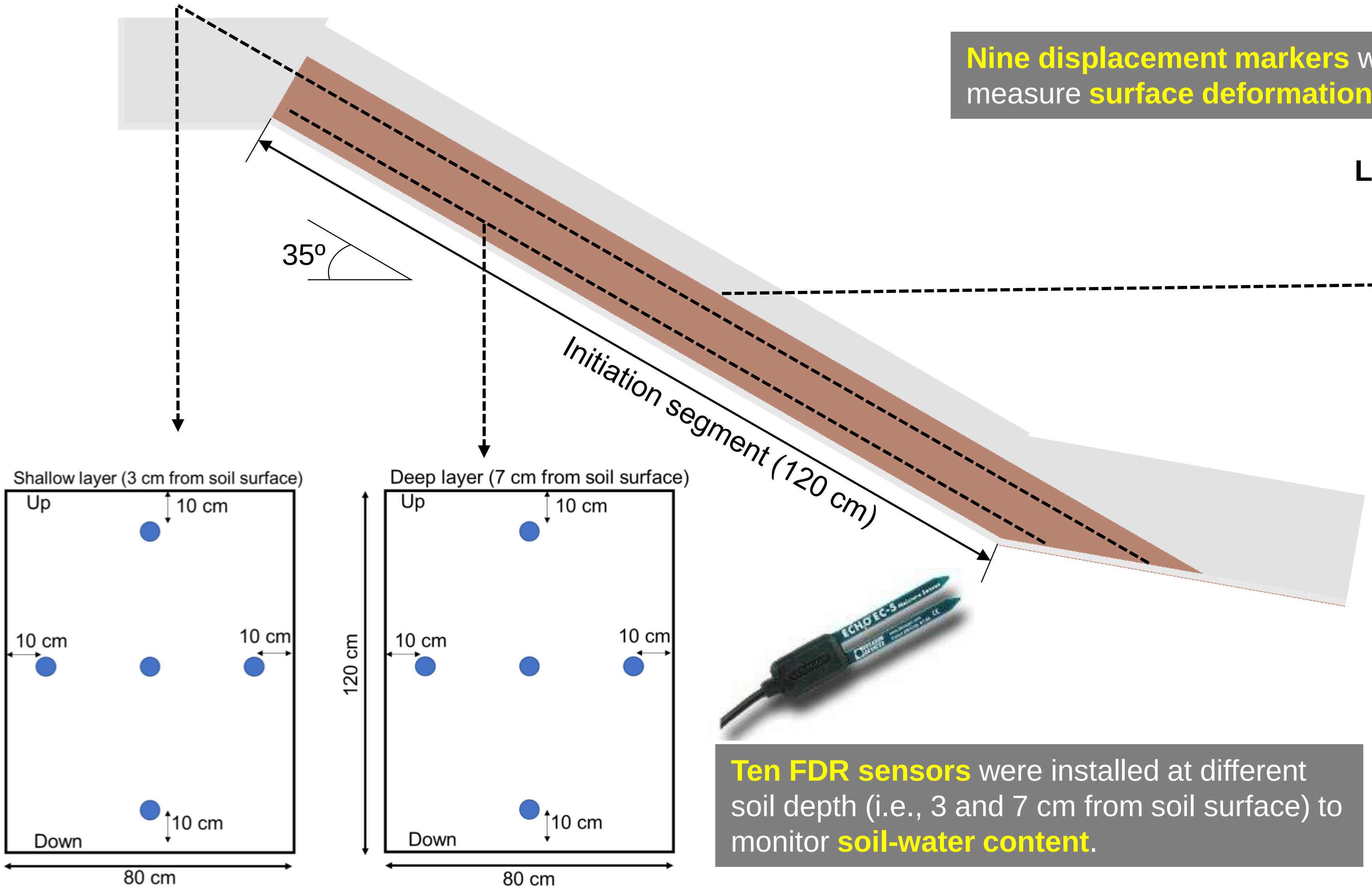
- A flume was constructed at 1/70 scale to simulate **rainfall-induced shallow landslides** where the root effects are effective.



Material	ρ_d (g/cm³)	D_{50} (mm)	n (%)
Sand	1.4	0.23	55.4

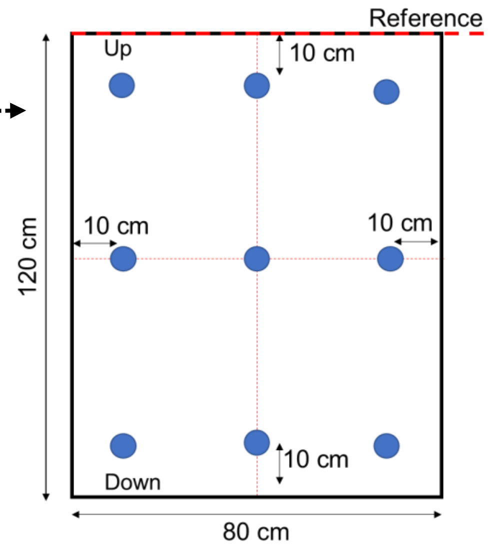
Instrumentation

Nine displacement markers were placed on soil surface to measure **surface deformation**.



Configuration of FDR sensors

Location of displacement markers

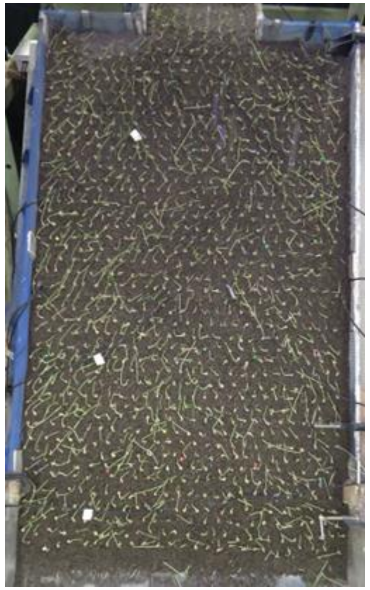


Ten FDR sensors were installed at different soil depth (i.e., 3 and 7 cm from soil surface) to monitor **soil-water content**.

Application of vegetation

https://www.kewpie.co.jp/

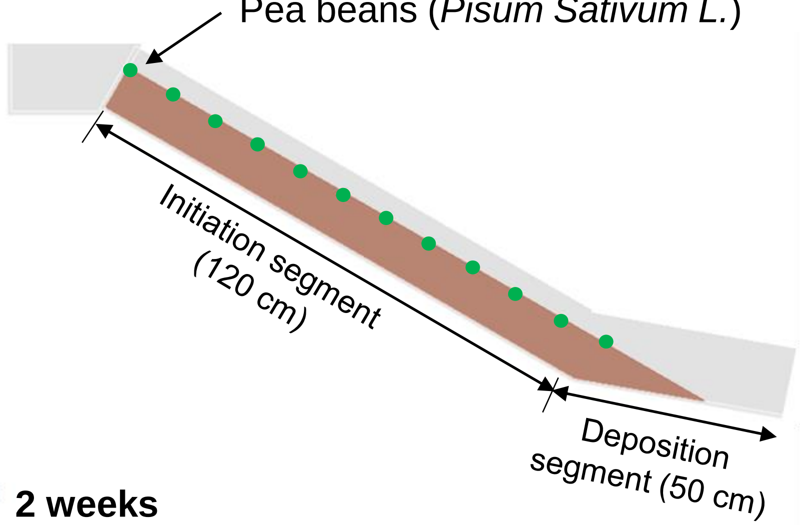
Vegetation density



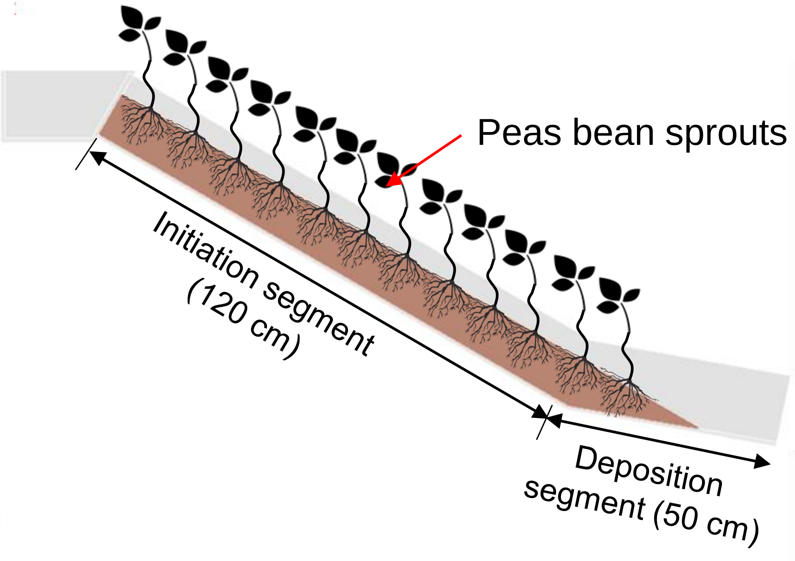
3 cm interval (2,200 stems/ha)

7 cm interval (400 stems/h)

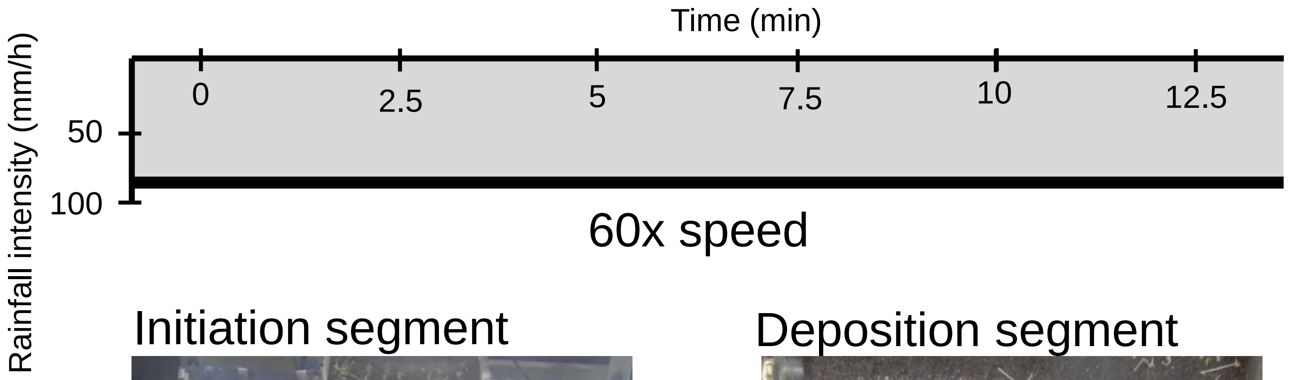
0 week



2 weeks



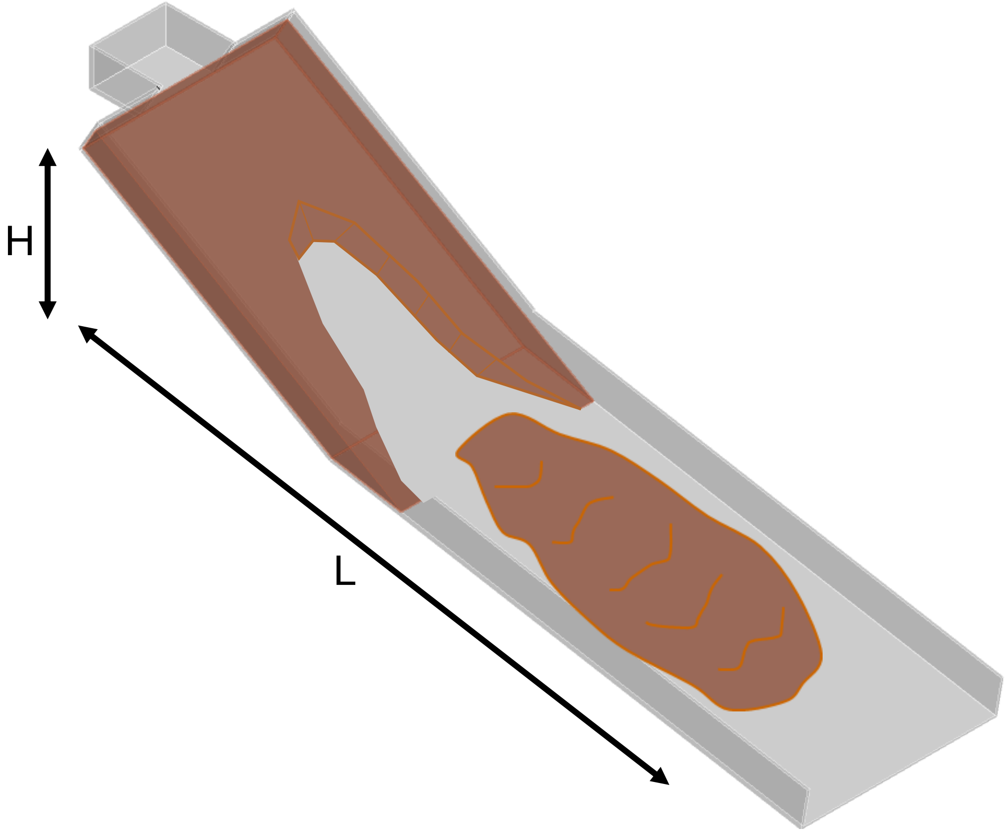
Experiment processes (example: 3 cm interval)



60x speed

Initiation segment

Deposition segment



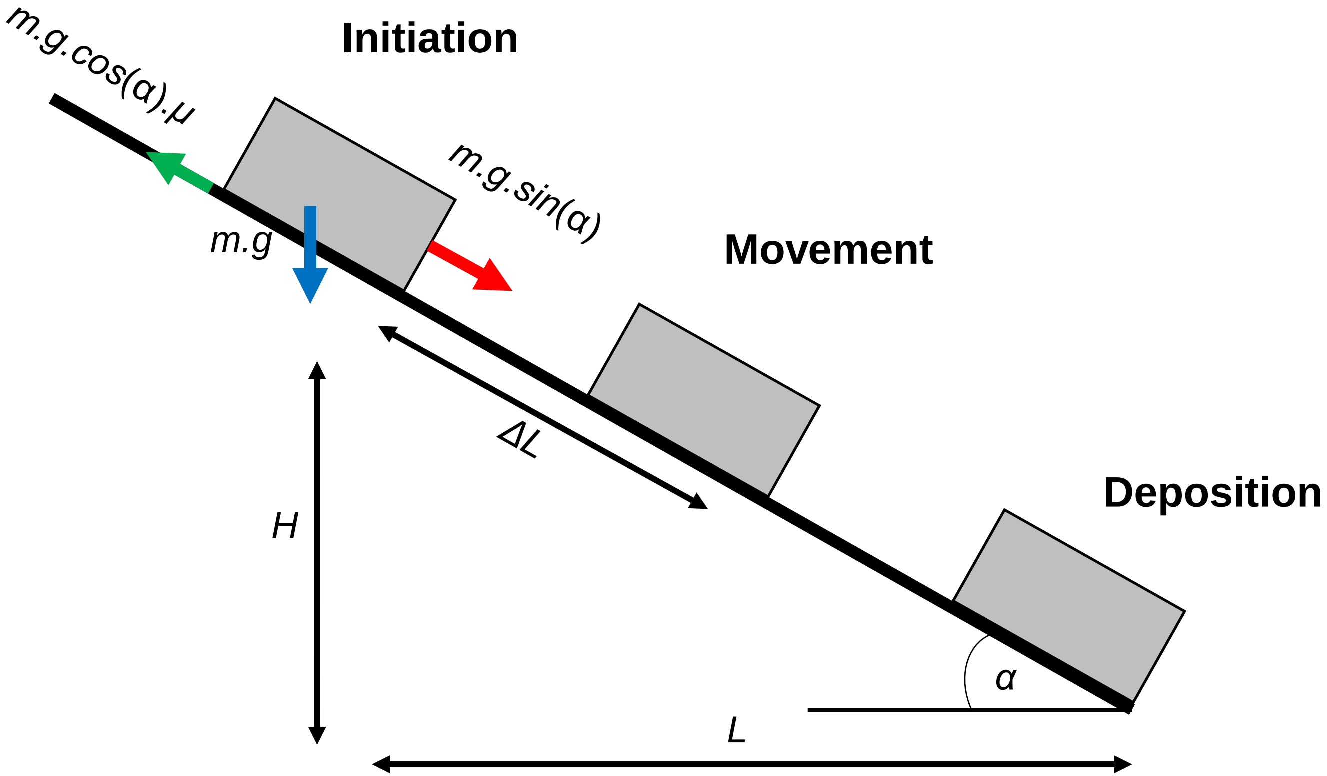
Measurement:

- Total travel distance (L)
- Total drop height (H)
- Water content
- Area

https://youtu.be/6xQVkVeSe9Y

Measurement of mobility

M : Mobility
µ : Friction coefficient
L : Total travel distance (cm)
H : Total drop height (cm)



$$\Delta E_m = F_{nc}\Delta L$$

$$E_{p_i} - E_{p_{i-1}} + E_{k_i} - E_{k_{i-1}} = mg\cos\alpha\,\mu\left(\frac{L}{\cos\alpha}\right)$$

$$mgh_i - mgh_{i-1} + \frac{1}{2}mv_i^2 - \frac{1}{2}mv_{i-1}^2 = mg\mu L$$

$$mgH = mg\mu L$$

$$\mu = \frac{H}{L}$$

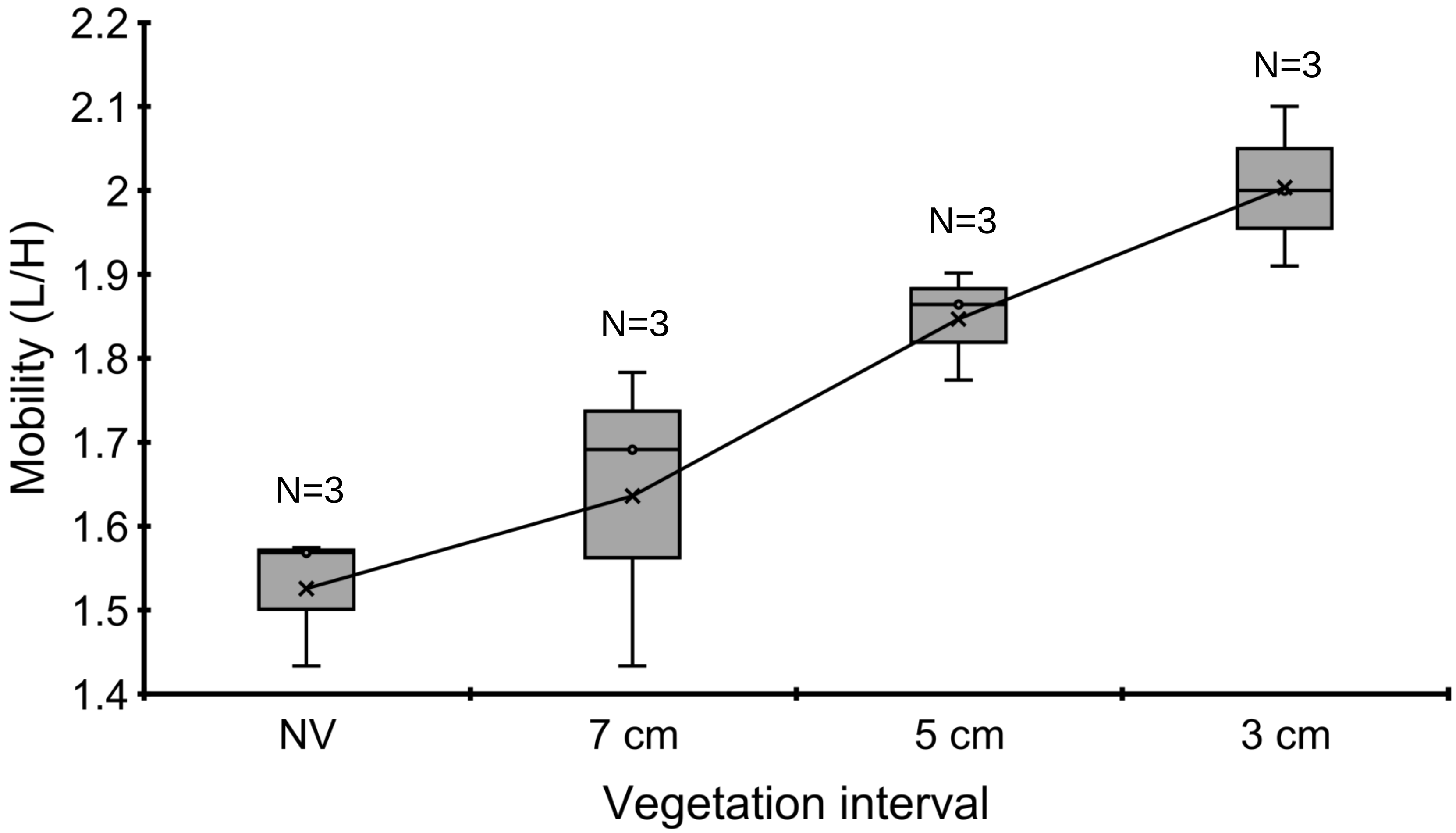
Commonly be used in **topography-based** analysis (e.g., *Hayashi and Self, 1996*)

$$M = \frac{1}{\mu}$$

$$M = \frac{L}{H}$$

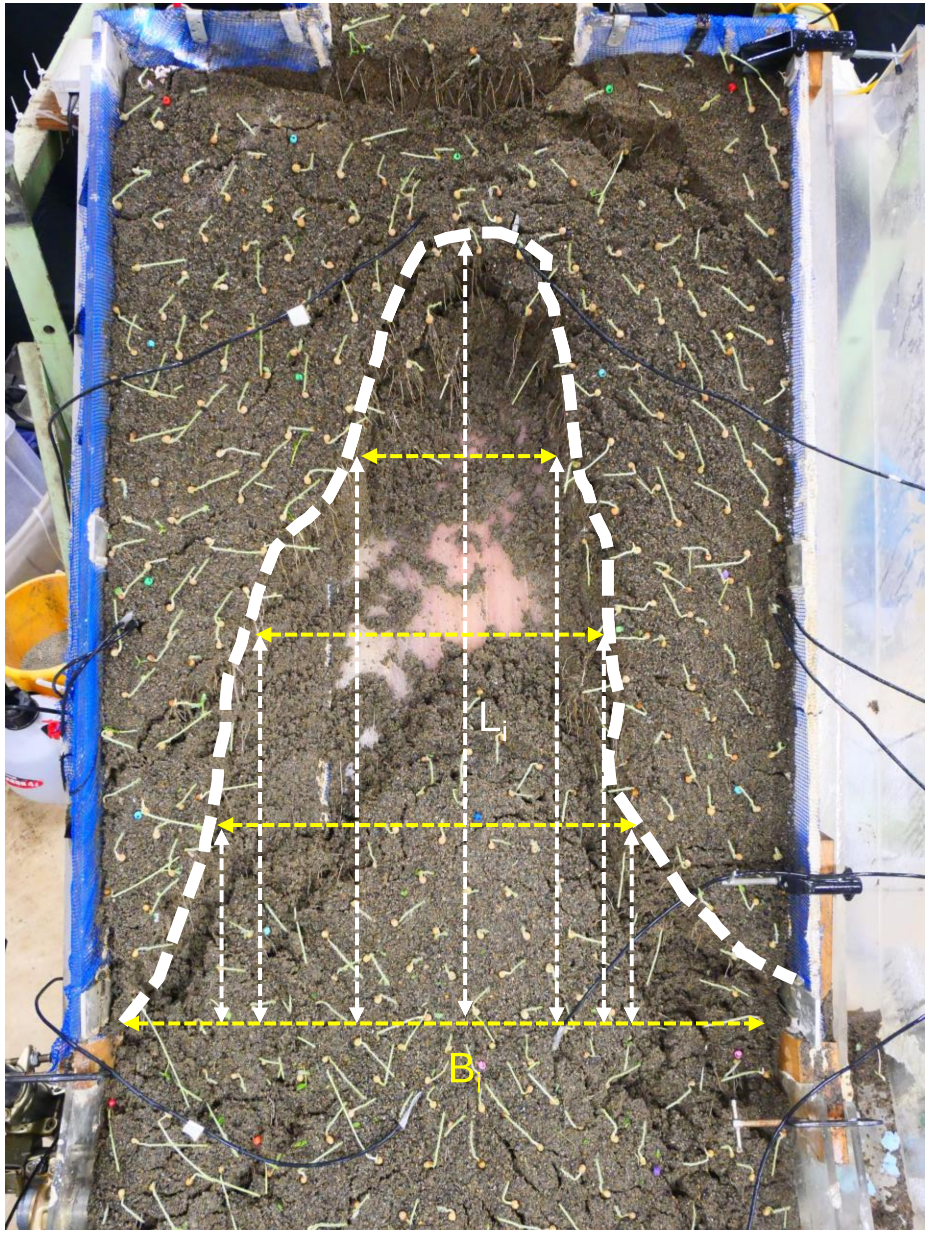
Inverse of friction coefficient (*Staron and Lajeunesse, 2005*)

L/H ratio



Differences in L/H ratio might be associated with **landslide size**

Measurement of size (area)



Landslide size (area) was measured based on **mean landslide width and length**.

$$A = \sum_{i=1}^{n}\left(\frac{B_i}{n}\right) \times \sum_{j=1}^{m}\left(\frac{L_j}{m}\right)$$

A : Landslide size (cm^2)
B : Landslide width (cm)
L : Landslide length (cm)
n : Total number of elements used in mean width calculation
m : Total number of elements used in mean length calculation

Landslide size (area)

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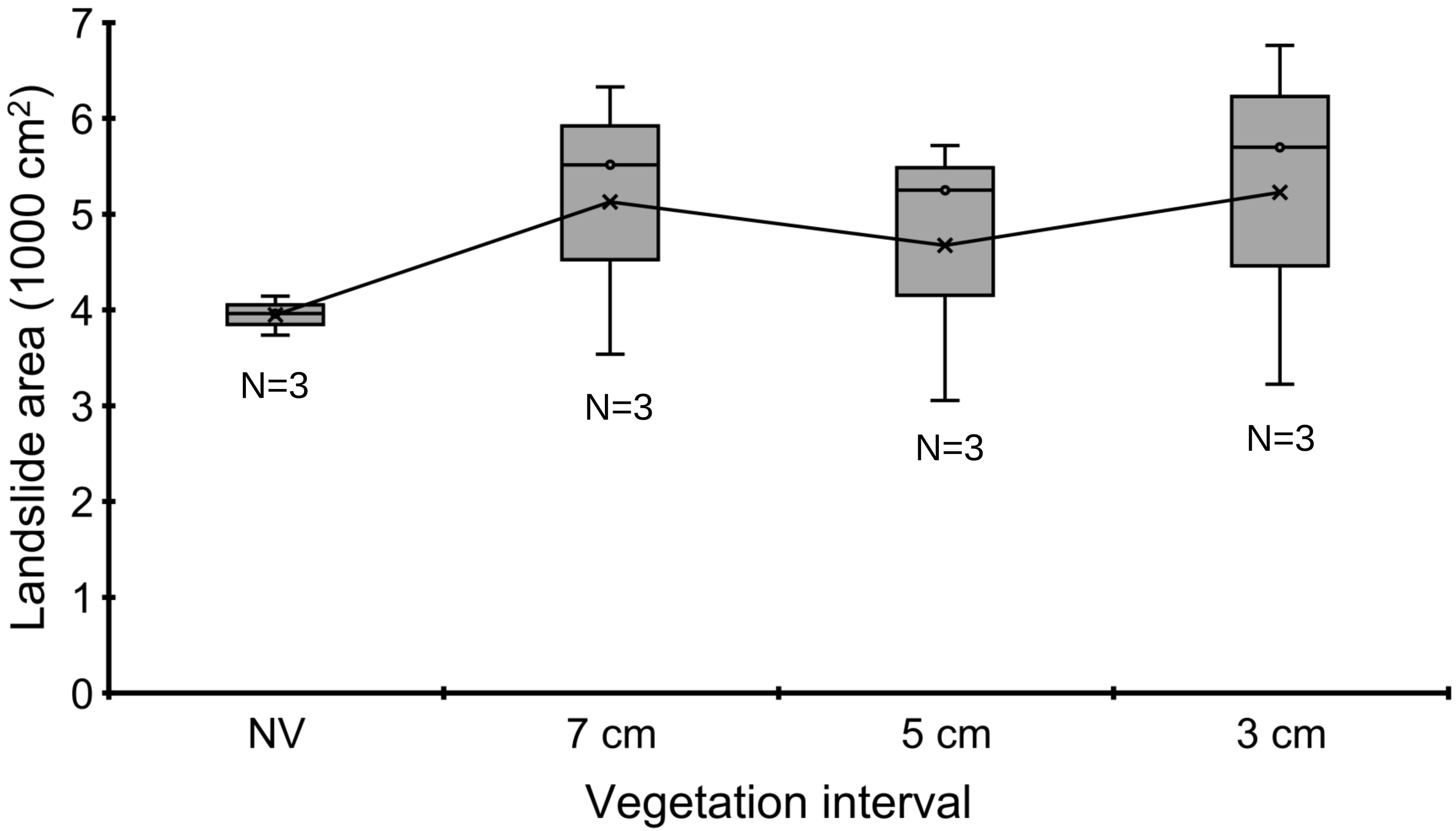
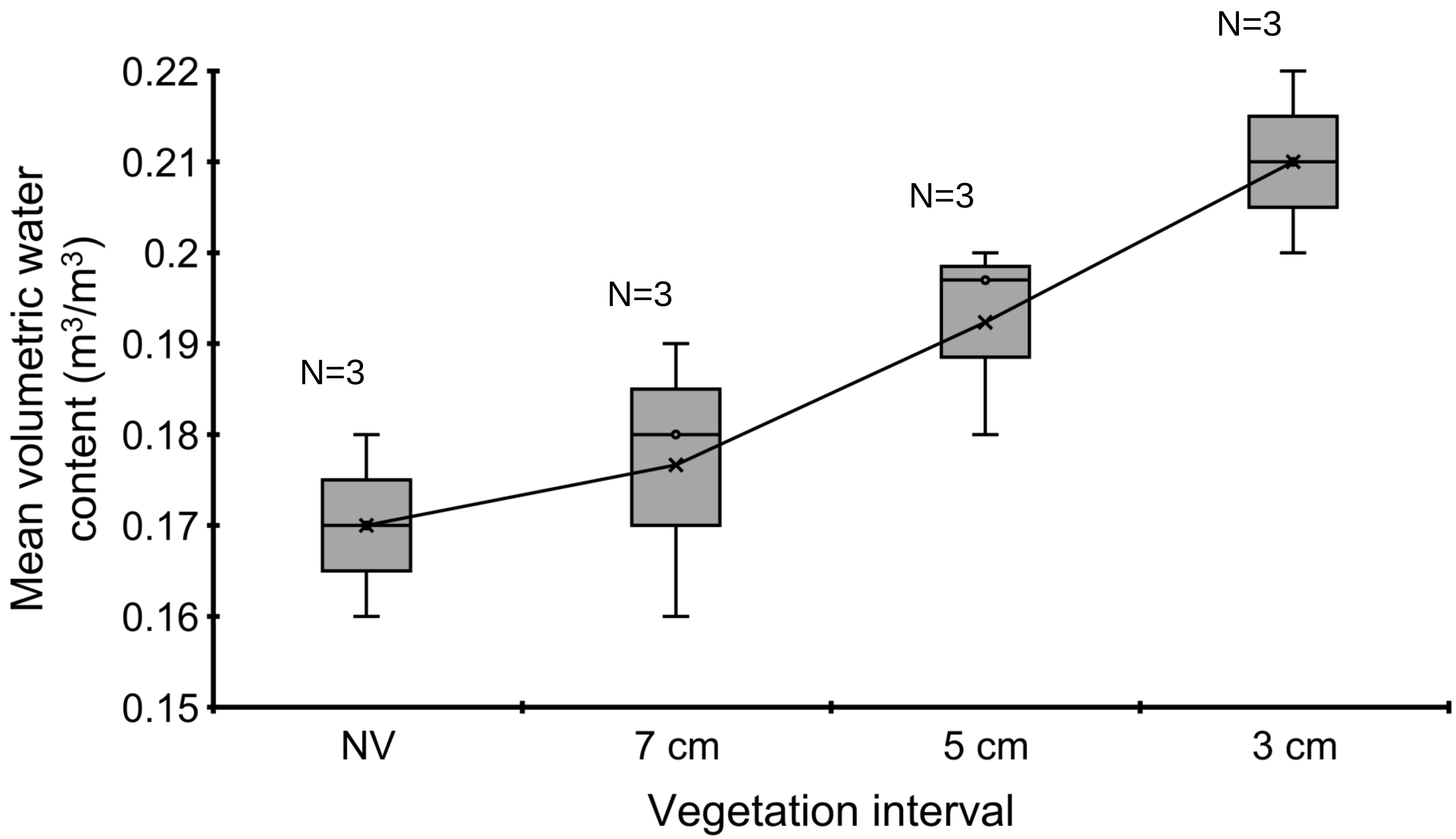


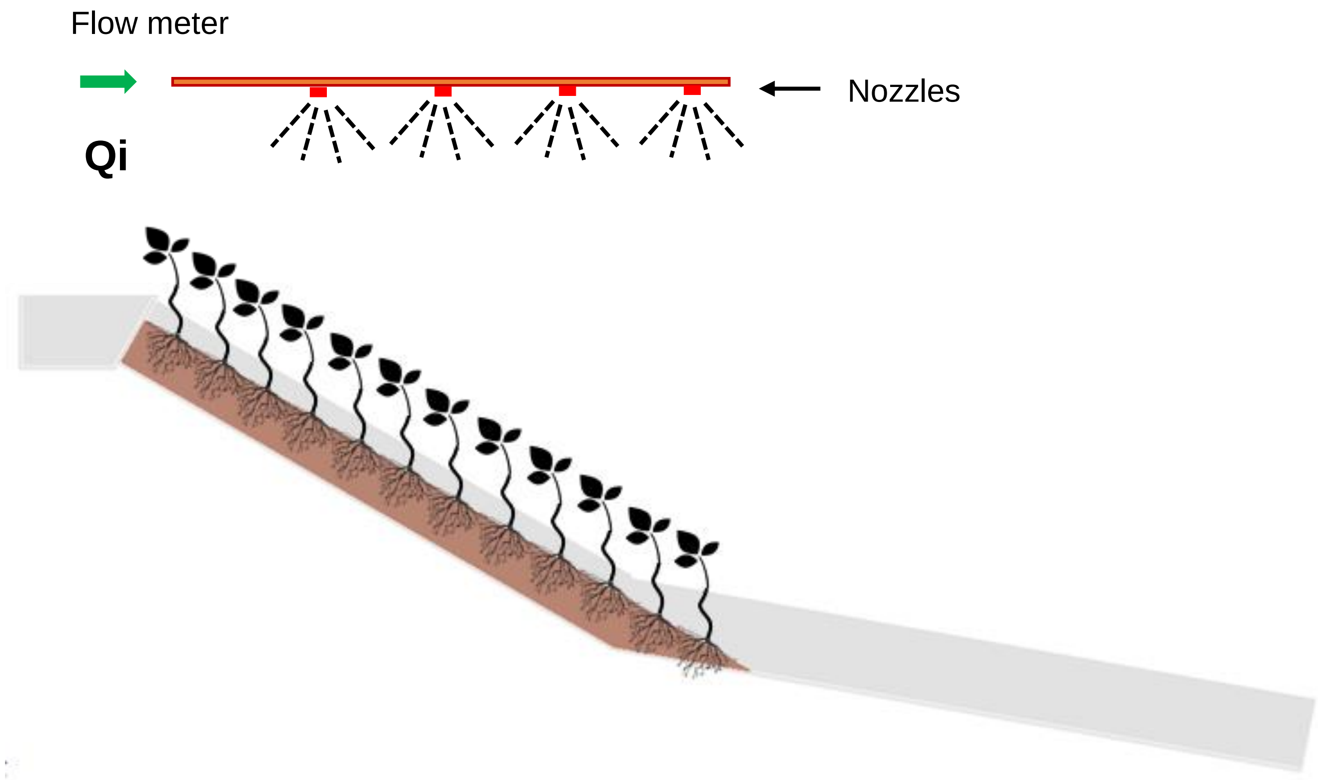
Landslide size might be controlled by the **spatial distribution** of lateral root networks.

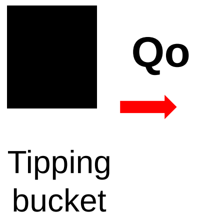
Water content



Differences in the initial water content might be associated with root **hydrological** effects.

Water balance analysis





Vo : Outflow volume (liter)
Vi : Inflow volume (liter)
Qo : Outflow discharge (liter/minute)
Qi : Inflow discharge (liter/minute)
t : Time for discharge measurement (minute)

Outflow volume

$$Vo = \sum_{i=1}^{n} Qo_i \times \left(t_i - t_{i-1}\right)$$

Inflow volume

$$Vi = \sum_{i=1}^{n} Qi_i \times \left(t_i - t_{i-1}\right)$$

Water storage

$$S = \Delta V$$

$$S = Vi - Vo$$

Outflow volume

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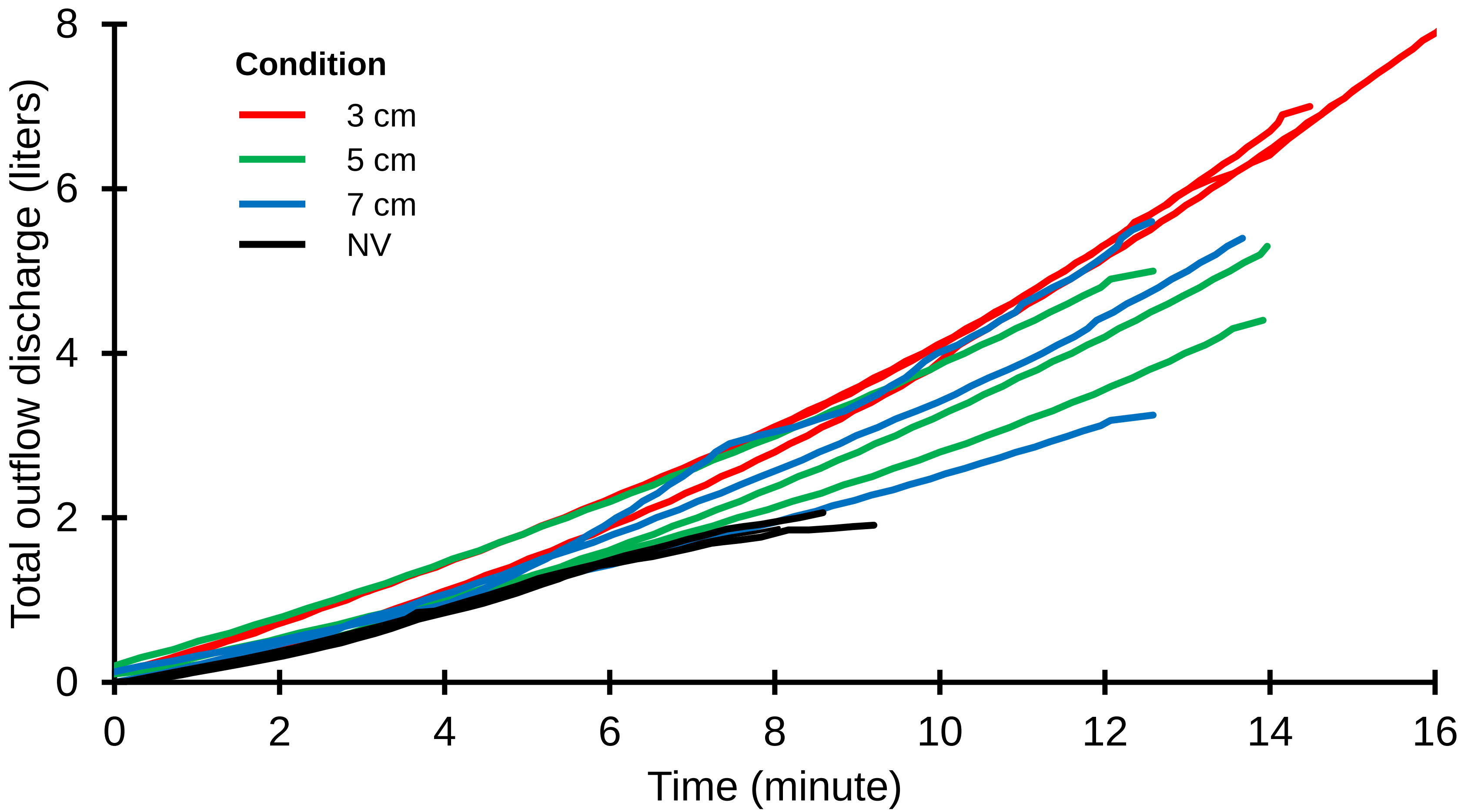
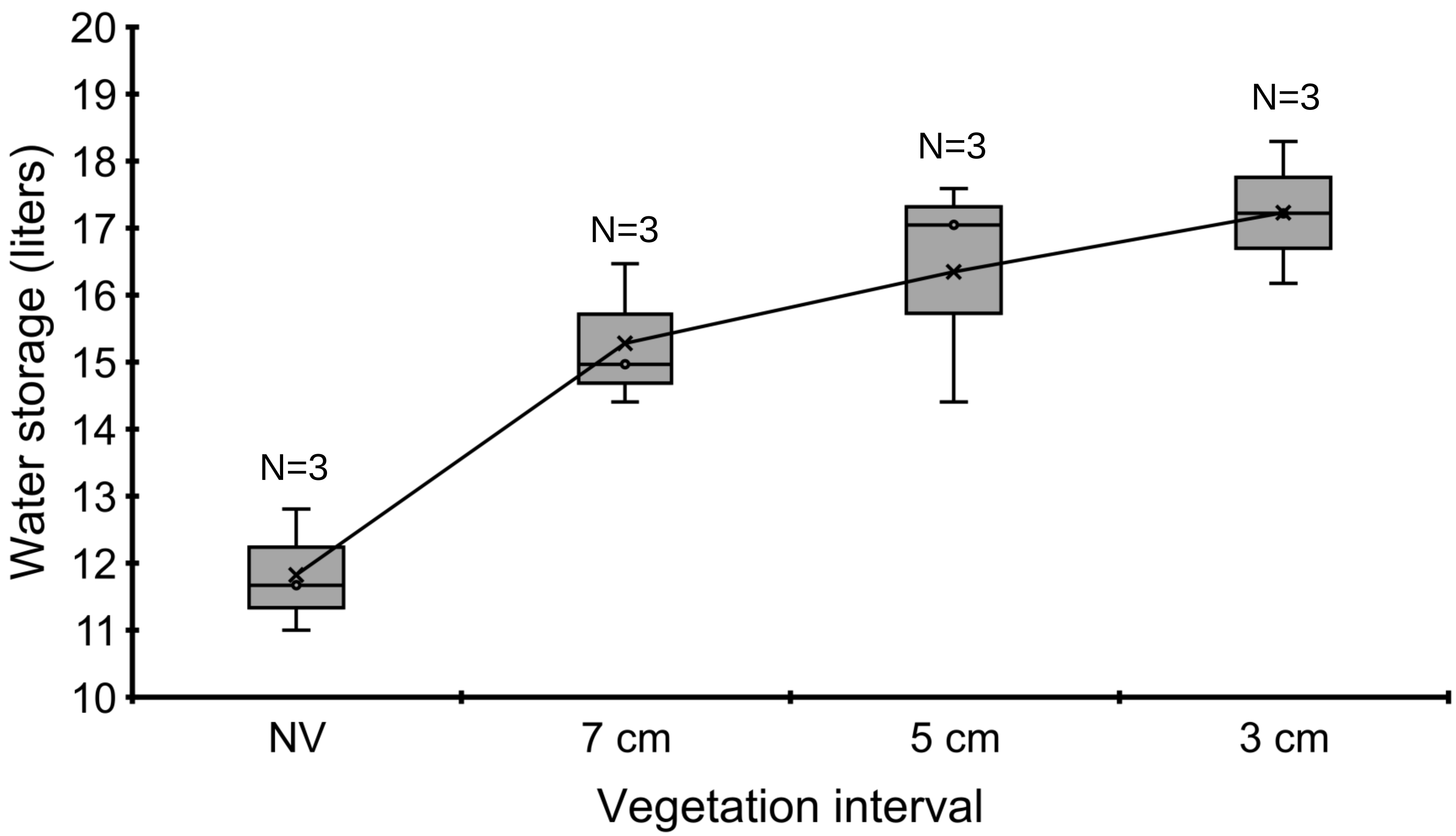


Plant roots, alive or dead, can promote **slope drainage** by functioning as hillslope-scale preferential flow paths (*Stokes et al., 2009*; *Ghestem et al., 2011*).

Water storage for various vegetation intervals



While promoting slope drainage, vegetation root systems also enhance **water storage** on the slope.

Water content distribution

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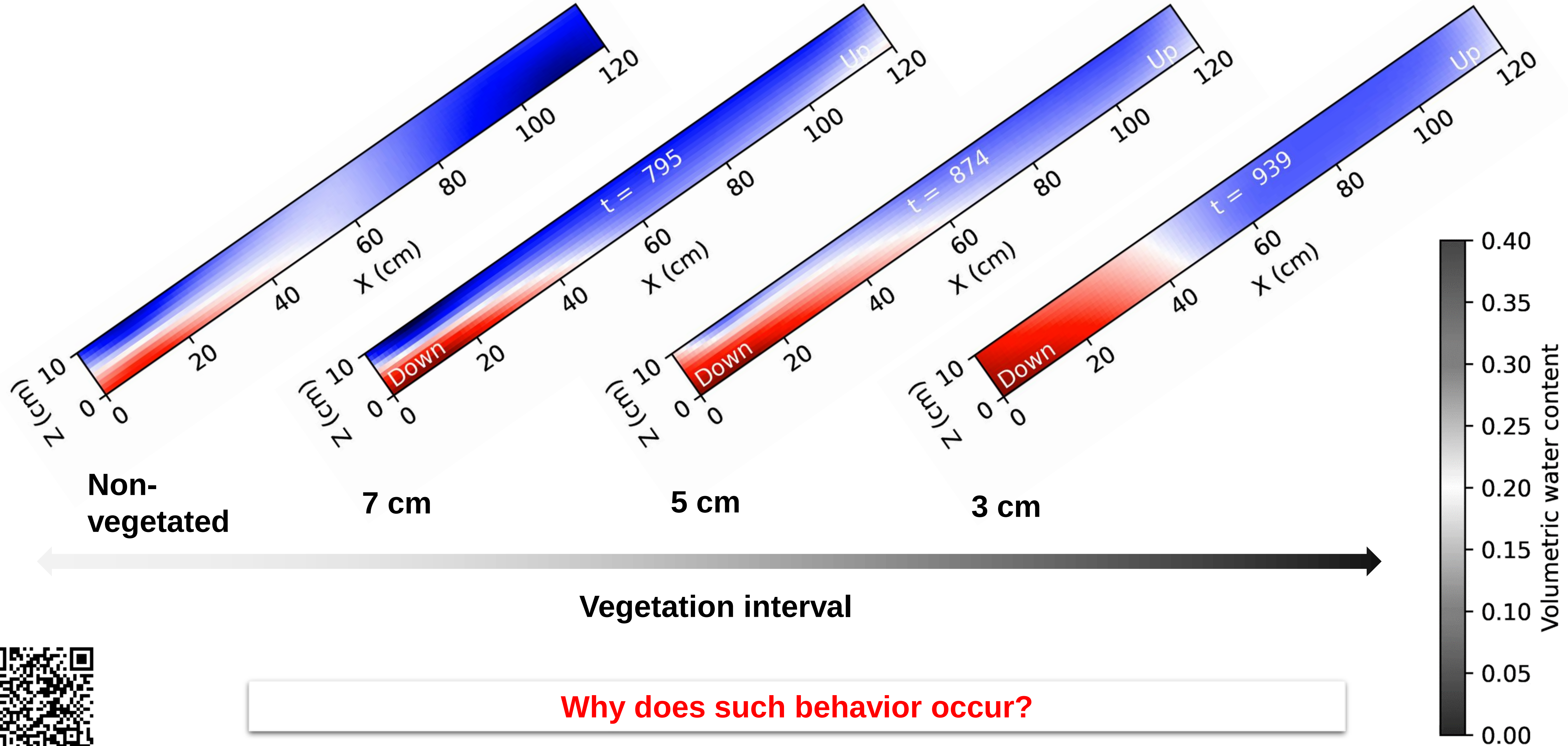
*The timing for landslide initiation **differed** depending on **vegetation density**.



Why does such behavior occur?

Root reinforcement estimation

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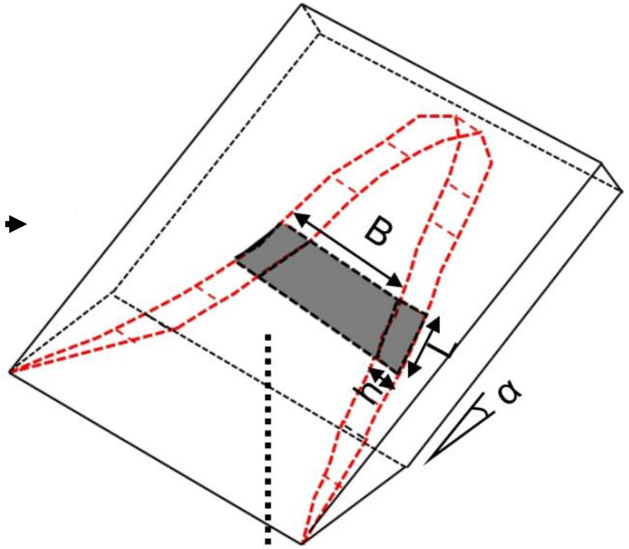
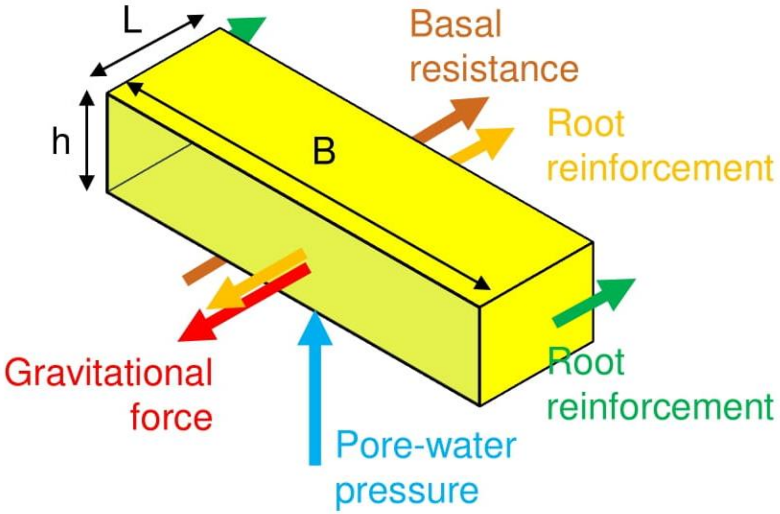


$$\Delta C_h = \frac{\sum_{i=1}^{n} W_i \sin\alpha_i - \sum_{i=1}^{n} (W_i - U_i)\cos\alpha_i \tan\varphi_i}{(\sum_{i=1}^{n} 2L_i h_i \cos\gamma_i)}$$



- *W* : Gravitational force (N)
- *U* : pore-water pressure (N/cm^2)
- φ : Internal friction angle (°)
- *L* : Width of each slice (cm)
- *h* : Thickness of each slice (cm)
- γ : Inclination of landslide shape (°)
- α : slope inclination

Root reinforcement

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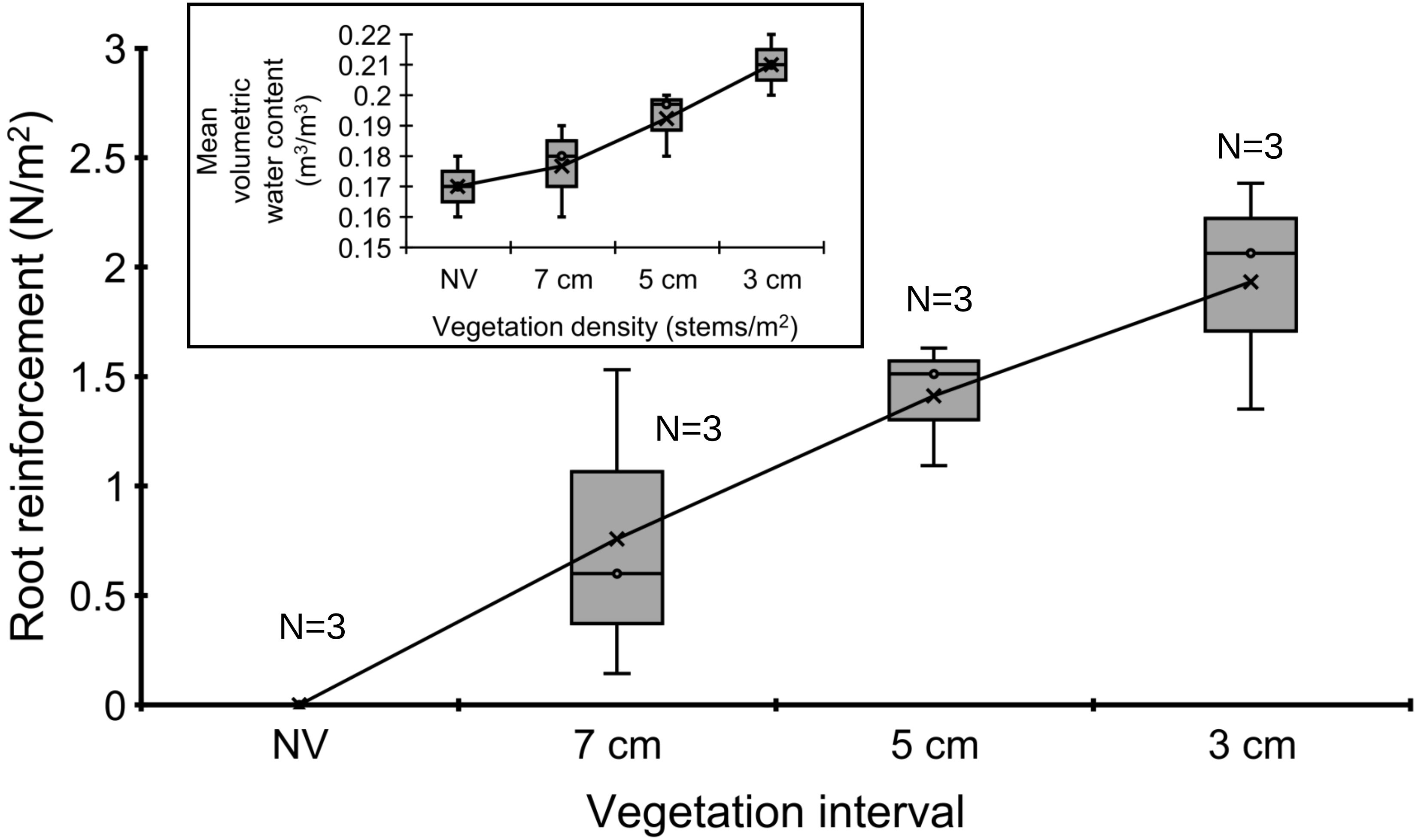
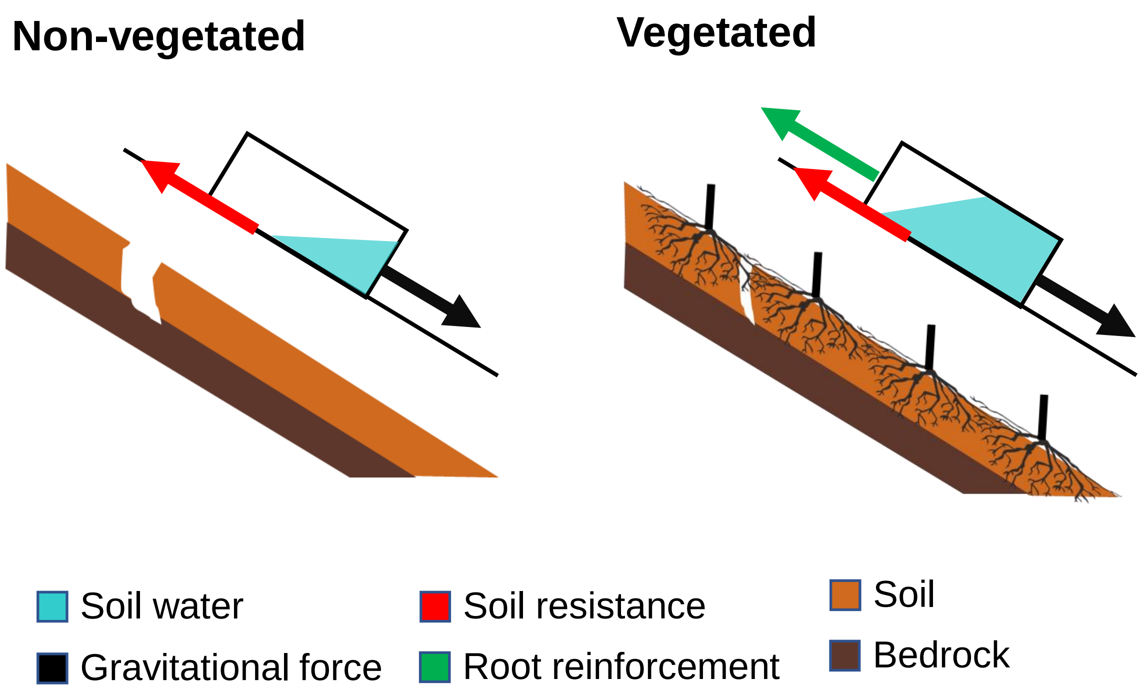
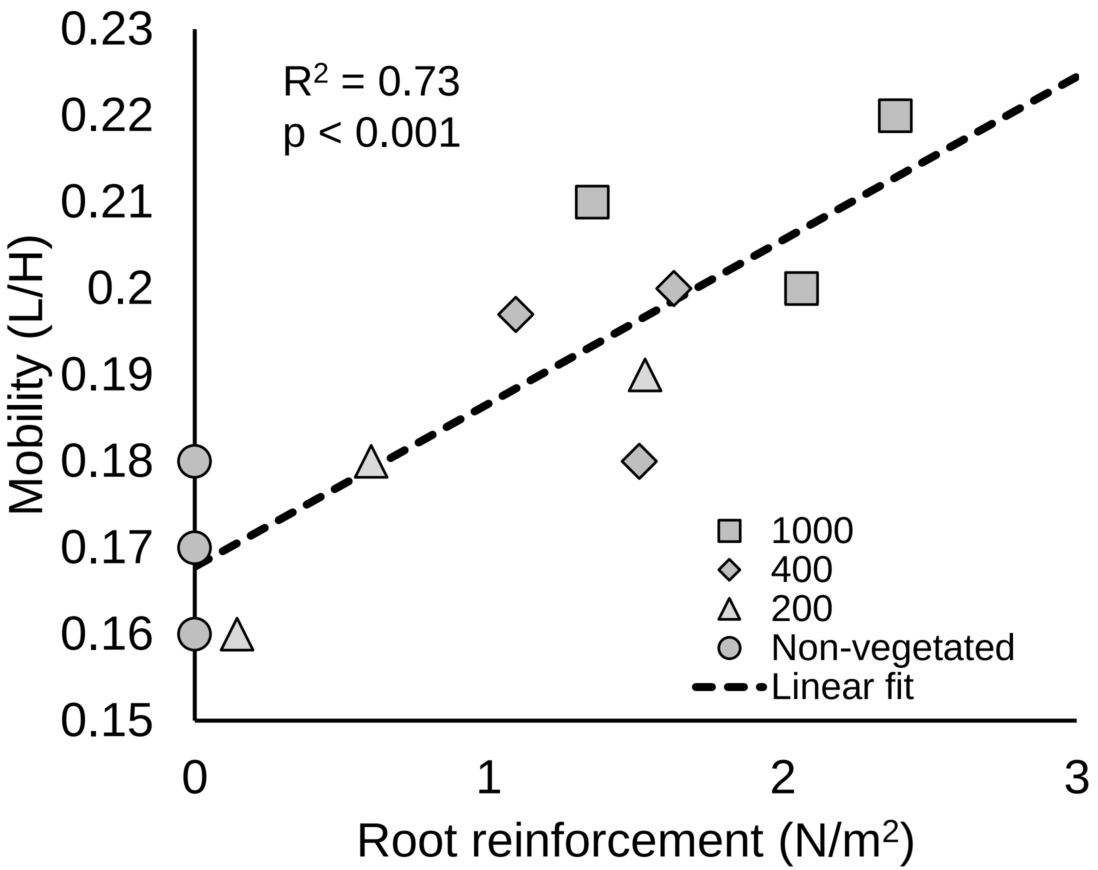


Root reinforcement potentially **enhances** landslide mobility.

The effect of vegetation root reinforcement on landslide mobility



Because of root reinforcement, greater **gravitational force and pore-water pressure** are needed to destabilize the slope, which consequently elevates the **threshold of water content** for landslide initiation.



Since water content greatly influences mobility, **wetter conditions enhance the mobility** of the collapsed landslide mass.

Root reinforcement is **influential** for the mobility of rainfall-induced shallow landslides and one of the **key factors** for landslide risk assessment.

Conclusions

1. We agree with previous studies that vegetation root systems can **reinforce** soil structures and thereby improve slope instability.

2. We highlight that such reinforcement can also enhance the **mobility**, which may elevate the potential impacts of landslides.

Thank you!

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