SARAWAK TROPICAL PEAT RESEARCH INSTITUTE (TROPI)

SOIL MOISTURE MANAGEMENT OF TROPICAL PEATLAND

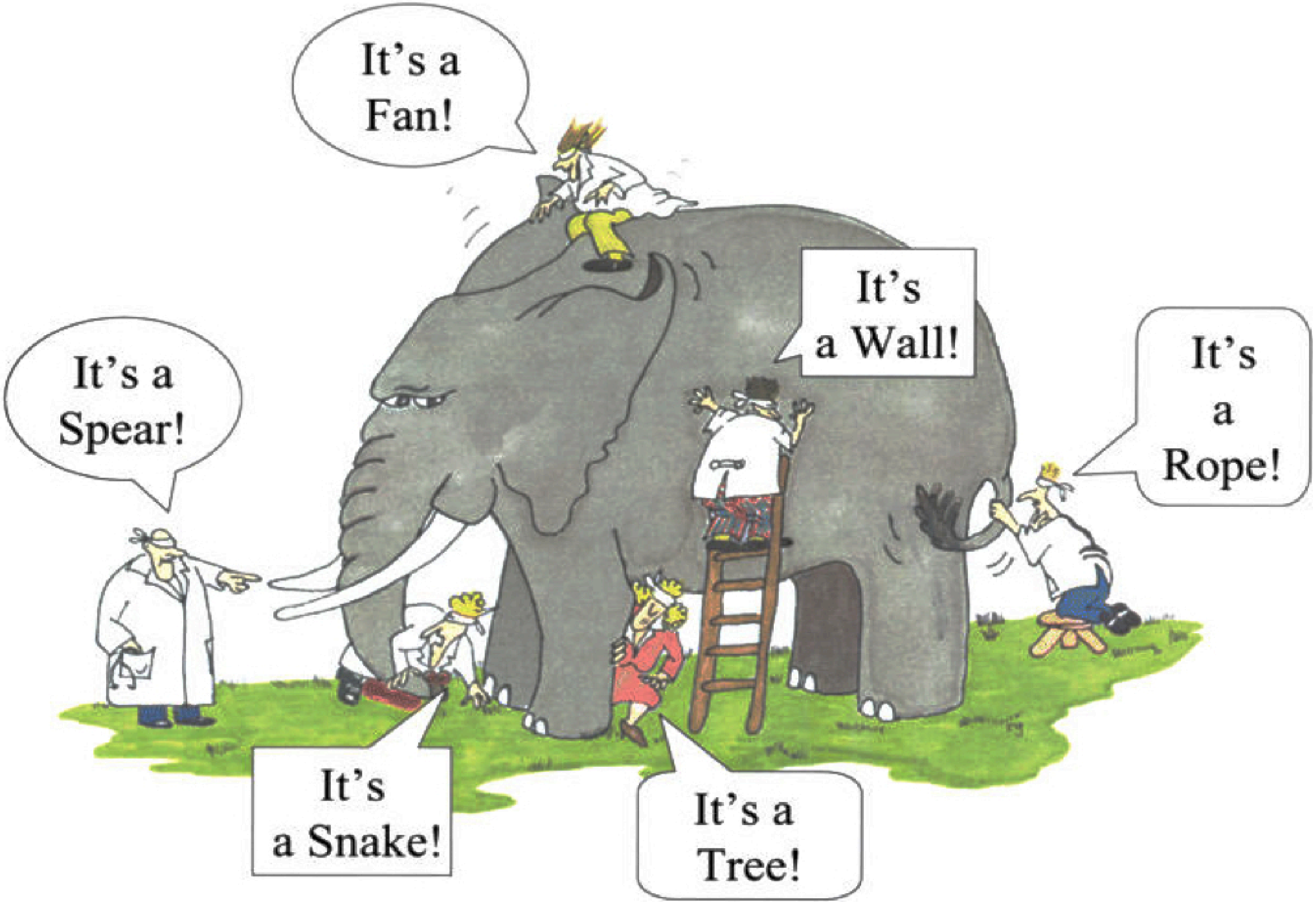
Lulie Melling & Angela Tang

Workshop on 'Haze and Biomass Burning in Asia – A Systems Perspective to Reveal Opportunities with Benefits for Long-term Transformations'
4th – 5th October 2018

TROPICAL PEAT – *what are the issues ???*

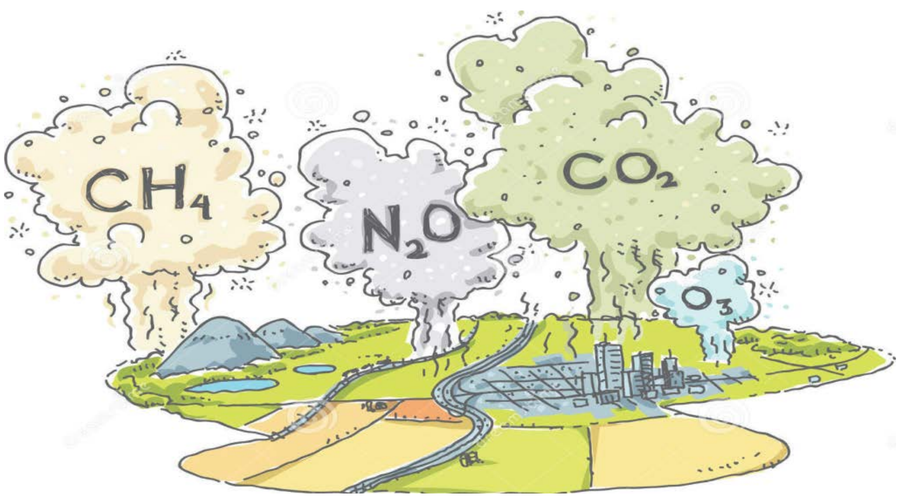
- Tropical Peatland has been **perceived** differently by Agriculturist, Foresters, Geologist, Engineers and the men on the street
- **BUT** all acknowledge on the **Wetness** & the **Low bulk density.**
- Agriculturist has always recognised peat as a **problematic soil** with **marginal** agricultural capability due to its
  - High water table,
  - Low bulk density
  - High acidity and
  - Low fertility.
  - **This sequence of solving peat development is very CRITICAL.**

Understanding on Tropical Peatland



TROPICAL PEATLAND

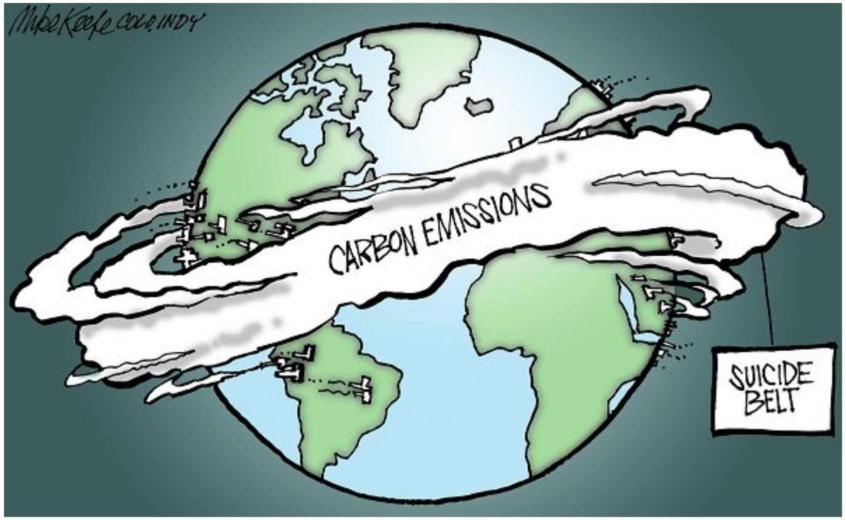
- Tropical peatlands occupy 9-12% (33-49 Mha) of the world's total area of peatlands, of which 8% are in Malaysia and Indonesia.
- There has been a need to enhance agricultural eco-efficiency on tropical peatland
- Especially in relation to the magnitude of GHG fluxes & the environmental factors that regulate the variation in tropical peat ecosystems.



TEMPERATE PEAT

TROPICAL PEAT

- CO_2, CH_4 and N_2O – gases significantly contribute to global warming & influenced by anthropogenic activities (drainage built for cultivation).
- Unlike temperate and boreal peats, tropical peatland is predominantly covered by forests and lignified litter which is more resistant to decay (Melling and Goh, 2010).
- Thus, the decomposition rate is lower compare to its supply.



- Effects of lowering water table for agriculture purposes from peatland degrades and accelerates peat oxidation (Page *et al.*, 2011; Hergoualch and Verchot, 2011; Laurance *et al.*, 2014).
- However, studies have been proven that soil C fluxes were lower in oil palm plantation compared with forests (Melling *et. al.*, 2005b; 2012; 2016).

Agro-Environmental Management Approach

- To alleviate C emissions associated with peat development, Sarawak developed an **agro-environmental management approach.**
- Besides drainage, **peat compaction** is prerequisite before planting the oil palm to increase soil bulk density and bearing capacity and water-filled pore space (WFPS) (Melling *et al.*, 2005a; 2008).
- **UNINTENDED BENEFITS** from mechanical compaction:
  - decreased soil CO_2 emissions; and
  - reduced susceptibility of peat fire outbreaks due to optimum soil moisture from the lower soil porosity enhances the capillary rise of water.

The Petri Dish

WHERE SCIENCE HITS THE HEADLINES

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OCTOBER 2015

Peat science saves Sarawak

Last month's trans-boundary haze could have been more disastrous for the East Malaysian state, says local scientist.

BY JAY ROSHAN

KUCHING: Last month's trans-boundary haze, an annual feature affecting Indonesia, Singapore, West and East Malaysia was choke-fully bad for people in these regions, but it could have been more catastrophic for the East Malaysian state of Sarawak which shares a common border with Kalimantan.

The application of good science to peat management in the state, where the soil condition was kept moist and compact by employing proper techniques in water management saved the day for Sarawak, *The Borneo Post* reported in its front page story on Oct 1.

According to the newspaper, good soil management and transfer of scientific knowledge to relevant stakeholders saved the state's 1.6 million hectares of peat land from turning into a blazing underground inferno - a searing flashpoint that had occurred in neighbouring Kalimantan sending API readings beyond 1,000.

Local scientist, Dr Lulie Melling told *The Borneo Post*: "If we have not kept our peat land compact and moist via good water management, we would have suffered the same fate as Kalimantan, with peat fires sweeping through our land."

Lulie who is also director of Tropical Peat Research Laboratory Unit said the plantation community, including smallholders and major industrial players had managed to keep their peat land from fires because scientific knowledge about peat had effectively been imparted from the laboratory to the stakeholders, including the government, industrial decision makers and the plantation workers.

The Borneo Post quoted Lulie as saying: "We have been able to pass scientific knowledge on how to handle peat through compaction and water management via workshops, private meetings and international conferences since 2007.

"And through effective communication, especially to those directly involved in handling the peat, and the correct way of handling it, our peat has been kept tight and moist, so we were spared from the peat fires."

She also pointed out that Indonesian President Joko Widodo's plan to create large canals in fire-prone peat land areas will not work because it lacked one vital element, and that is compaction.

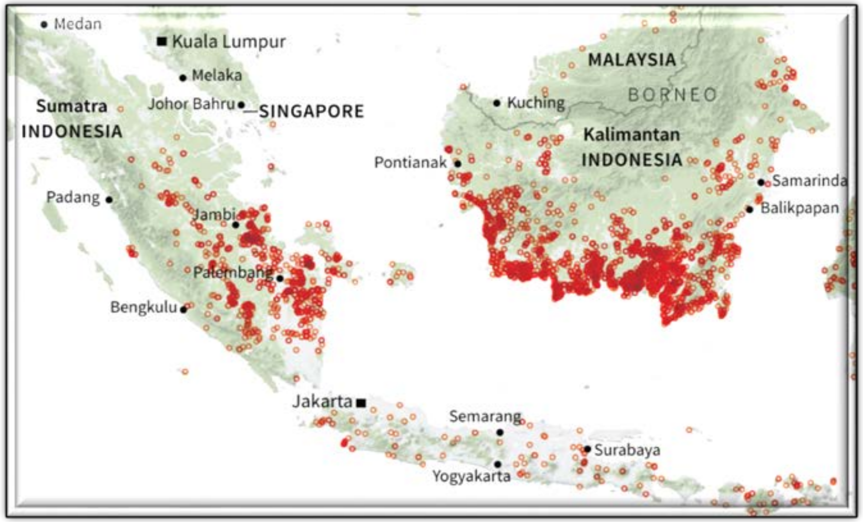
She cautioned, without compaction, peat fires will still occur.

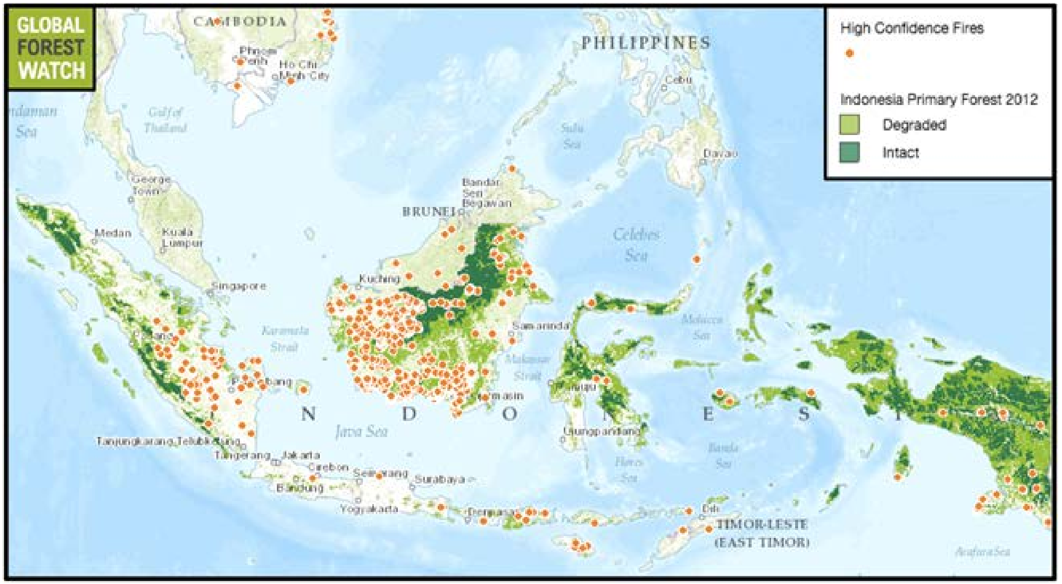
> "If we have not kept our peat land compact and moist via good water management, we would have suffered the same fate as Kalimantan, with peat fires sweeping through our land."

Watch video on Aurasma #NoToHaze developed by Muhammad Nazrin Baharudin, PutraELITES, UPM

>More on Page 2...

SOUTH EAST ASIA HOTSPOTS





Influence Of Water Table & Soil Bulk Density on GHG Emissions

- Scientific quantification on the effect of **agro-environmental management practices** (drainage & compaction) on GHG had been conducted at different types of ecosystems in Sarawak, Malaysia.
- Groundwater table changes due to drainage have a significant impact on carbon dioxide (CO_2) & methane (CH_4) fluxes (Melling *et al.*, 2005b; Watanabe *et al.*, 2009).
- Water table is best controlled between 50 cm to 70 cm below the peat surface in order to maximize crop production as it is deemed suitable for oil palm rooting system (Henson and Chai, 1997).
- Drainage, mechanical compaction & watertable management are **prerequisite** to achieve higher soil bulk density & optimum water level resulting in in managed OPP compared with that of forest, sago, & un-compacted OPP (Table 1).

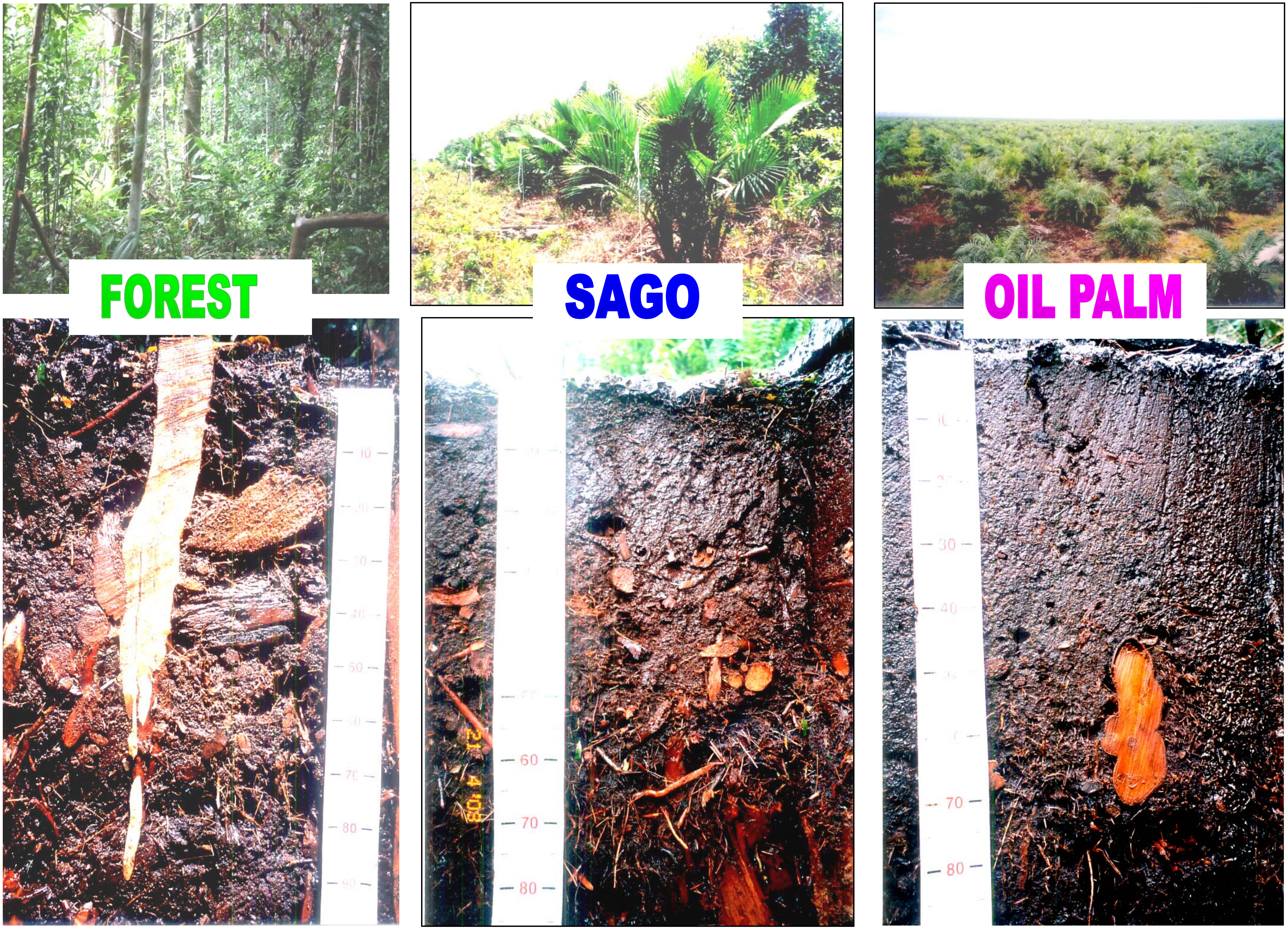

FOREST
SAGO
OIL PALM

Table 1 : Water table, WFPS, bulk density, soil CO_2 & CH_4 fluxes of different ecosystems

Ecosystem	Mean water table (cm)	WFPS (%)	Bulk density ($g\ cm^{-3}$)	Soil CO_2 flux ($t\ C\ ha\ yr^{-1}$)	Soil CH_4 flux ($t\ C\ ha^{-1}\ yr^{-1}$)	Reference
Forest	-45.3	57.6	0.15	21.9	0.0002	Melling *et al.*, 2005a
Sago	-27.4	78.1	0.16	12.0	0.0019	
Oil Palm	-60.2	60.4	0.20	16.6	-0.0003	
Oil Palm	-67.6	70.1	0.23	9.0	0.002	Melling *et al.*, 2012
SF	-14.7	66.5	0.11	11.2	0.05	
PSF	-3.9	70.0	0.11	12.3	0.13	
Compacted Oil Palm	-60.7	83.3	0.15	9.5	NA	Melling *et al.*, 2016
Un-compacted OPP	-59.8	71.3	0.13	11.2		
PSF	-15.1	75.1	0.11	12.5		

OPP = oil palm plantation; SF = Secondary peat swamp forest; PSF = Natural peat swamp

Water Management

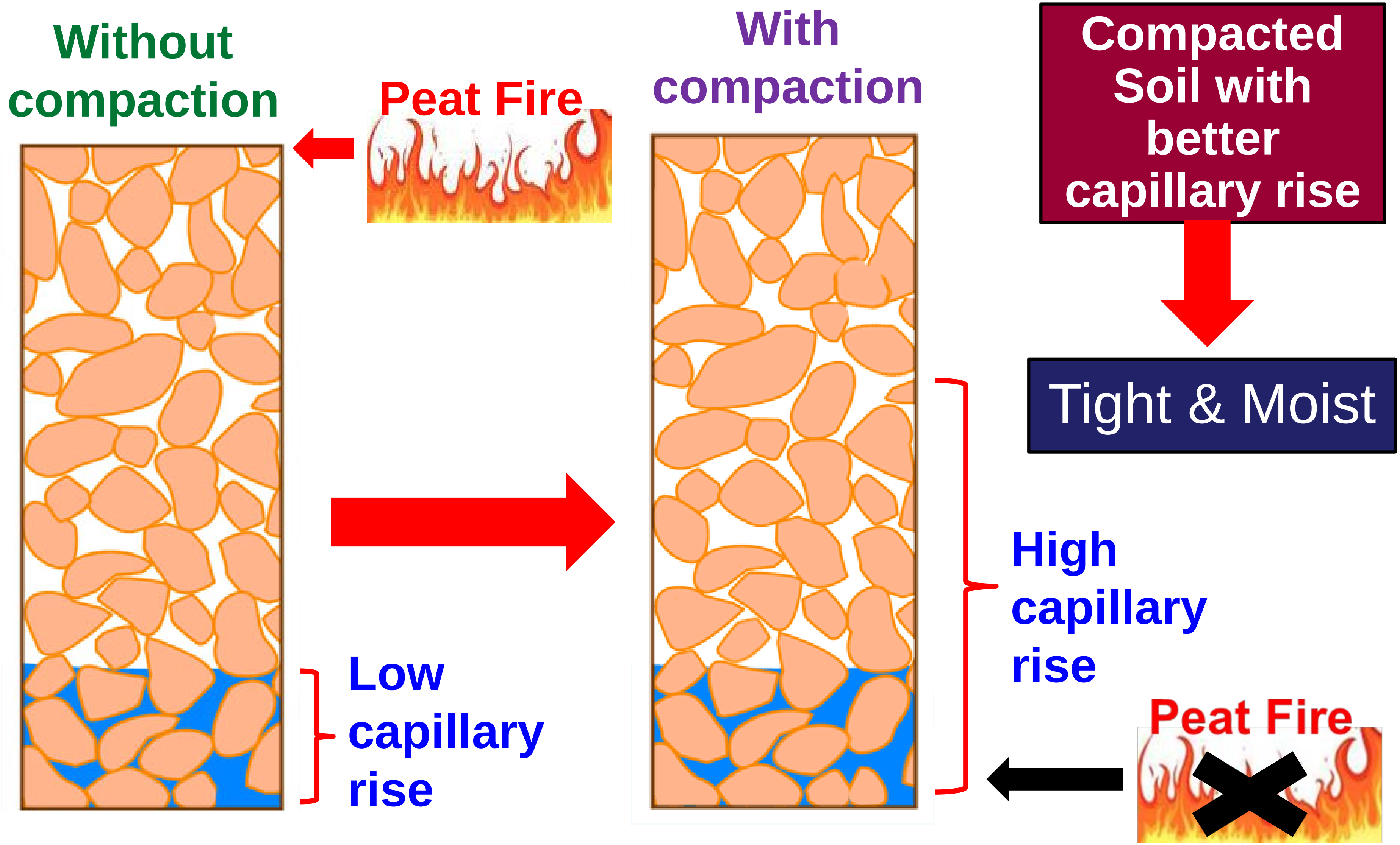
- Is it just Water Table Control..!!

Text-Book based on understanding for Mineral Soil .!!!...

Water Management On Peat

Keep it Moist NOT Keep it Wet

Effect of Compaction on Capillary Rise



Soil Compaction

- Compaction changes peat properties through improved bulk density & moisture content (Ball *et al.*, 2008), i.e. reduced macropores (Kasimir-Klemedtsson *et al.*, 1997) & increase micropores that results in better capillary rise.
- Hence, nutrient loss via leaching is reduced resulting in better growth & crop yield.
- This has been PROVEN by a study conducted by Melling *et al.* (2016) where in oil palm, fresh fruit bunch (FFB) increased with WFPS.

Even though the water table depths were similar

Un-compacted OPP	Compacted/Managed OPP
16.8 t ha^{-1} yr^{-1}	32.2 t ha^{-1} yr^{-1}

Same results reported by Lim *et al.*, (2012)

Soil CO_2 Flux

Table 1 : Water table, WFPS, bulk density, soil CO_2 & CH_4 fluxes of different ecosystems

Ecosystem	Mean water table (cm)	WFPS (%)	Bulk density (g cm^{-3})	Soil CO_2 flux (t C ha yr^{-1})	Soil CH_4 flux (t C ha^{-1} yr^{-1})	Reference
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- Observing from the influence of water table on soil CO_2 flux in Table 1, the **lowest soil CO_2 flux** was recorded at the site with the **lowest water table.**

- Soil CO_2 fluxes in a managed opp were lower at approximately 15%-20% than the other sites due to:
  - higher bulk density,
  - lower porosity &
  - higher soil moisture (exceeds 70%) (Melling *et al.*, 2005b; Ruser *et al.*, 2006; Melling *et al.*, 2012).

- Melling *et al.* (2013); Novita *et al.*, (2013) also demonstrated similar results. Thus, soil CO_2 flux decreased beyond the effect of drainage by lowering the water table alone.

Soil CO_2 Flux

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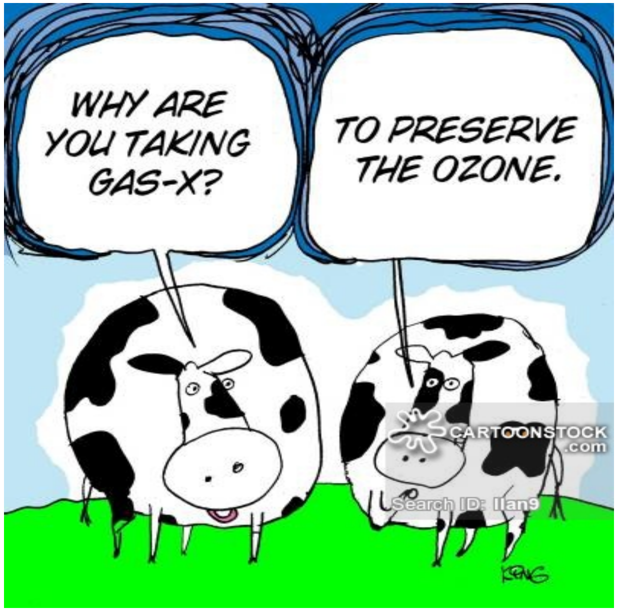
- Due to the higher moisture in the soil pore space, underground biotic activity and soil gas diffusiveness were reduced resulting in lower soil CO_2 emissions (Ball *et al.*, 2008; Castellano *et al.*, 2011).
- Hence, also proving that increased emissions of soil CO_2 as a result of water table drainage in peat soils did not occur at all environment (Smith *et al.*, 2003; Melling *et al.*, 2005b).

Soil CO_2 Flux

- Lower CO2 fluxes at OPP also results from the dynamics of its monoculture community type (lower enzyme diversity) (Carney & Matson 2005).
- Greater biomass & litter quality accelerates decomposition in the forest (Lohila et al., 2003), irrespective of water table (Hirano et al., 2007).
- Soil temperature seasonal fluctuation in a tropical ecosystem were relatively small.
- Therefore, it is no surprise that higher moisture content had a significant impact on the soil CO2 emissions.

Soil CH_4 Flux



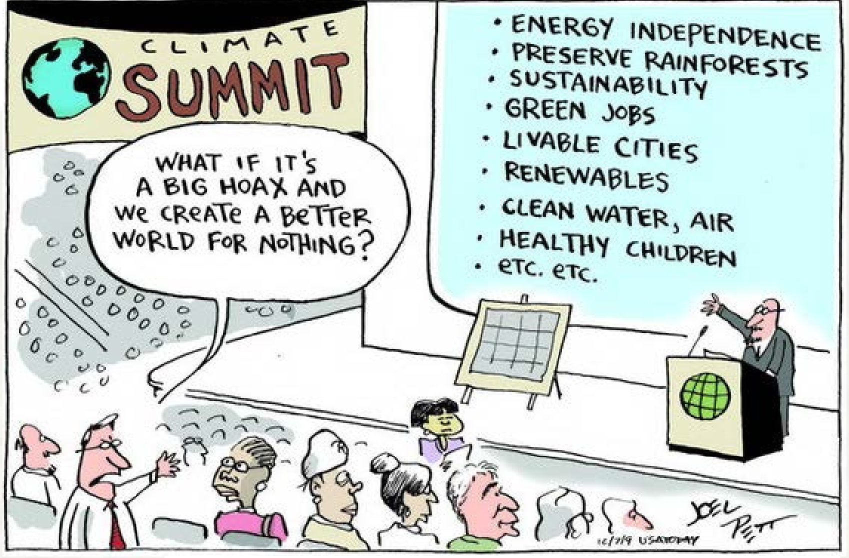
- As for methane fluxes, the pattern is similar with that of soil CO_2 where at the lowest water table which is OPP had the lowest soil CH_4 flux.
- In a natural peat swamp ecosystem that is mainly dominated by large Alan trees (*Shorea albida*) (Anderson, 1972), with heavily buttress trees and low bulk density could also contribute to the higher soil CH_4 flux (Melling *et al.*, 2008).

Soil CH_4 Flux

- Meanwhile, **lower soil CH_4 flux** in oil palm ecosystem was due to the lower watertable that increases oxygen (O_2) availability at the rooting zone & **suppressing** the anaerobic methanogenic bacteria activities resulting in decreased CH_4 production *(Updegraff et al., 2001; Holden, 2005; Couwenberg, 2011).*
- This findings also supports a study conducted by Moore and Knowles (1989) where water table was the major control of soil CH_4 flux.

Soil CO_2 & CH_4 flux

- Overall, results have shown that soil CH_4 flux was predominantly influenced by water table, but it is not the case for soil CO_2 flux.
- Also, total soil CH_4 flux was much lower than soil CO_2 flux indicting that water table was not the sole factor influencing the soil C flux in a tropical peatland.
- Controls over soil CO_2 flux were far more complex upon lowering the water table, as it incorporates multiple interactions of covariate factors between physical and biotic factors.



"Vegetables are very good for you, but don't overdo it. You're suffering from greenhouse gas!"

Other studies/factors supporting the influence of water table and bulk density on GHGs fluxes

Xhuan *et al.*, 2016

- Groundwater level (GWL) & soil water content (SWC) were the main factors controlling CH_4 & were positively correlated (both $r = 0.41$ and 0.39, $P < 0.001$) with CH_4 flux from a primary tropical peat swamp forest in Sarawak.

Okimoto *et al.*, 2016

- Reported a non-significant relationship between CO_2 efflux and GWL ($p > 0.05$) but a trend was found where CO_2 effluxes decreased as GWLs were lowered in an oil palm plantation of a tropical peat soil in Sarawak.

Busman *et al.*, 2018

- Highest bulk density (BD) of 0.24 g cm^{-3} release significantly the lowest soil CO_2 flux compared with of that 0.14 g cm^{-3}, & 0.18 g cm^{-3}
- These results showed a similar trend under two temperature conditions of 25°C and 35°C.

Melling & Chaddy., 2016

- Reported that water table depth was the fundamental factor controlling soil N_2O, regardless of palm age.
- Negative relationships were found between water table depth & N_2O fluxes, where the highest N_2O fluxes were observed from water table close to the peat ground surface (Jauhiainen *et al.*, 2012).

Sakata *et al.*, 2014

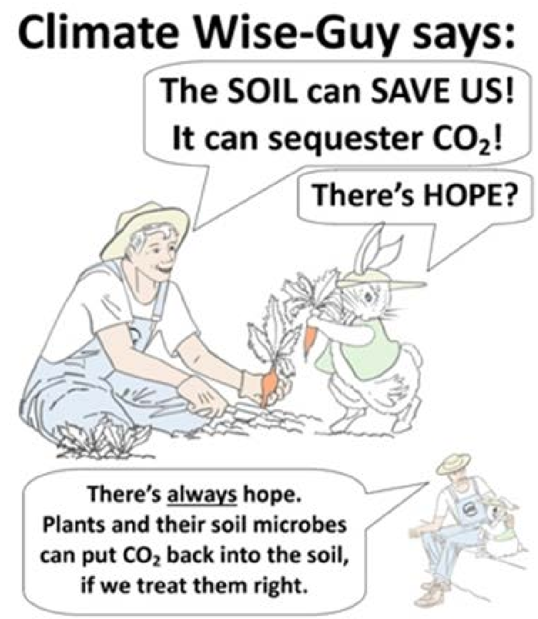
- N_2O was significantly higher in the lower slope (1.59 to 61.2 µ N_2O-N m^{-2} h^{-1}) but no significant difference in the upper (0.34 to 36.3 µ N_2O-N m^{-2} h^{-1}) & middle slope (-4.28 to 34.9 µ N_2O-N m^{-2} h^{-1}).
- Agricultural landscape is also an important element in relation with hydrological processes.

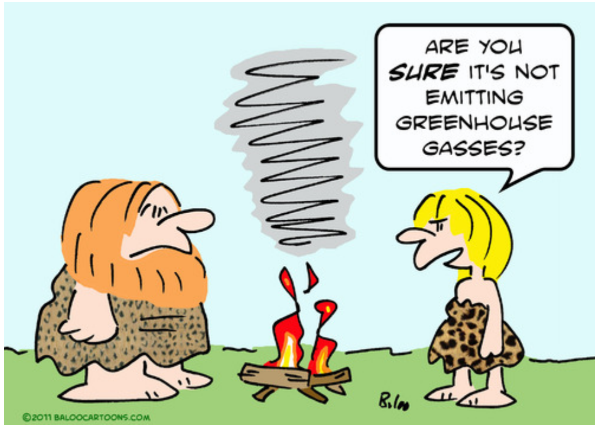
Watanabe *et al.*, 2016

- A potential crop that can grow on tropical peat soil with a higher water table.
- Measured C cycle in a sago palm cultivation system in tropical peatland found that C accumulation (3-4 t C ha^{-1} y^{-1}) depends on the sago litter C & increase in aboveground biomass C in the trunk elongation stage.

Temporal Variations of GHG Fluxes

- In Sarawak, the annual rainfall pattern is driven mainly by two seasons which are the dry season (April to September) and wet season (October to March).
- Rainfall distribution has a direct influence on the peat water table fluctuations as it is an ombrogenous type that receives water & nutrients solely from rainfall.
- Studies conducted at a tropical peat swamp forest in Maludam National Park, Betong, Sarawak by Tang *et al.* (2016) and Xhuan *et al.* (2016) both reported the influence of rainfall on the C fluxes





Tang et al., 2016

- During dry season, there is a large C loss of > 500 g C m^{-2} resulted from an increase of vapour pressure deficit (VPD) and **declined** water table.
- Likewise, an increase in VPD from the high temperature and photosynthetic proton flux density (PPFD) limits the gross primary productivity (GPP) via stomatal closure which eventually leads to a **lower net CO_2 uptake.**
- Concluded that GPP plays a significant role at the annual timescale in modulating the overall **net C balance** especially during the dry season.

Xhuan et al., 2016

- As for CH_4 fluxes, wet season (22.3 nmol m^{-2} s^{-1}) generally produces higher CH_4 flux than in the dry season (15.8 nmol m^{-2} s^{-1}).
- Described the driest period where the GWL was the lowest have the most significant influence on CH_4 in their study site at a primary tropical peat swamp forest.
- Linear relationships were found between CH_4 with GWL and soil water content (SWC) indicating the activities of methanogenesis.

AGRO-ENVIRONMENTAL MANAGEMENT OF TROPICAL PEATLAND

Keep it Tight & Moist

Swiss Cheese

Drainage

Mechanical Compaction

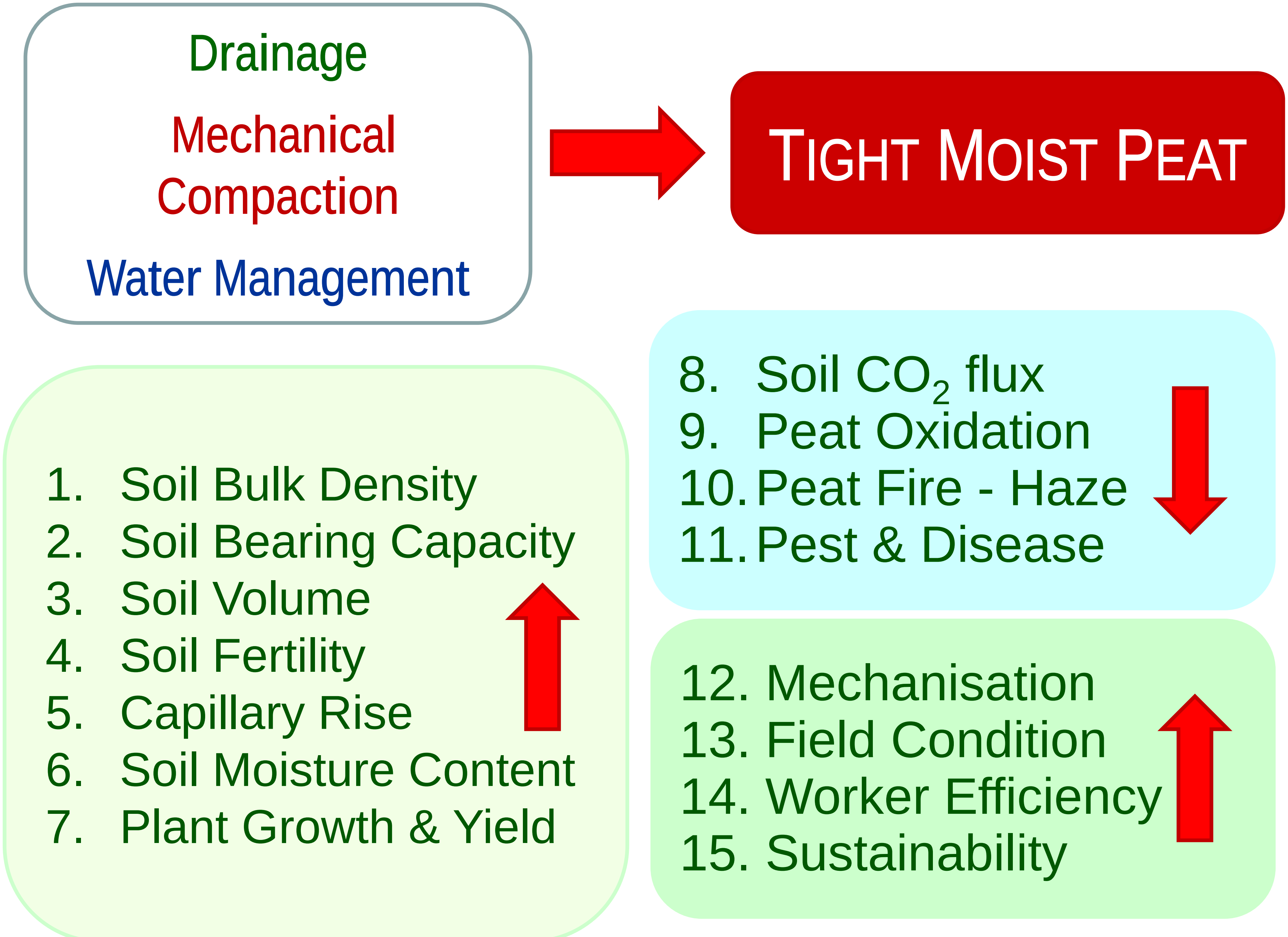
Water Management

Cheese Cake

TIGHT MOIST PEAT ensures Good **Plant Growth** & **High Yield**.

Decrease Soil CO_2 emission

Prevent Peat Fire


Drainage
Mechanical
Compaction
Water Management
TIGHT MOIST PEAT
8. Soil CO_2 flux
9. Peat Oxidation
10. Peat Fire - Haze
11. Pest & Disease
1. Soil Bulk Density
2. Soil Bearing Capacity
3. Soil Volume
4. Soil Fertility
5. Capillary Rise
6. Soil Moisture Content
7. Plant Growth & Yield
12. Mechanisation
13. Field Condition
14. Worker Efficiency
15. Sustainability

CONCLUSION

1. The outcomes from the studies provide beneficial knowledge on the role of peatlands & GHG fluxes, particularly the independency of GWL & soil compaction to GHG fluxes.
2. Effective water management can be achieved by apposite compaction procedure & the control of water table.
3. Agro-environmental management can reduce soil C fluxes & can act as an exemplary model for future sustainable agriculture development.
4. Besides that, the promotion and communication of this successful concept should be intensified, with government incentives & incorporate into good agriculture practice certification for oil palm on peat.
5. However, the success of the implementation lies heavily on good procedural synthesis of scientific findings, knowledge & understanding on tropical peat.

SARAWAK TROPICAL PEAT RESEARCH INSTITUTE

Establis…

Tr…

Research is Our Vocation

THANK YOU

Field Research

Establish a full Ecosystem Study via Eddy Covariance