Dinámica de carbono, nutrientes y desarrollo de la palma de aceite en Colombia

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
OPAL Oil Palm Adaptive Landscapes

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Bandar Seri Begawan, Brunei, Borneo

Turberas tropicales, bosques pantanosos, peat swamp forests

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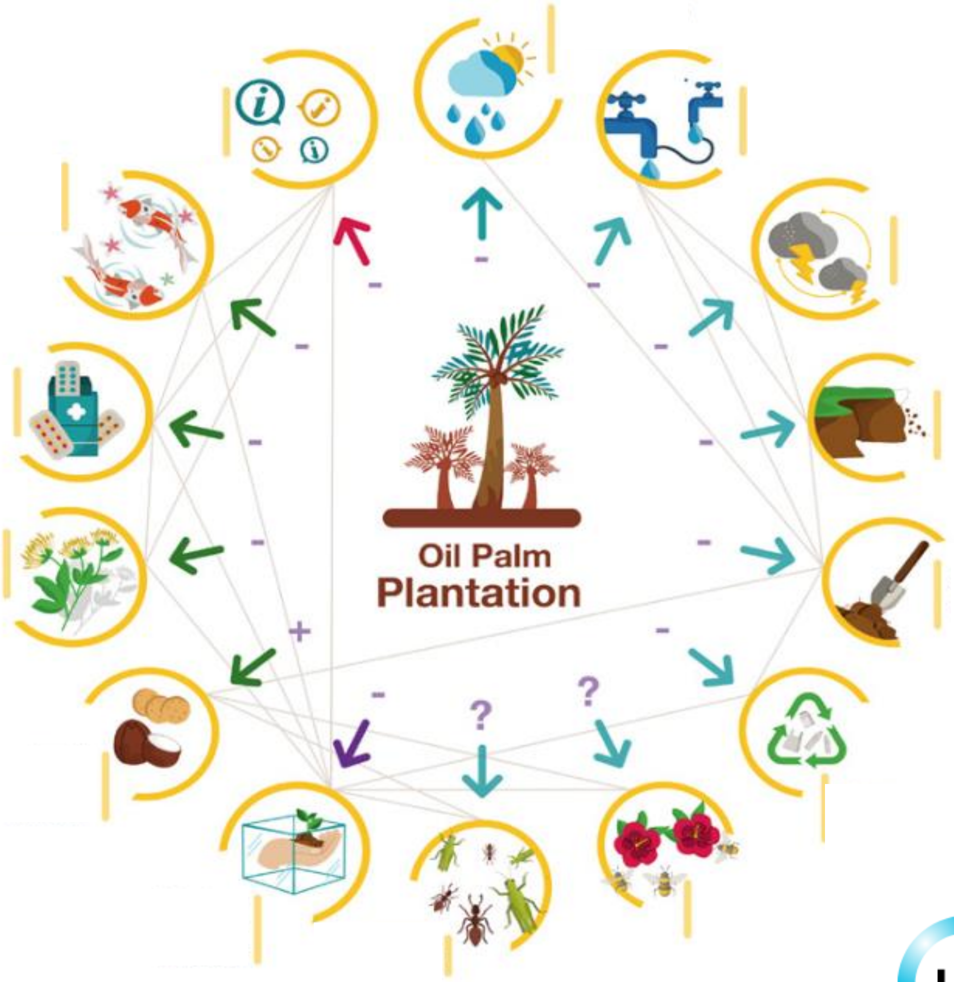
KE ARAH KESEMPURNAAN INSAN

Bosques pantanosos degradados

EL PODER TRANSFORMADOR DE LA PALMA DE ACEITE



Juan Carlos Quezada, September 2022.

SCIENCE ADVANCES | RESEARCH ARTICLE

ECOLOGY

Carbon neutral expansion of oil palm plantations in the Neotropics

Juan Carlos Quezada[1,2]*, Andres Etter[3], Jaboury Ghazoul[4,5,6], Alexandre Buttler[1,2,7], Thomas Guillaume[1,2]

Alternatives to ecologically devastating deforestation land use change trajectories are needed to reduce the carbon footprint of oil palm (OP) plantations in the tropics. Although various land use change options have been proposed, so far, there are no empirical data on their long-term ecosystem carbon pools effects. Our results demonstrate that pasture-to-OP conversion in savanna regions does not change ecosystem carbon storage, after 56 years in Colombia. Compared to rainforest conversion, this alternative land use change reduces net ecosystem carbon losses by 99.7 ± 9.6%. Soil organic carbon (SOC) decreased until 36 years after conversion, due to a fast decomposition of pasture-derived carbon, counterbalancing the carbon gains in OP biomass. The recovery of topsoil carbon content, suggests that SOC stocks might partly recover during a third plantation cycle. Hence, greater OP sustainability can be achieved if its expansion is oriented toward pasture land.

Received: 5 December 2018 | Revised: 20 May 2019 | Accepted: 22 May 2019
DOI: 10.1002/ldr.3380

RESEARCH ARTICLE

WILEY

Drivers of soil carbon stabilization in oil palm plantations

Johanna Rüegg[1,2] | Juan Carlos Quezada[1,3] | Mathieu Santonja[1,3,4] | Jaboury Ghazoul[2] | Yakov Kuzyakov[5,6,7] | Alexandre Buttler[1,3,8] | Thomas Guillaume[1,3]

Received: 29 October 2021 | Revised: 1 December 2021 | Accepted: 1 December 2021
DOI: 10.1111/gcb.16069

Global Change Biology

RESEARCH ARTICLE

Deforestation-free land-use change and organic matter-centered management improve the C footprint of oil palm expansion

Juan Carlos Quezada[1] | Thomas Guillaume[1,2] | Christopher Poeplau[3] | Jaboury Ghazoul[4,5,6] | Alexandre Buttler[7,8]

Geosci. Model Dev., 14, 3879–3898, 2021
https://doi.org/10.5194/gmd-14-3879-2021

Geoscientific Model Development
Open Access
EGU

Partitioning soil organic carbon into its centennially stable and active fractions with machine-learning models based on Rock-Eval® thermal analysis (PARTY$_{SOC}$v2.0 and PARTY$_{SOC}$v2.0$_{EU}$)

Lauric Cécillon[1,2], François Baudin[3], Claire Chenu[4], Bent T. Christensen[5], Uwe Franko[6], Sabine Houot[4], Eva Kanari[2,3], Thomas Kätterer[7], Ines Merbach[8], Folkert van Oort[4], Christopher Poeplau[9], Juan Carlos Quezada[10,11,12], Florence Savignac[3], Laure N. Soucémarianadin[13], and Pierre Barré[2]

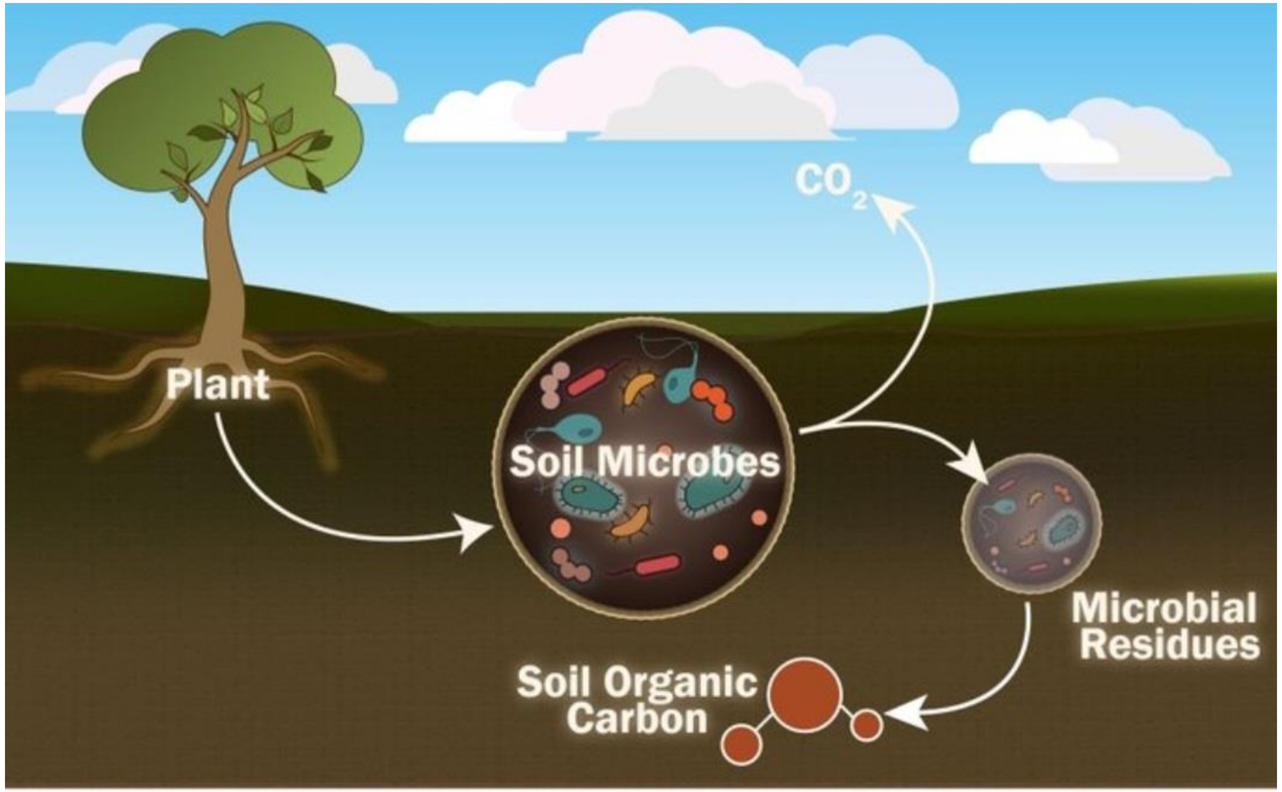
Principales preguntas

Qué pasa con el C a lo largo del ciclo/ciclos del cultivo de palma?
Cómo es la dinámica de nutrientes?
Cómo se comporta la actividad biológica del suelo?

Key/take home messages

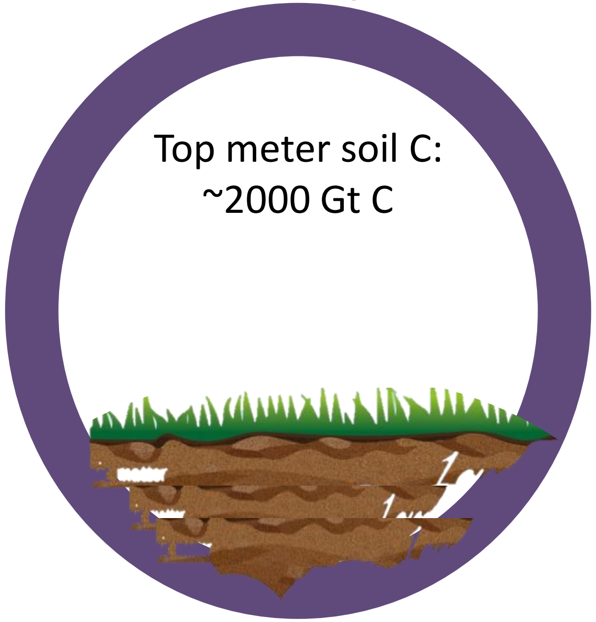
- Muy **poca evidencia empírica** sobre la expansión de la palma en **zonas de sabanas y pasturas** en zonas de sabana
- Mucho menor información en cuanto a **la huella de C** por la conversión de sabanas y pasturas en plantaciones de palma
- Desconocimineto de **aspectos fundamentales de la dinámica de C y nutrientes** durante ciclos enteros de de producción
- La **conversión de sabana en palma deja una huella positiva de C** a nivel del ecosistema lo largo del 1 ciclo del cultivo
- La dinámica del C en el ecosistema palmero a través de un ciclo de producción es **mediada por el manejo agronómico**
- Plantaciones derivadas de **pasturas (indirectamente de sabanas) tienen un balance neutro de C (balance de C no se afecta por conversion a palma)** a nivel del ecosistema a lo **largo de dos ciclos de cultivo**
- La **fertilidad química del suelo aumentó** durante el tiempo de cultivo y aún no se acerca al equilibrio
- Mayor estabilización de C y mayor actividad microbiológica del suelo en **zonas de palera y plato**
- **La dinámica del C en el suelo a largo plazo (dos ciclos) se compone de dos tendencias diferentes**. Primero se da una fuerte pérdida de las stocks/cantidades **de C y luego se estabiliza**.

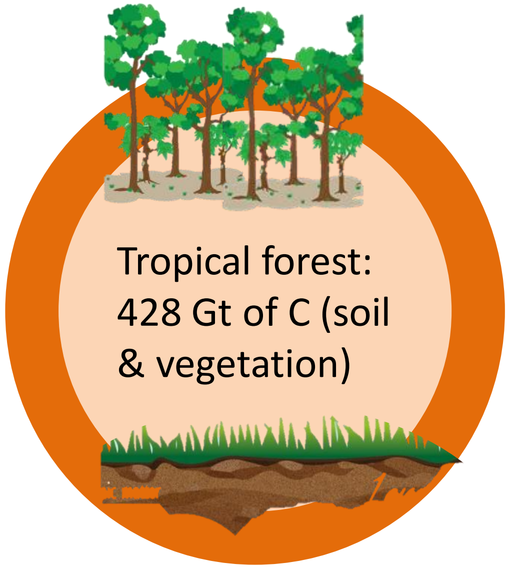
Activar la biología del suelo con capacidad de secuestro de C



Global scale

~10 % lost in the last 150 yrs.





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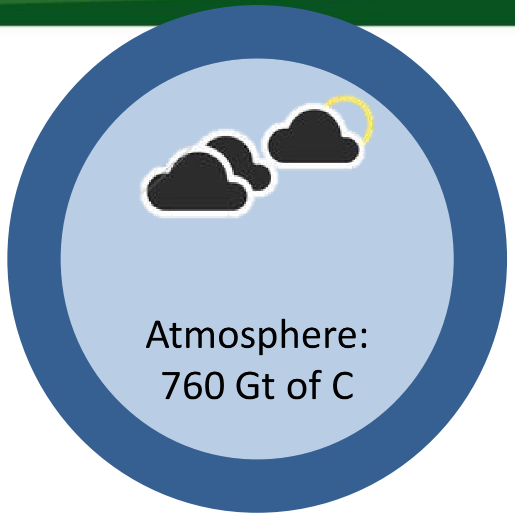
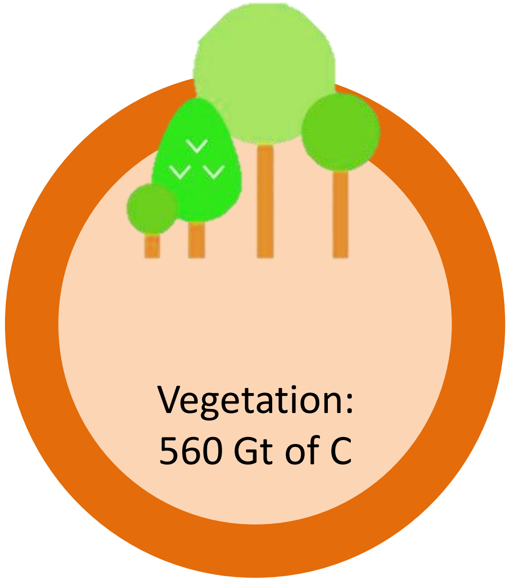


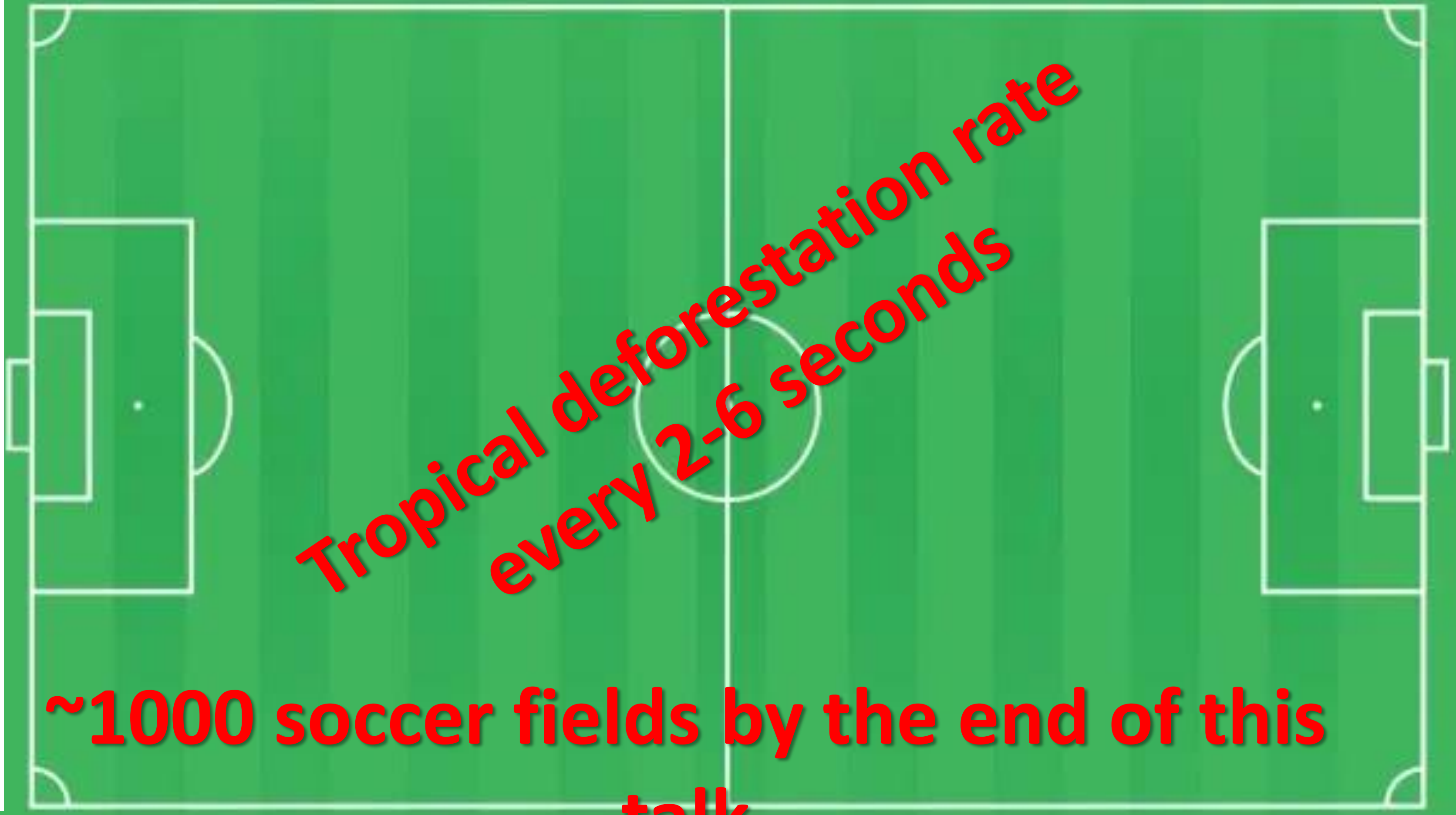


Anthropogenic perturbations -> Land use Change -> Disturb the C cycle -> global C balance

Hairiah K. et al., 2001. ICRAF publication

90-120 m

64 -75 m

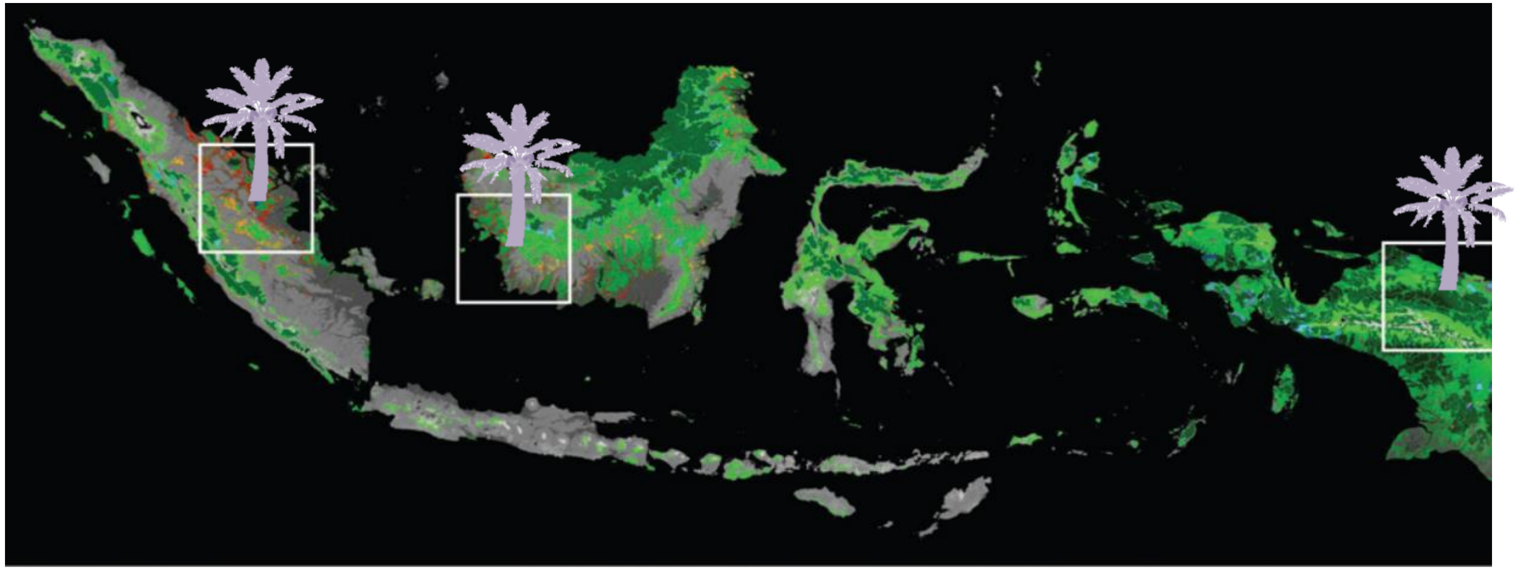


Tropical deforestation rate every 2-6 seconds

~1000 soccer fields by the end of this talk

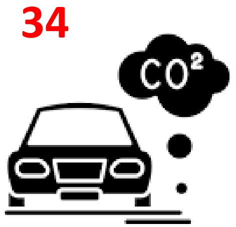
Deforestation scenario for OP in SE Asia

- One of the highest world's deforestation rates **0.84 Mha yr^{-1}**
- Indonesia produces **~50%** of global palm oil, together with Malaysia **~80%**
- Since 2000, **70%** of OP expansion on forests, peatlands, agroforest
- **4th** highest GHG emission rate

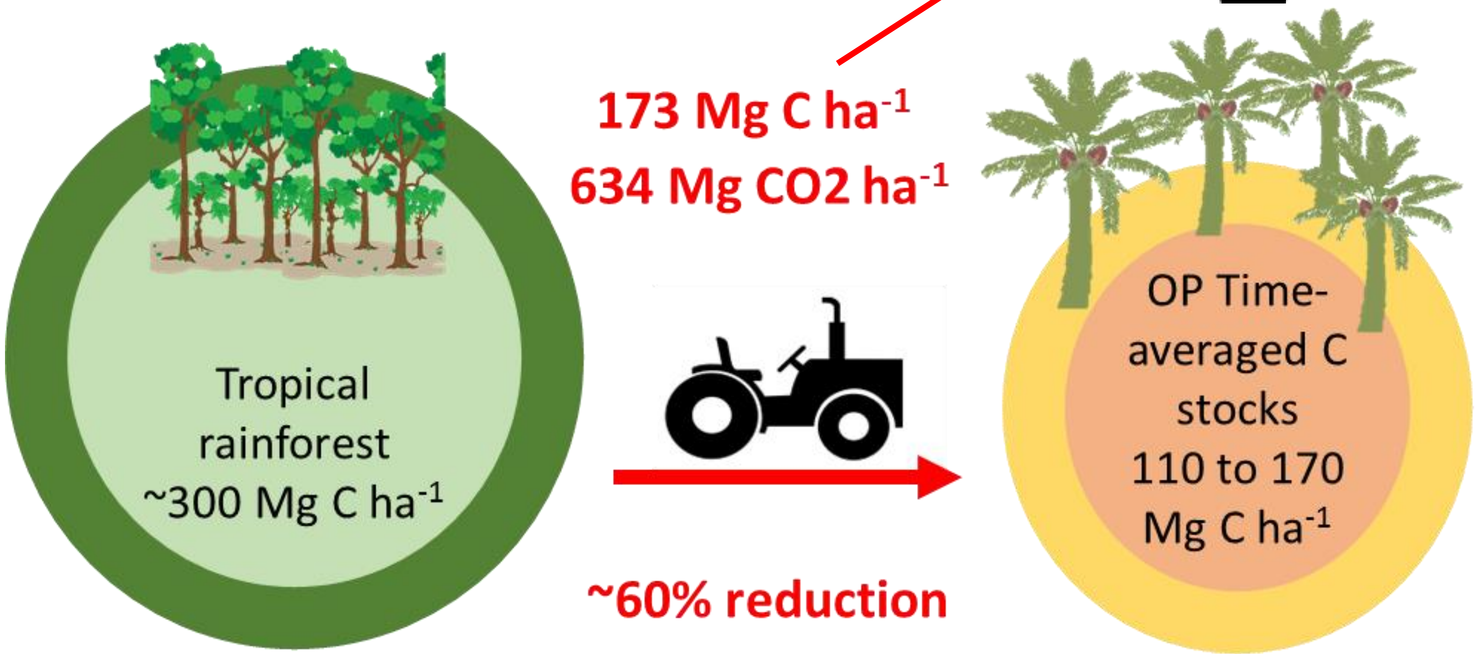


Margono B. et al., 2014. NCC

Deforestation scenario for OP in SE Asia



Ecosystem C stocks:



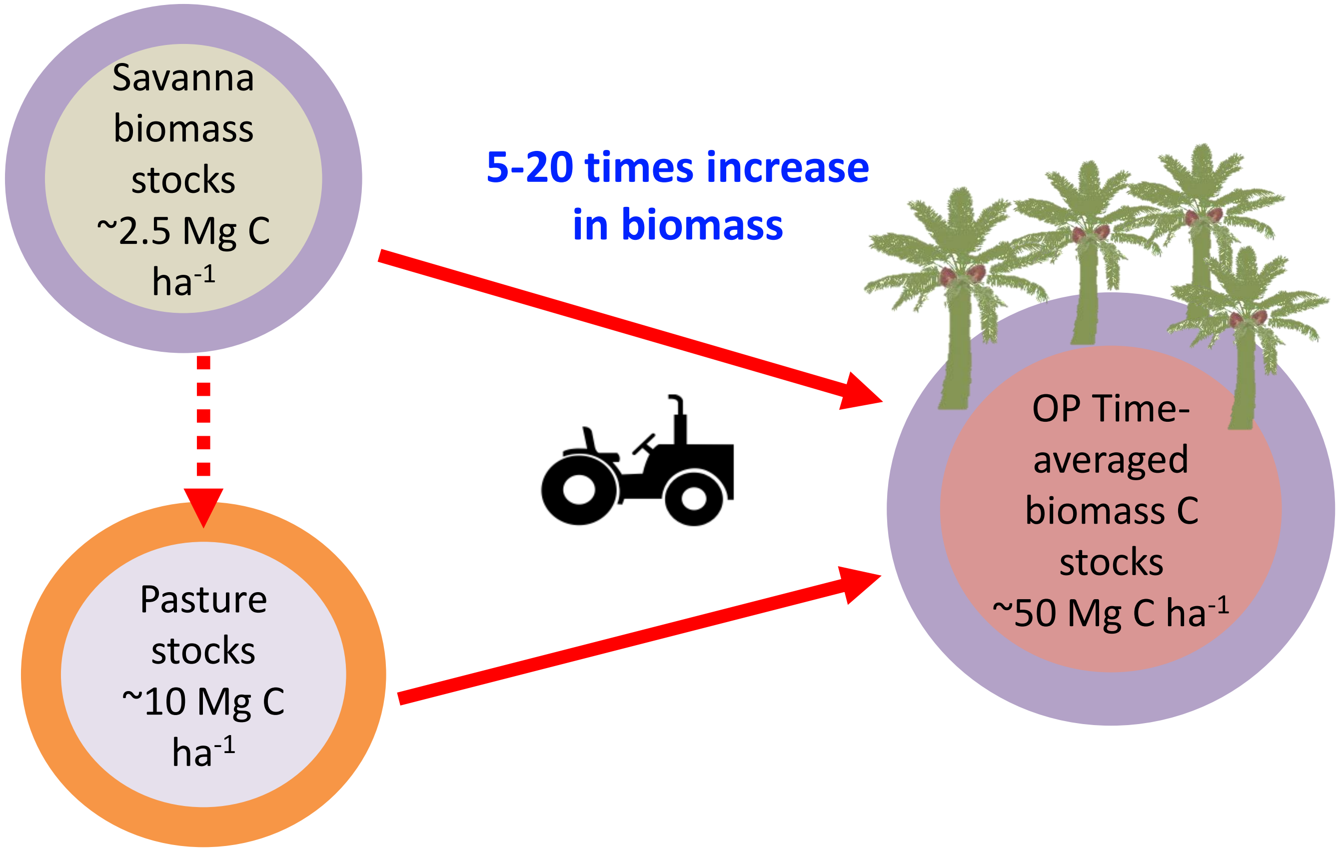
Alternatives to deforestation?

Guillaume T. et al., 2016. Nat. Comm.

Converting ecosystems with low biomass?

Biomass C stocks:

Deforestation-free Alternatives



Braz S. et al., 2013. Soil Sci. Soc. Ame.

Converting ecosystems with low biomass?

Colombia

- OP area: **~450,000 ha**
- **Minimal deforestation cost**

"Los Llanos" Orientales (Eastern Colombia)

- **~40%** of OP cultivated area
- **~22** million ha (**5 time the Swiss** territory)
- **Savanna ecosystem** (dominated by **C4 grasses**)
- Main land use: Extensive **cattle ranching**
- Expansion predicted to **continue**
- **2.5 million ha** of degraded pasture areas

Castiblanco C. et al., 2013. Environ. Sci. Poli.

Converting ecosystems with low biomass?

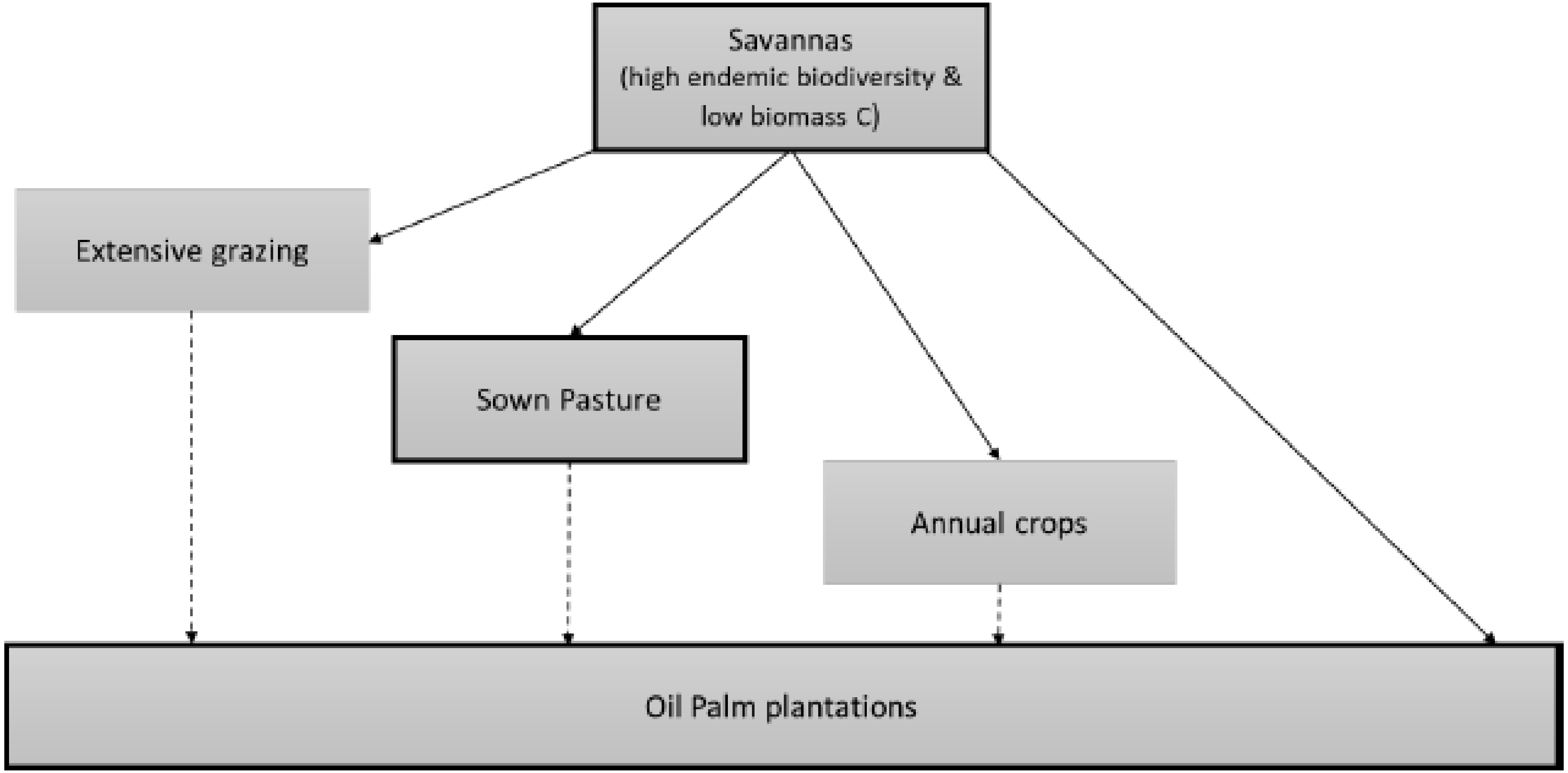
↳ **Evident increase of biomass C**

↳ **Knowledge gaps**

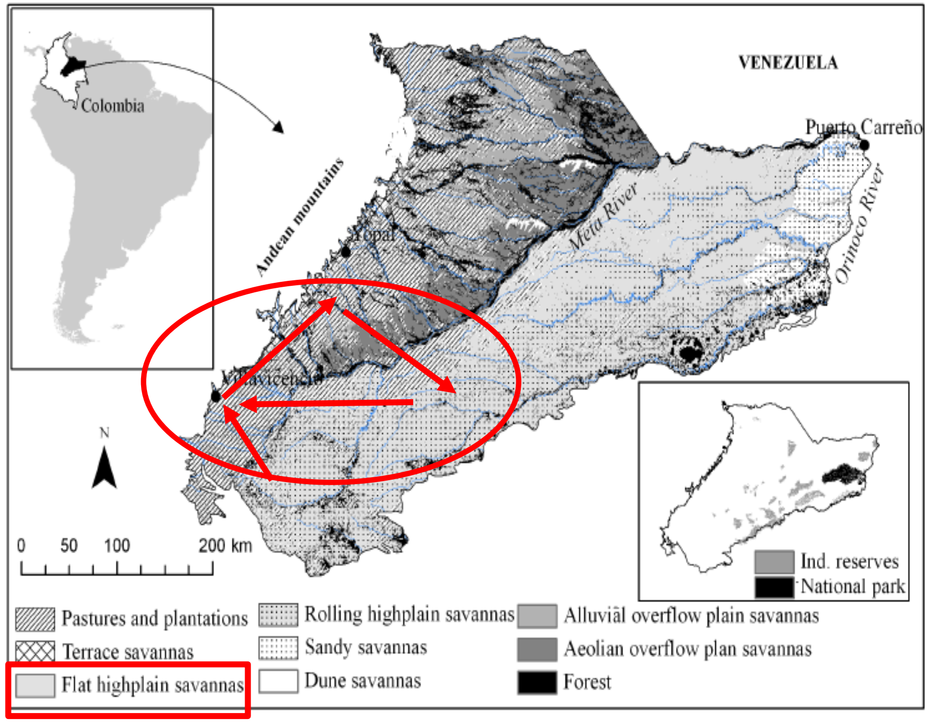
- **Few studies** on pastures/grasslands conversion into OP
- **No empirical data** on the soil C pool
- **SOC** dynamic aspects like **decomposition** and **accumulation**

Overall Objective

Assess quantitatively, with field-based measurements, the impacts of deforestation-free alternatives on soil biogeochemical properties and ecosystem C storage for a more sustainable expansion of OP agriculture in the tropics.


Savannas
(high endemic biodiversity &
low biomass C)
Extensive grazing
Sown Pasture
Annual crops
Oil Palm plantations

EASTERN PLAINS OF COLOMBIA "LOS LLANOS"

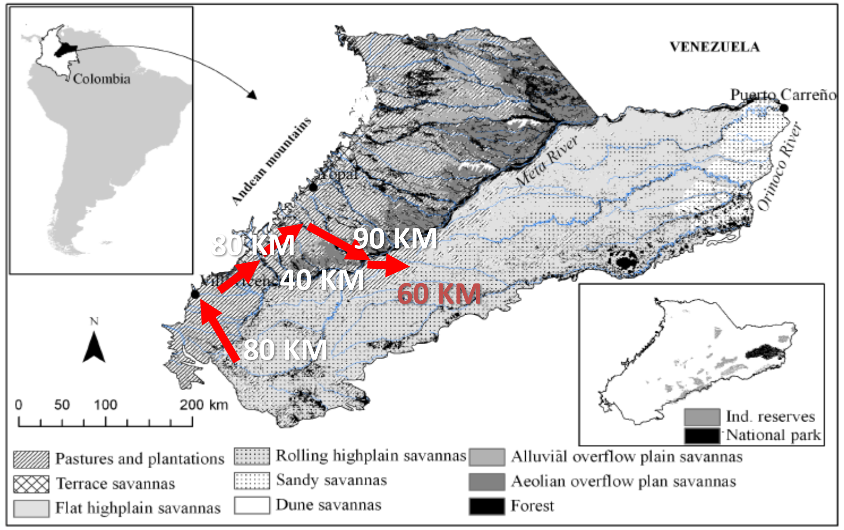


Main land use: extensive cattle ranching with almost no management an few external inputs

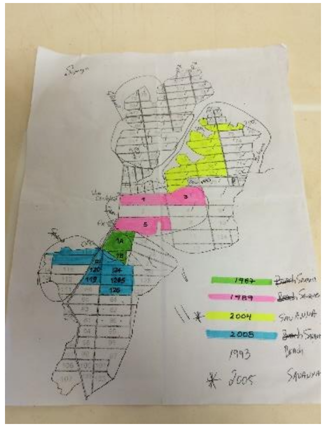
VISITS TO FARMS

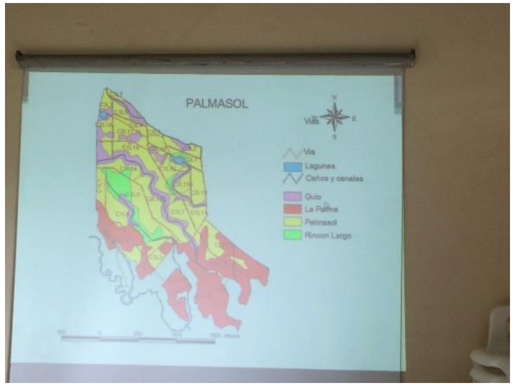
Plantation name	Soil Type	Land-use History*	OP plantation age range (yrs)	Plant material**	Management***
Palmasol	Well-drained Inceptisols	S --> P --> OP	0 - 30	H and G	CC, compost
Manapure	Well-drained Inceptisols	S --> R --> OP	0 - 30	H and G	CC
La Cabana	Well-drained Inceptisols	S --> P --> OP 1st-->OP 2nd	3 to 57	H and G	CC, compost, raw residues
La Cabana	Medium-drained shallow Inceptisols	S --> P --> OP 1st-->OP 2nd	3 to 57	H and G	CC, compost, raw residues
La Cabana	Shallow Gleysols	S --> P --> OP 1st-->OP 2nd	3 to 57	H and G	CC, compost, raw residues
Campo Alegre	Gleysols	S --> R --> OP	4 to12	H and G	CC
Palmera Santana	Gleysols	S --> R --> OP	4 to 28	G	CC, weeded circle no bare soil
La Vigia	Gleysols	S --> P --> OP	5 to 8	H and G	CC, reduced use of chemicals
Sillatava, Ocarraba, Samani	Oxisols (+ plinthite)	S --> OP	2 to 9	G	Implementing CC
Sapuga	Oxisols	S --> OP	7 to 30	G	No CC
Sapuga	Oxisols	S --> P --> OP	7 to 30	G	No CC

*S: Savanna, P: Pasture, OP: Oil palm, R: Rice
**H: Hybri, G: Guinensis
***CC: Cover crops

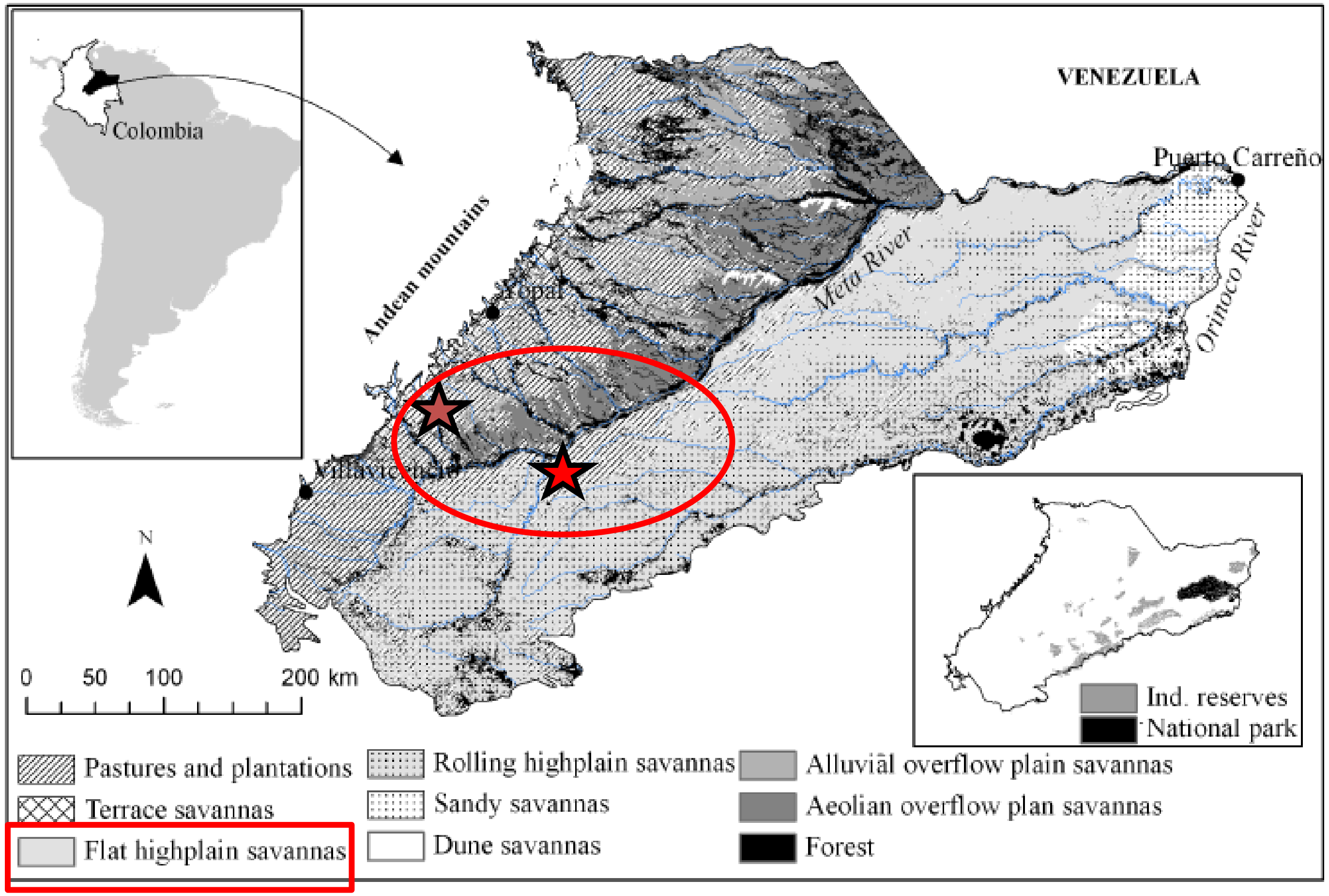


CRITERIA FOR SITE SELECTION



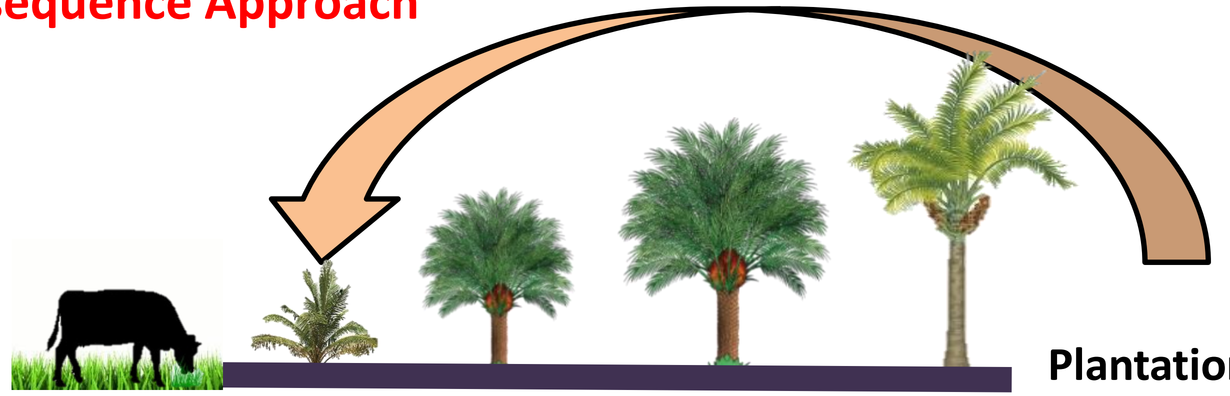


SELECTED RESEARCH SITES



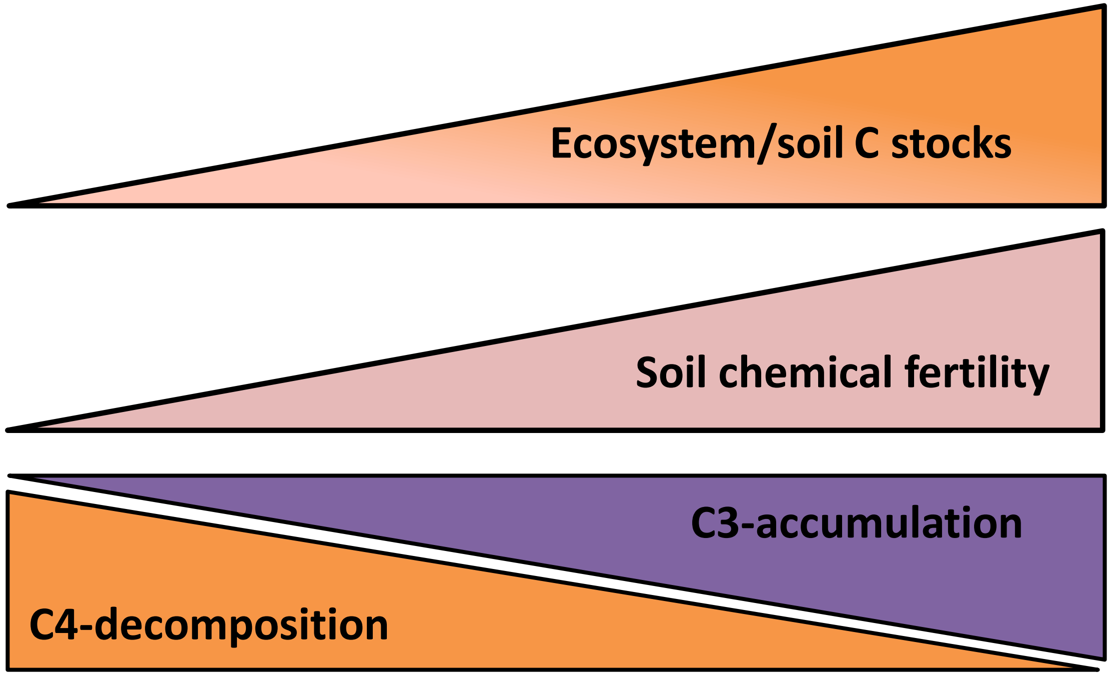
Methods

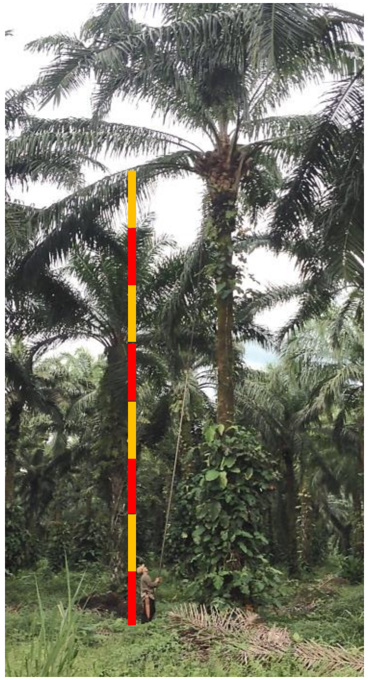
Chronosequence Approach



Plantation Renovation @ ~30 years

A Few General Research Questions/Hypotheses





Juan Carlos Quezada, September 2022.

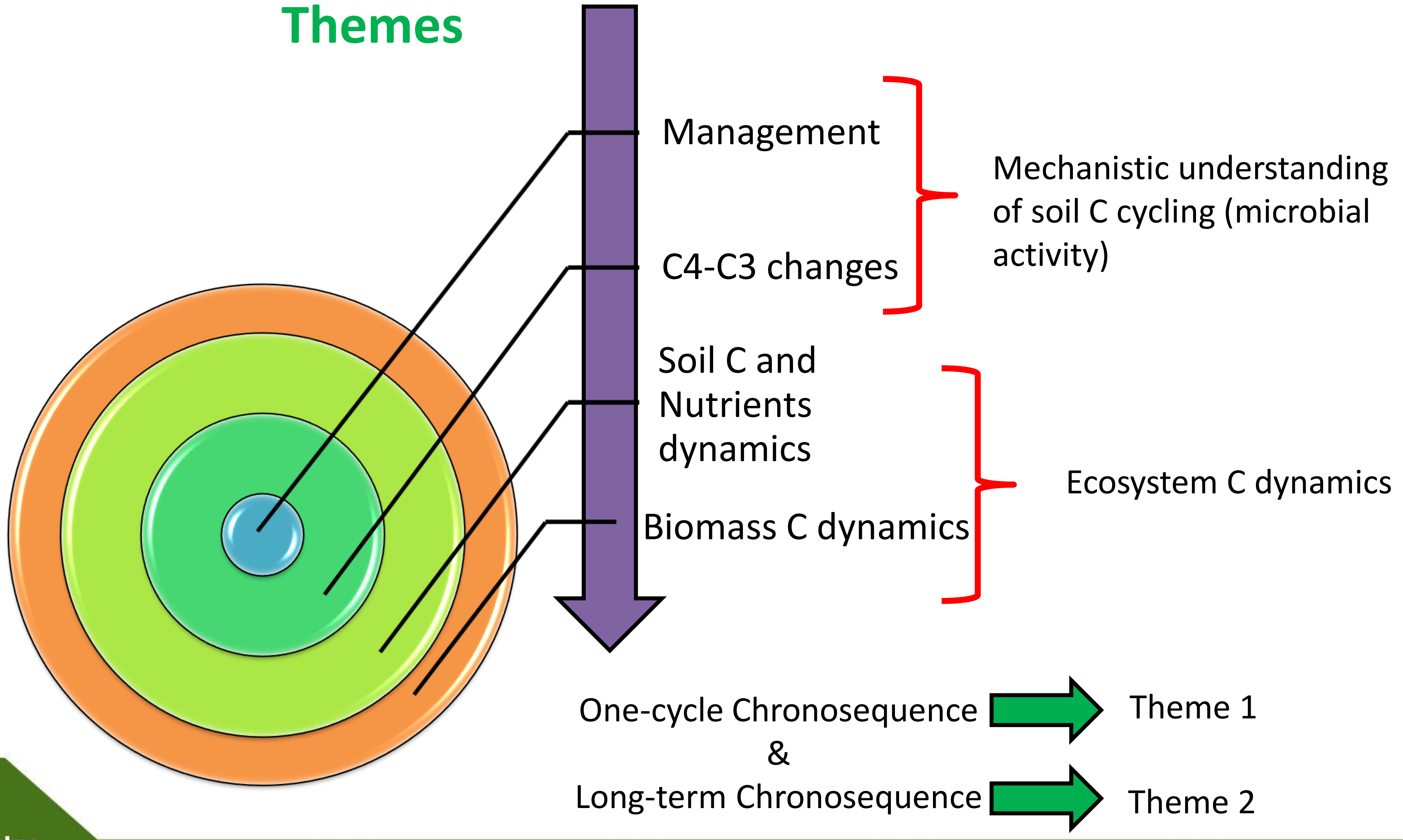
Methods

Natural ^{13}C abundance

- Vegetation change **(C4 to C3)**
- Natural **13C-labelling**
- **In-situ** estimations of **SOC turnover**
- **Clock** for C4 **decomposition** and C3 **stabilization rates**
- Only a **handful** of **studies** have used the natural abundance $\delta^{13}C$ approach

$\Delta\delta^{13}C$ signature: ~14 ‰

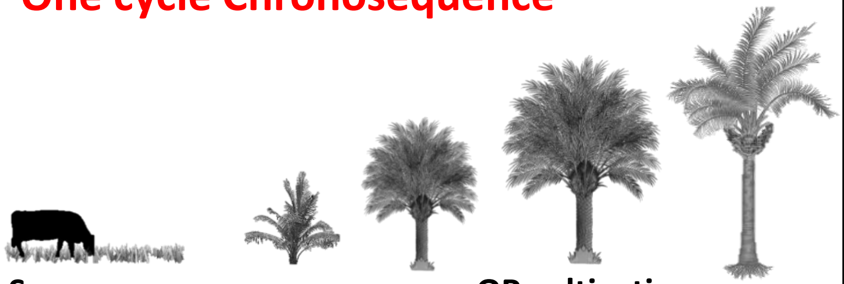
Themes

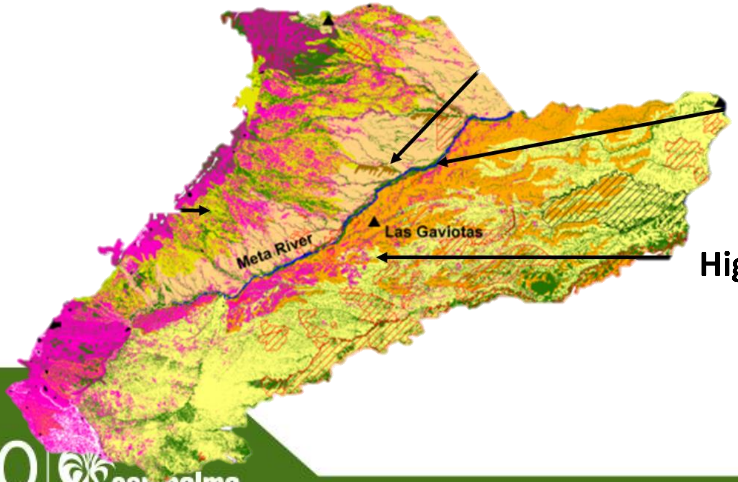

Management
C4-C3 changes
Soil C and Nutrients dynamics
Biomass C dynamics
Mechanistic understanding of soil C cycling (microbial activity)
Ecosystem C dynamics
One-cycle Chronosequence
&
Long-term Chronosequence
Theme 1
Theme 2

Methods

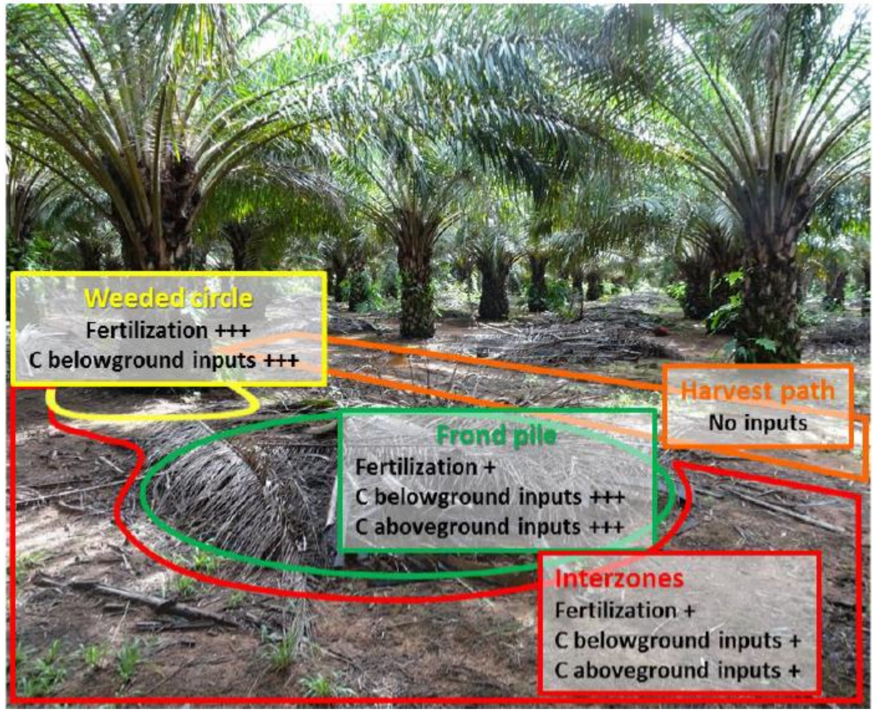
One-Cycle C Dynamics

**One full rotation cycle (27 years)/
One cycle Chronosequence**





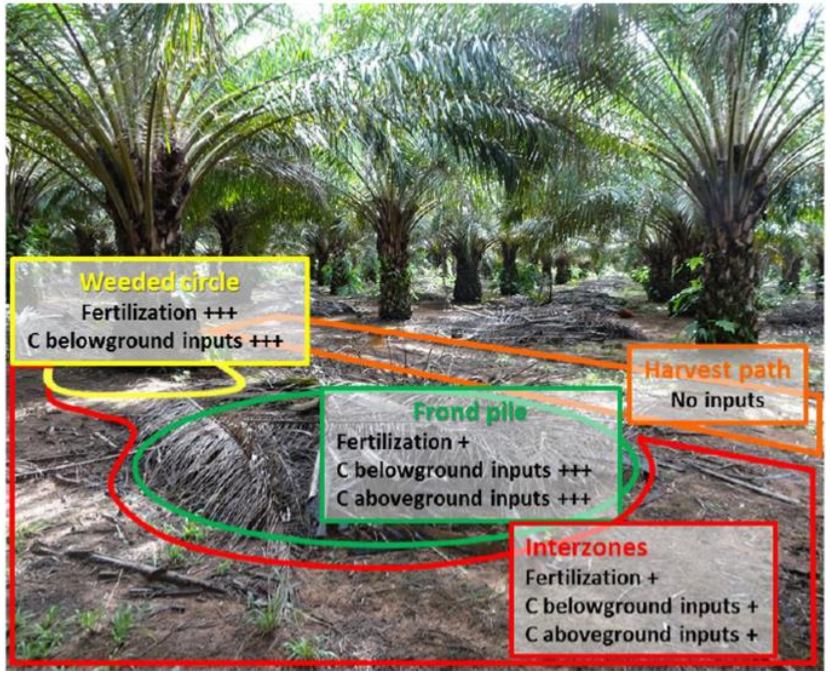
Effect of Management Practices



Mechanisms C accumulation and decomposition

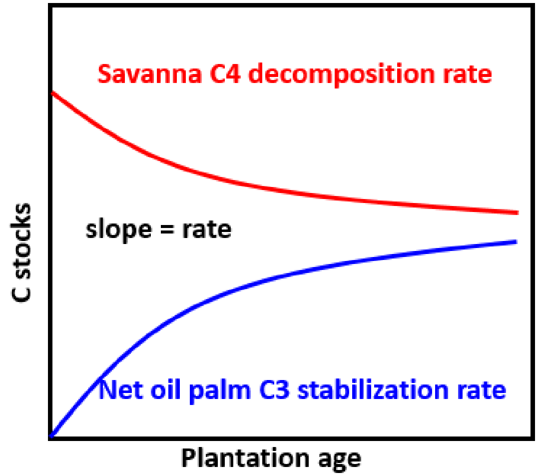
One-Cycle C Dynamics

Drivers of SOC stabilization by management



Hypotheses

W > F > IR> H



F > W > H > IZ

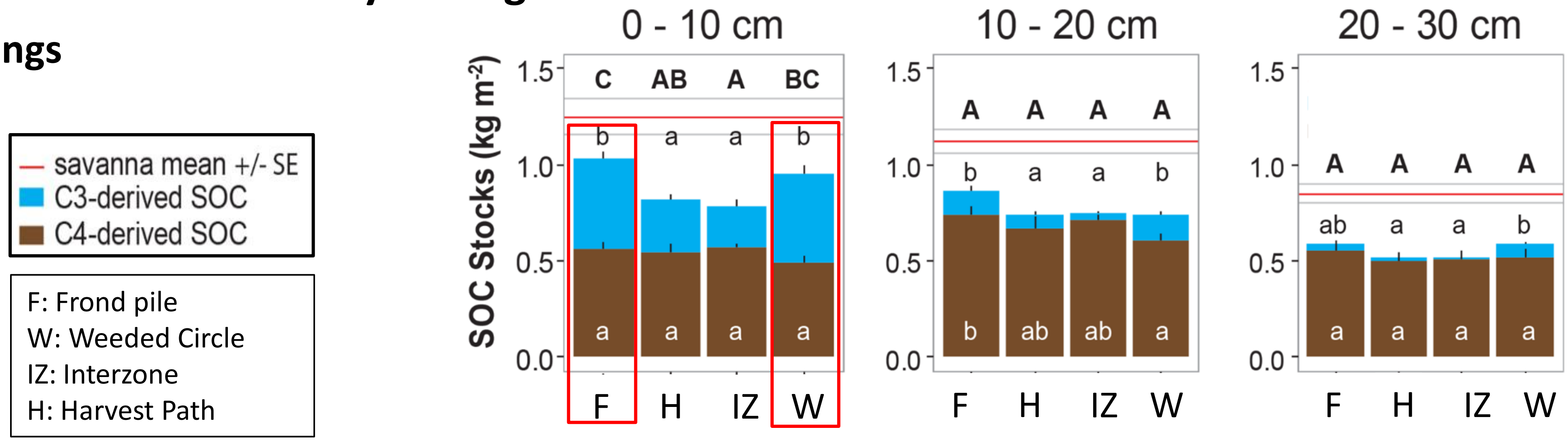
- 2,4 and 9 year-old plantation, 5 palms
- **Path analysis -> Direct** and **indirect** effects of fine roots, microbial activity and nutrient application on OP-derived C accumulation
- **Fine roots** (C inputs)

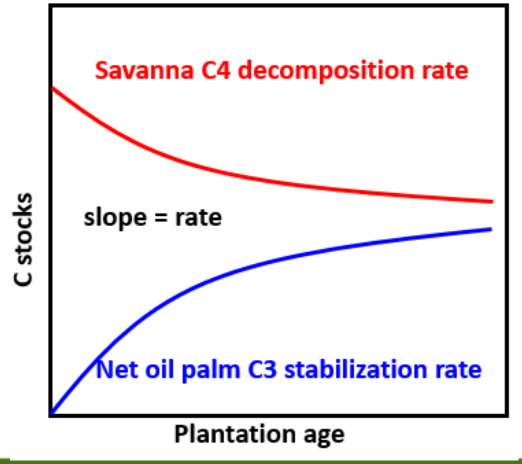
Rüegg et al., 2019. Land Deg. & Dev.

One-Cycle C Dynamics

Drivers of SOC stabilization by management

Major Findings





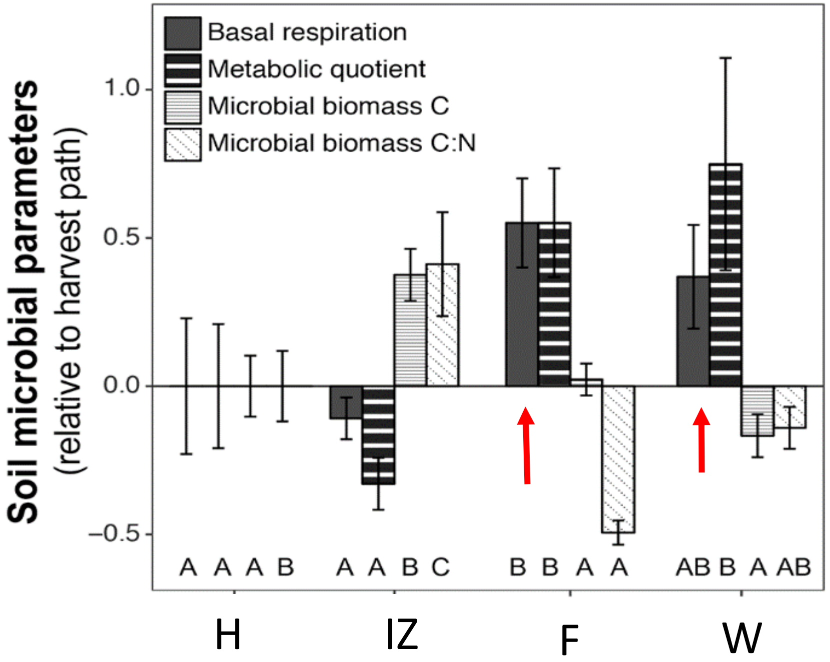
W > F > IZ> H

No Priming Effect

One-Cycle C Dynamics

Drivers of SOC stabilization by management

Major Findings



F: Frond pile
W: Weeded Circle
IZ: Interzone
H: Harvest Path

- **Active but inefficient microorganisms with low CN ratio +**

K strategists (H, IZ) **r strategists (F and W)**

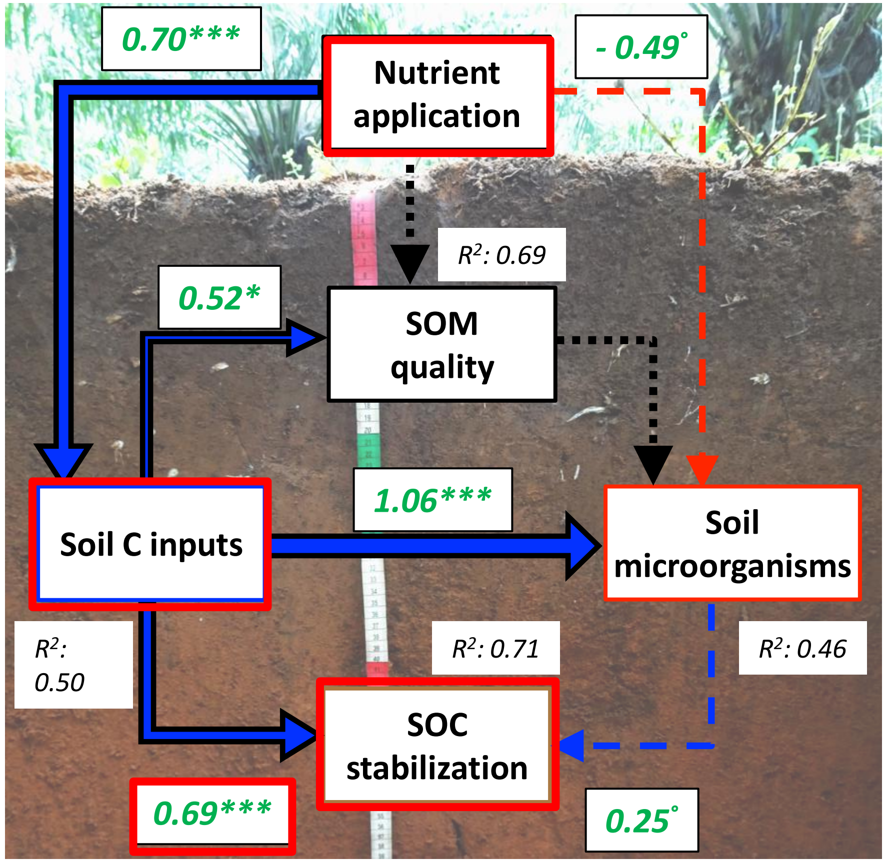
One-Cycle C Dynamics

Drivers of SOC stabilization by management

Major Findings

SOC stabilization is driven by soil C input

Cascading impact
nutrients -> root growth -> C inputs SOC



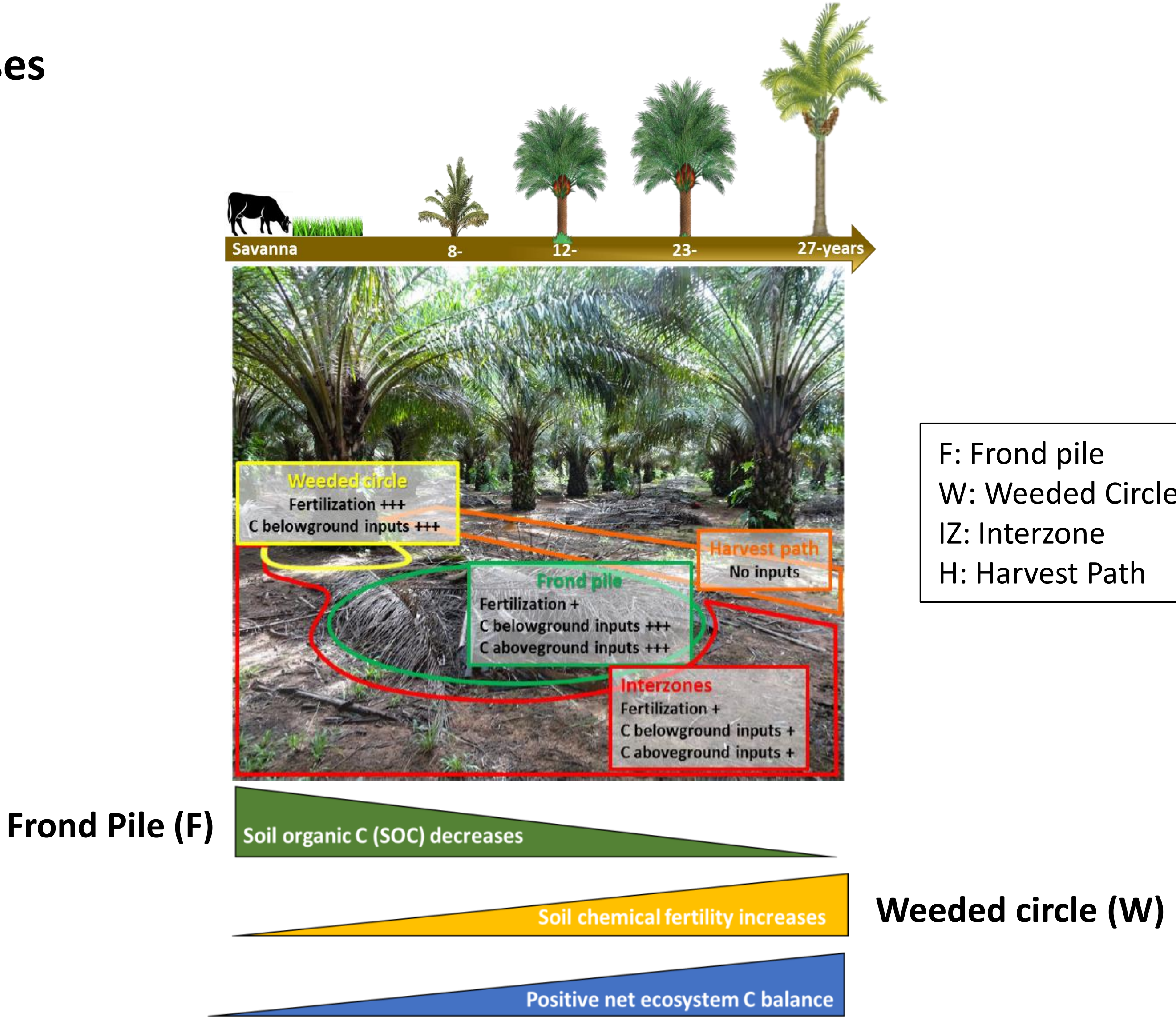
Pχ2 = 0.33, RMSEA = 0.09, TLI = 0.97, CFI = 0.99

Will these findings hold in time as OP-cultivation continues?

One-Cycle C Dynamics

Ecosystem C dynamics in Oil Palm on Savanna mediated by Management

Hypotheses



F: Frond pile
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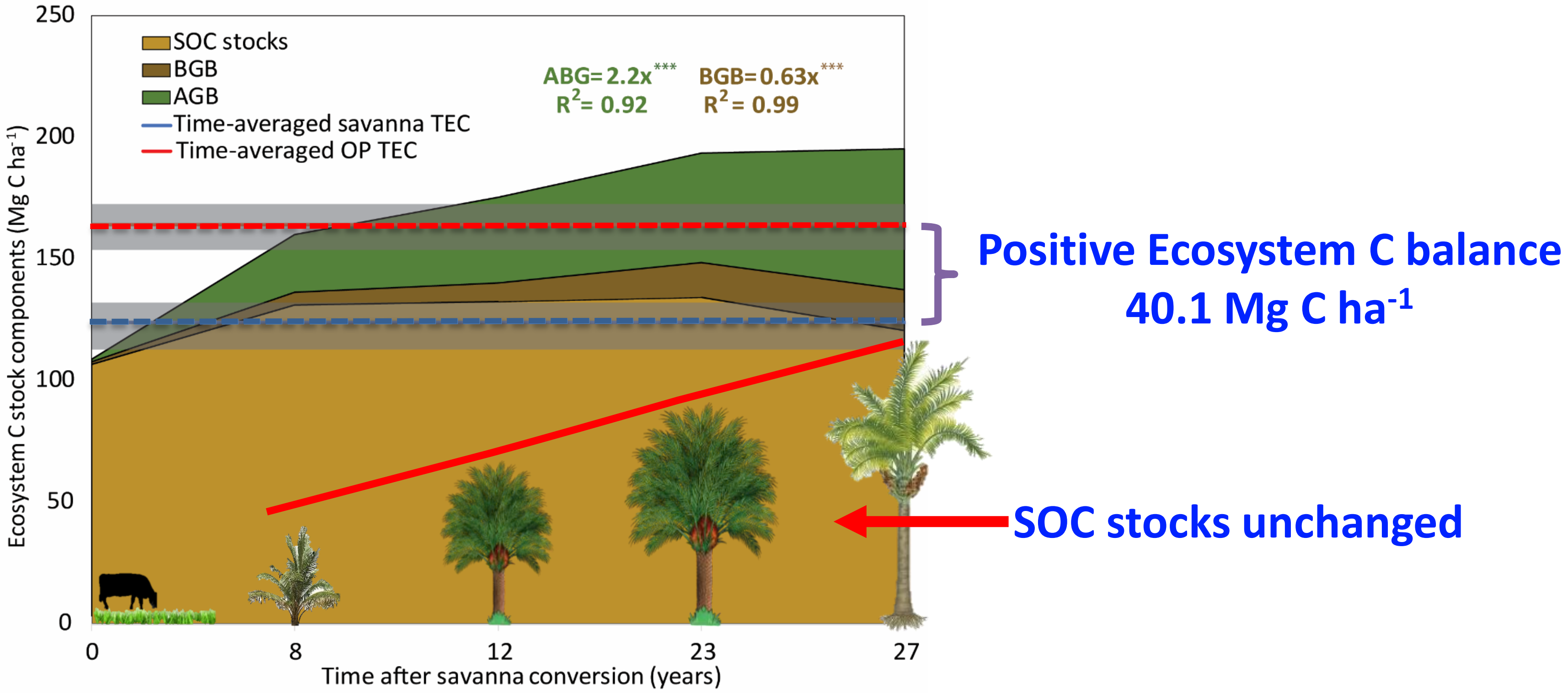
H: Harvest Path

One-Cycle C Dynamics

Ecosystem C dynamics in Oil Palm on Savanna mediated by Management

Major Findings



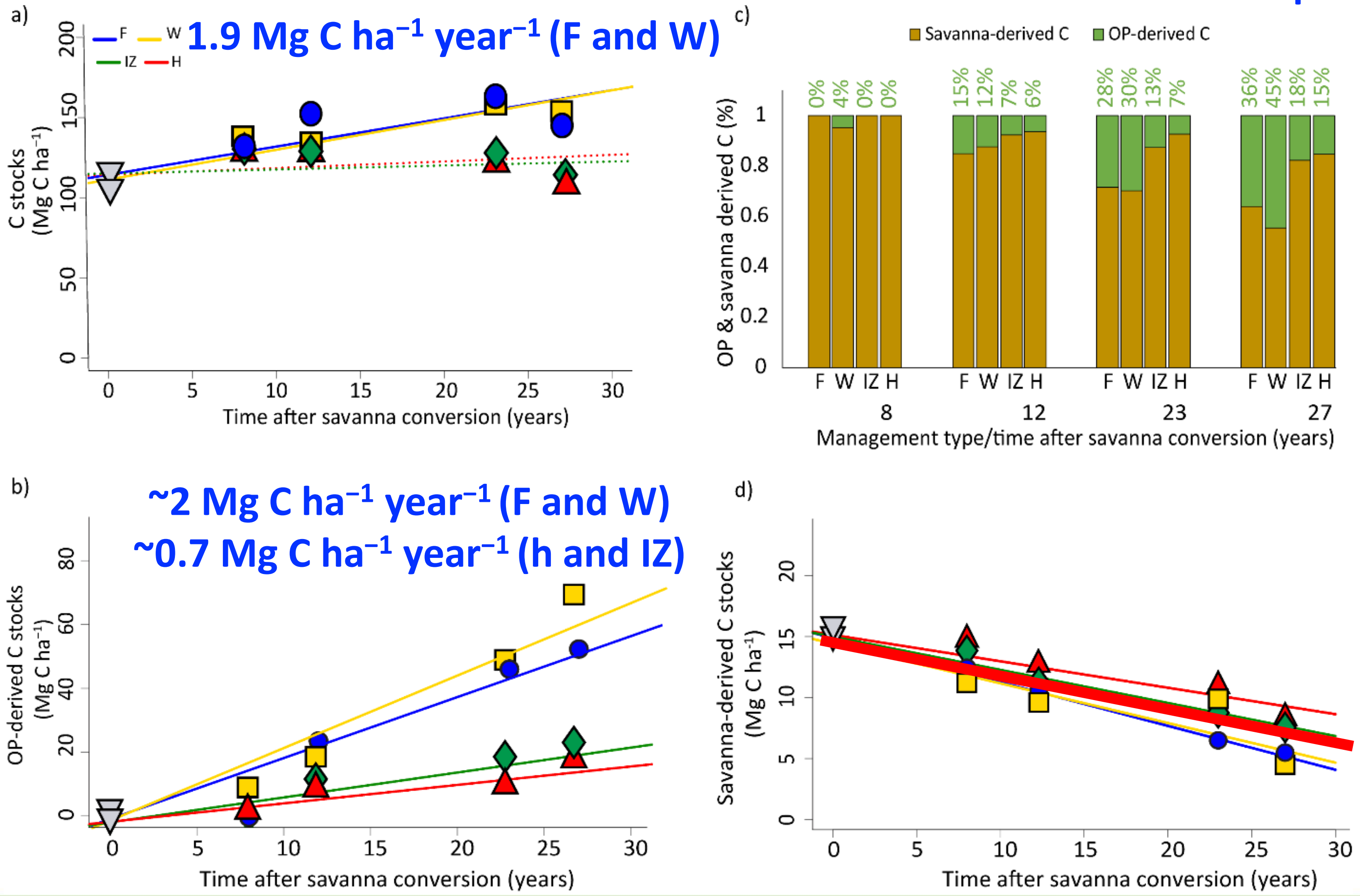
Ecosystem C dynamics in Oil Palm on Savanna mediated by Management

Major Findings

2x and 3x more OP-C in input areas F and W

23% OP-C

One-Cycle C Dynamics



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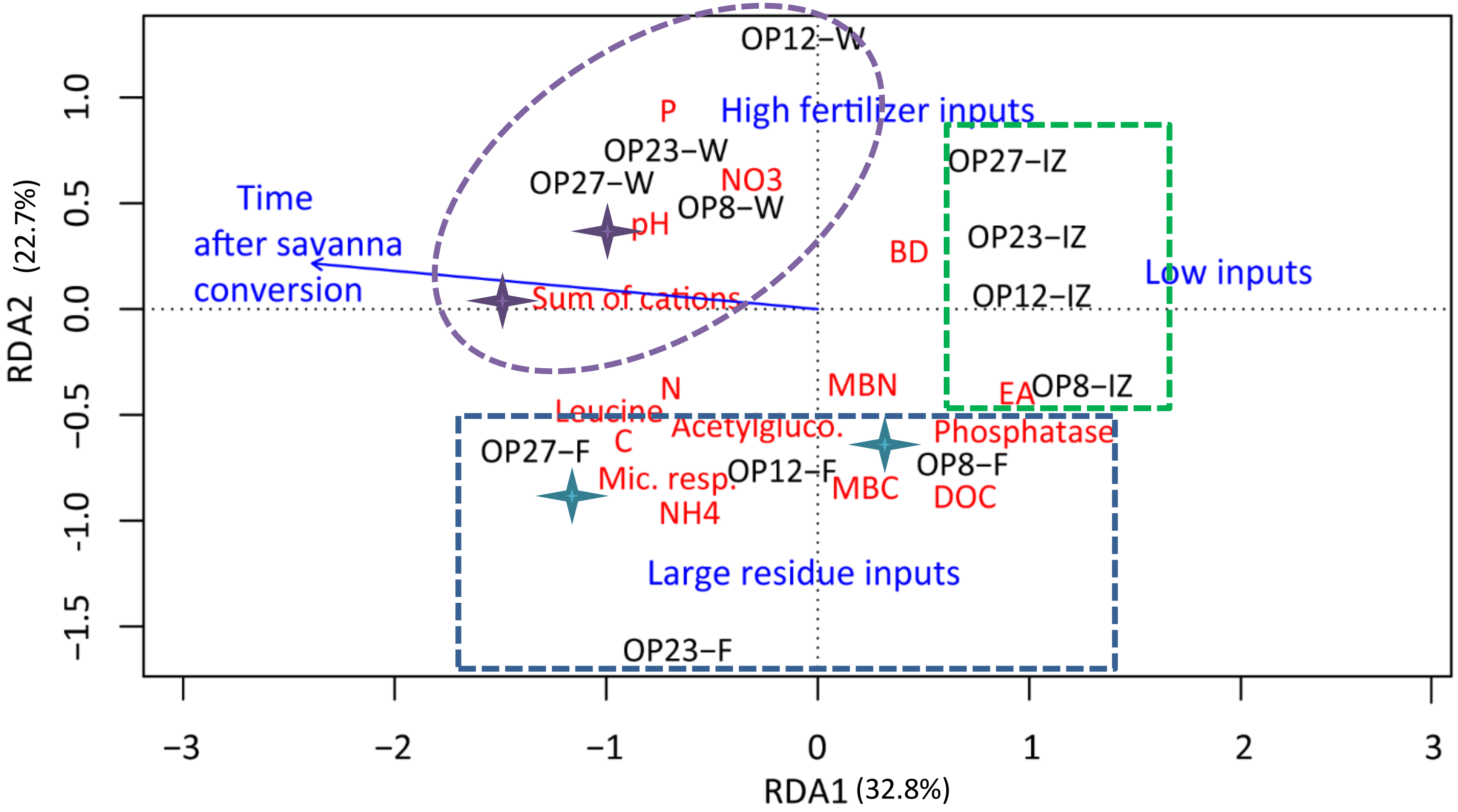
One-Cycle C Dynamics

Ecosystem C dynamics in Oil Palm on Savanna mediated by Management

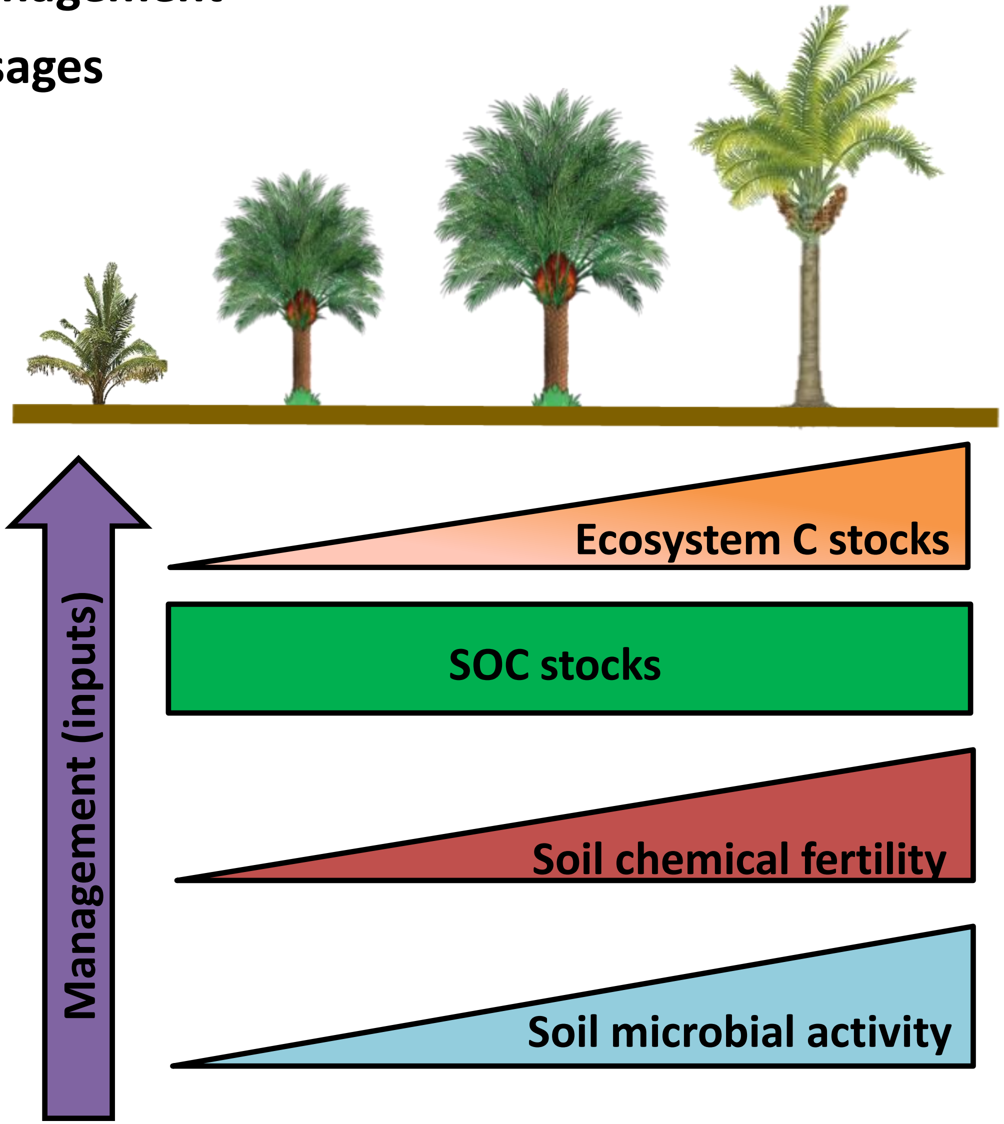


Management **~5 time > importance** (44%) to explain **variation in soil biogeochemical** properties **than LUC** (9%)

One-Cycle C Dynamics

Ecosystem C dynamics in Oil Palm on Savanna mediated by Management

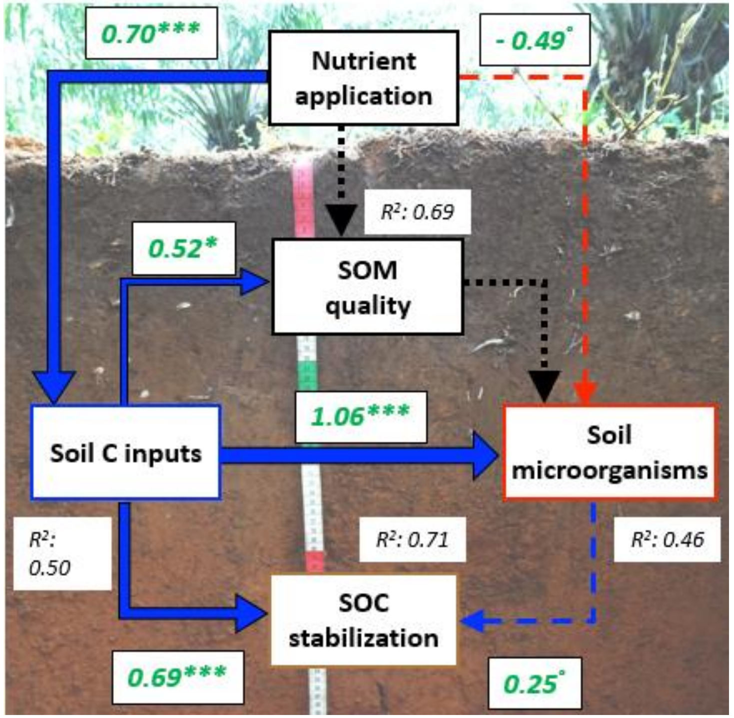
Take Home Messages



Juan Carlos Quezada, September 2022.

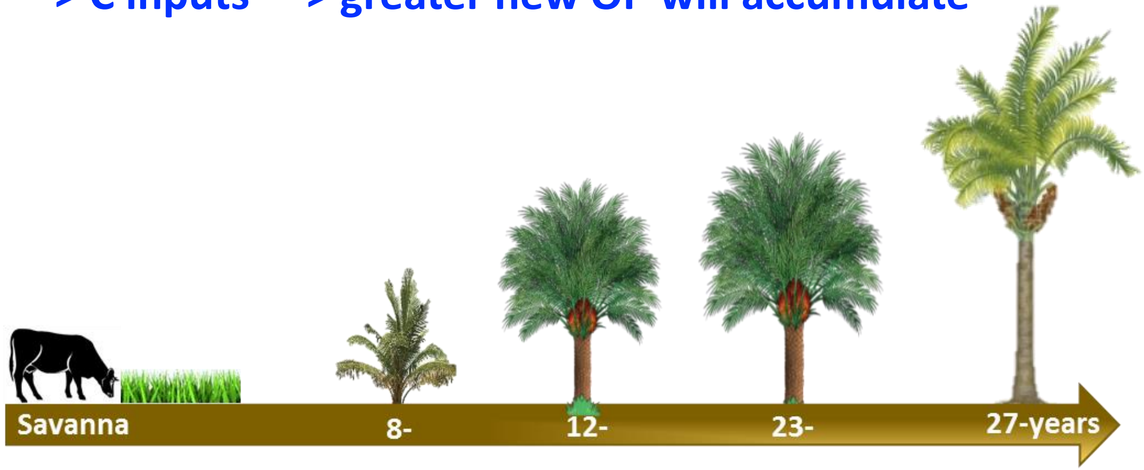
One-Cycle C Dynamics

Theme 1, Major Findings



Mature plantations findings confirmed over time

> C inputs ---> greater new OP will accumulate

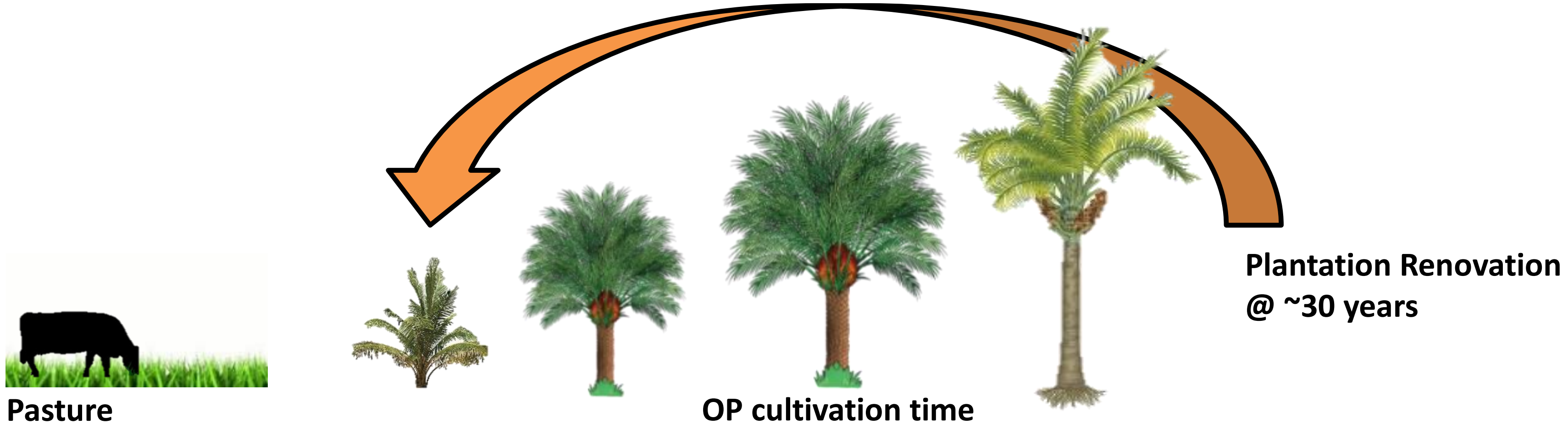


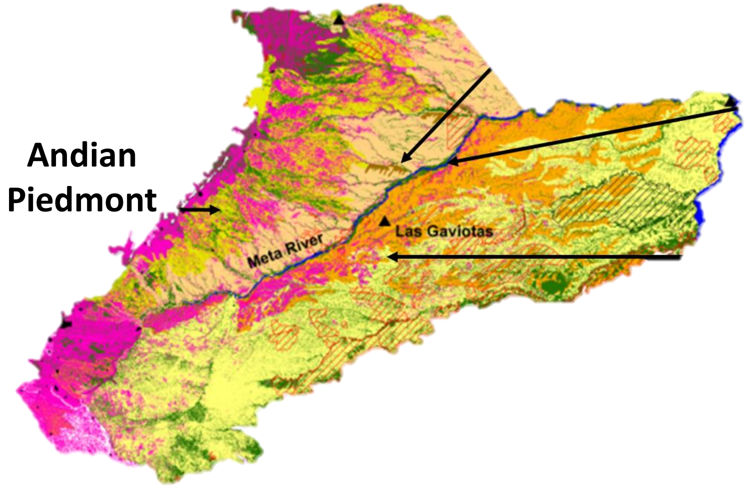
Ecologically oriented management > organic inputs ---> greater **microbial activity** ---> enhance **soil fertility**

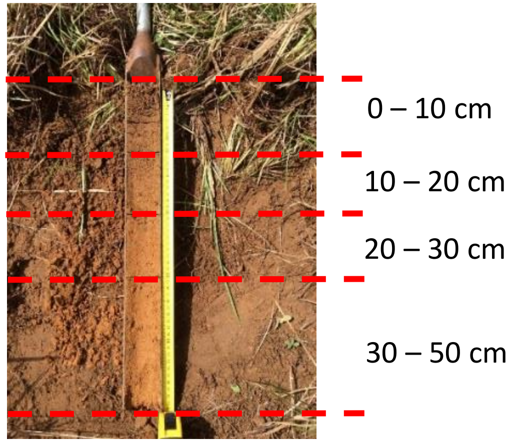
Long-term C dynamics

Methods

> Half century OP cultivation (56 years)/Long-term chronosequence





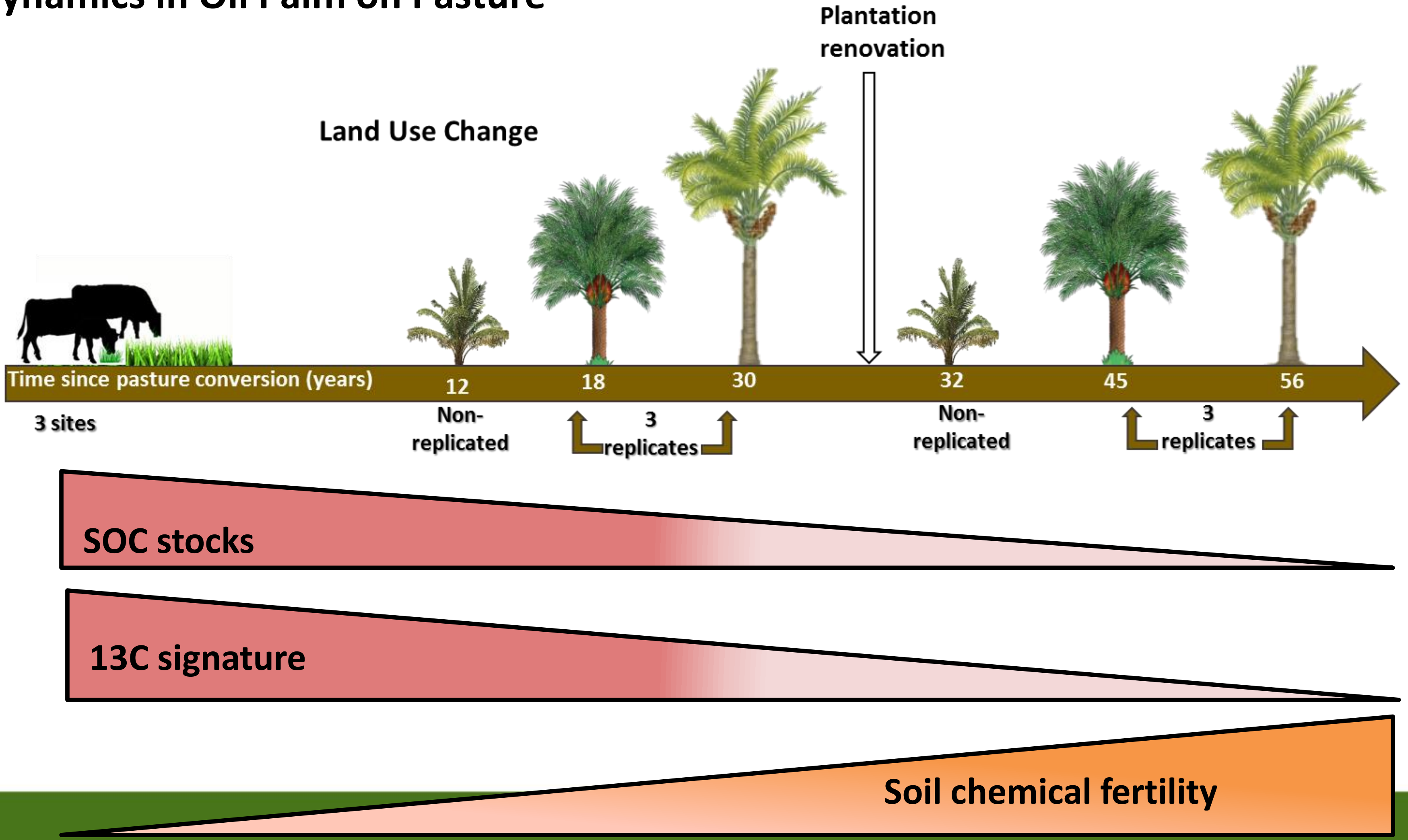


Nelson P. et al., 2015. Plant and Soil

Long-term C dynamics

Ecosystem C dynamics in Oil Palm on Pasture

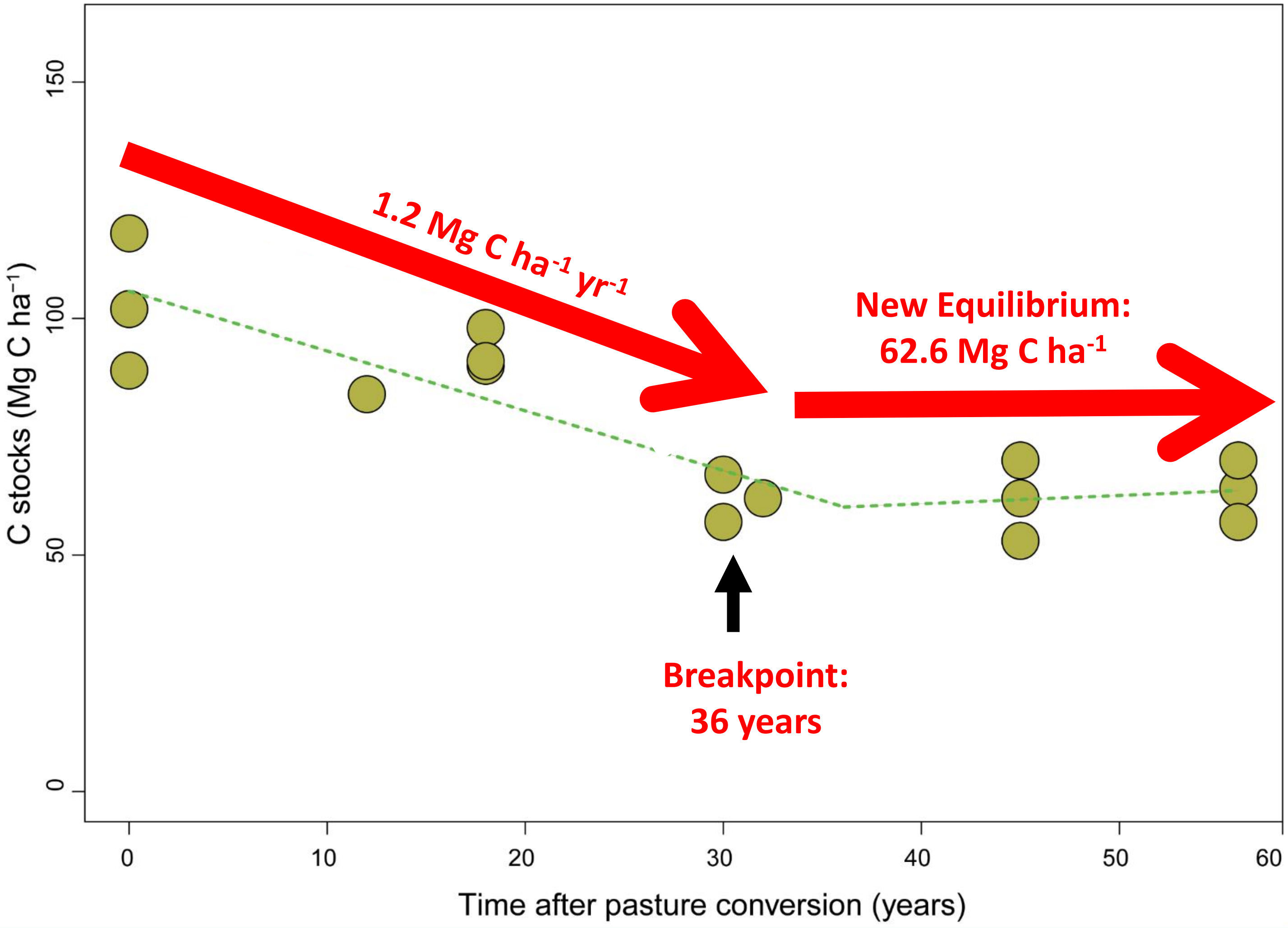
Hypotheses



Ecosystem C dynamics in Oil Palm on Pasture

Long-term C dynamics

Major Findings

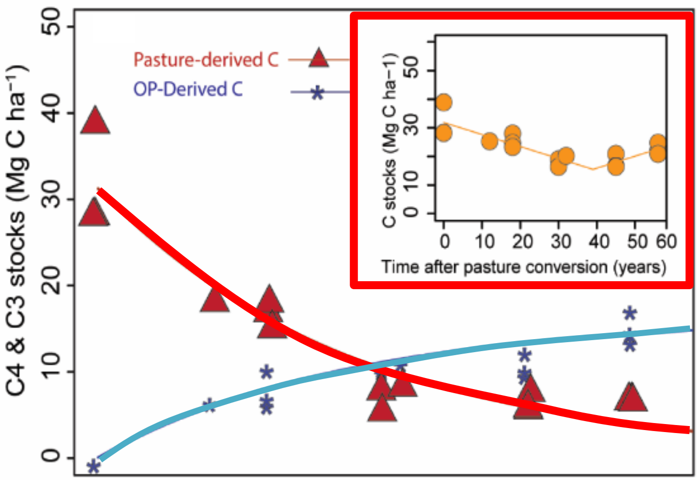


Long-term C dynamics

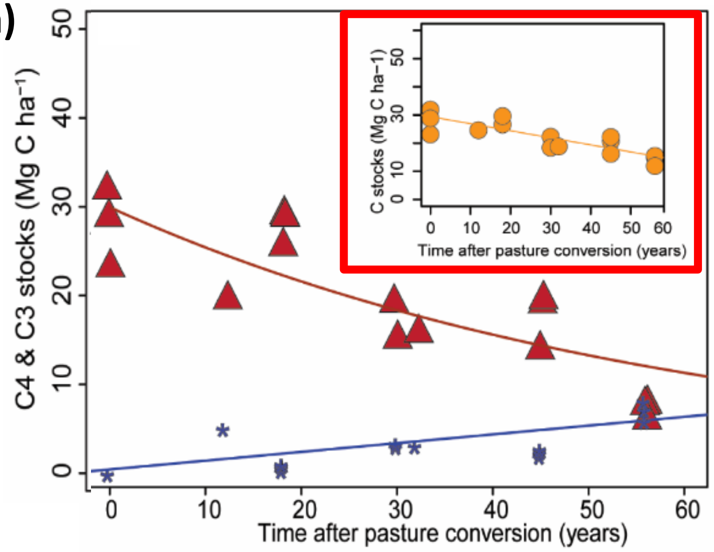
Ecosystem C dynamics in Oil Palm on Pasture

Major Findings

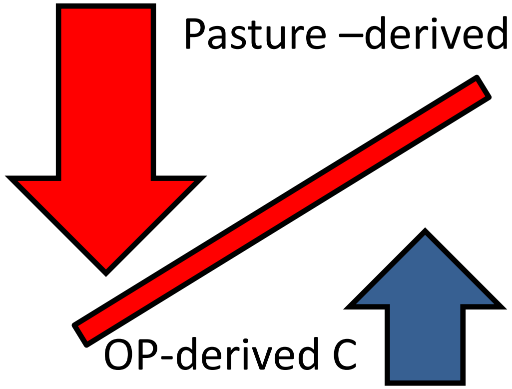
Topsoil (0-10 cm)



Subsoil (30-50 cm)



77% of pasture derived C loss



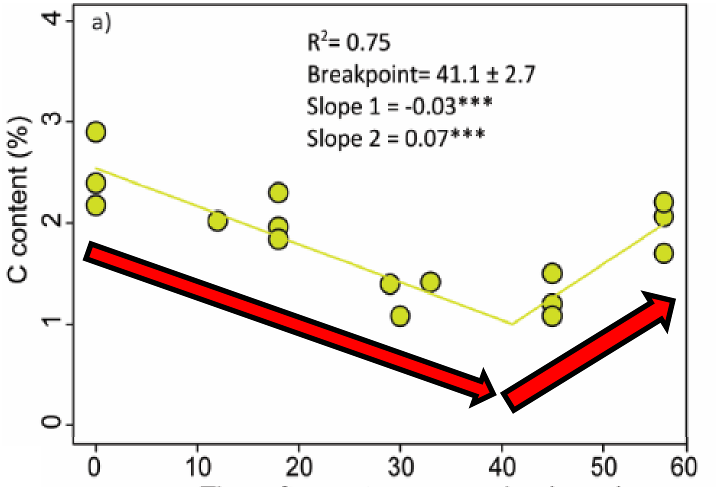
C loss rate: 0.25 Mg C ha^{-1} yr^{-1}

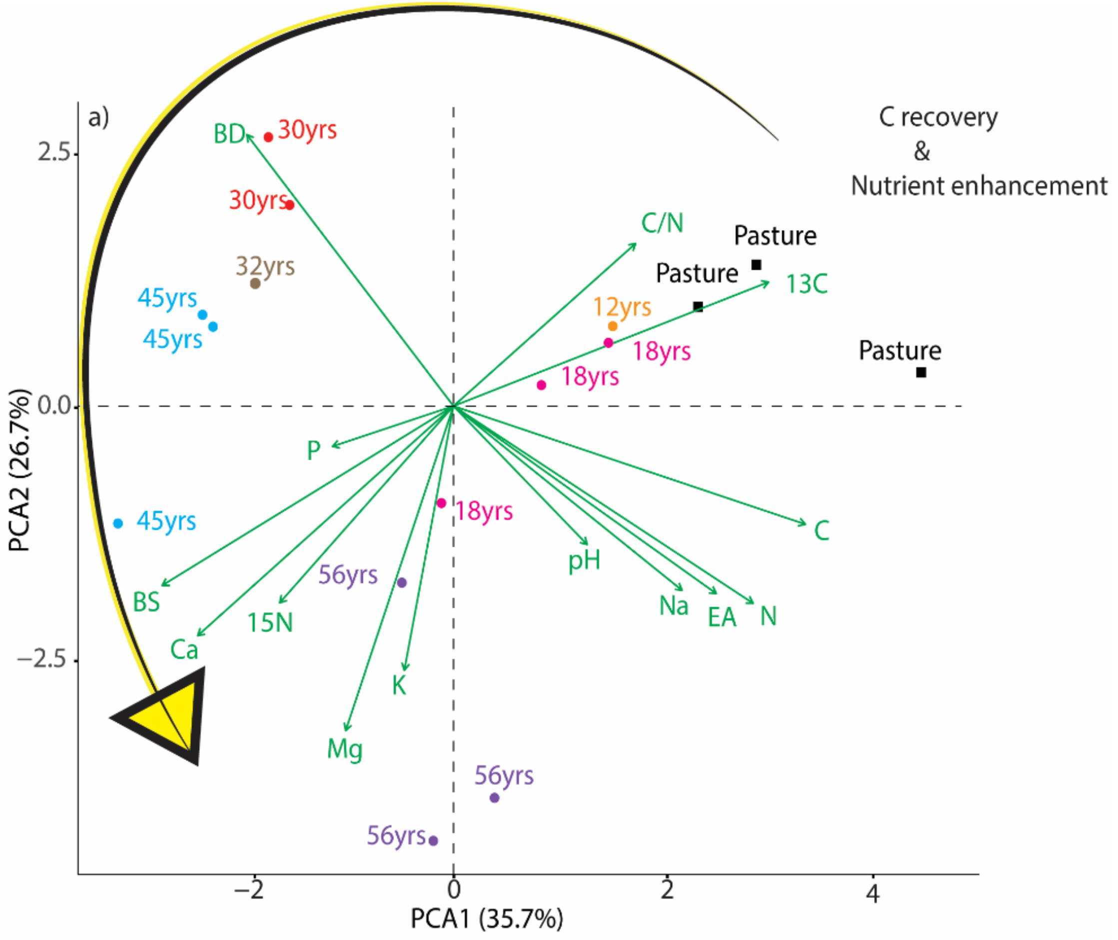
Quezada et al., 2019. Sci. Adv.

Long-term C dynamics

Ecosystem C dynamics in Oil Palm on Pasture

Major Findings





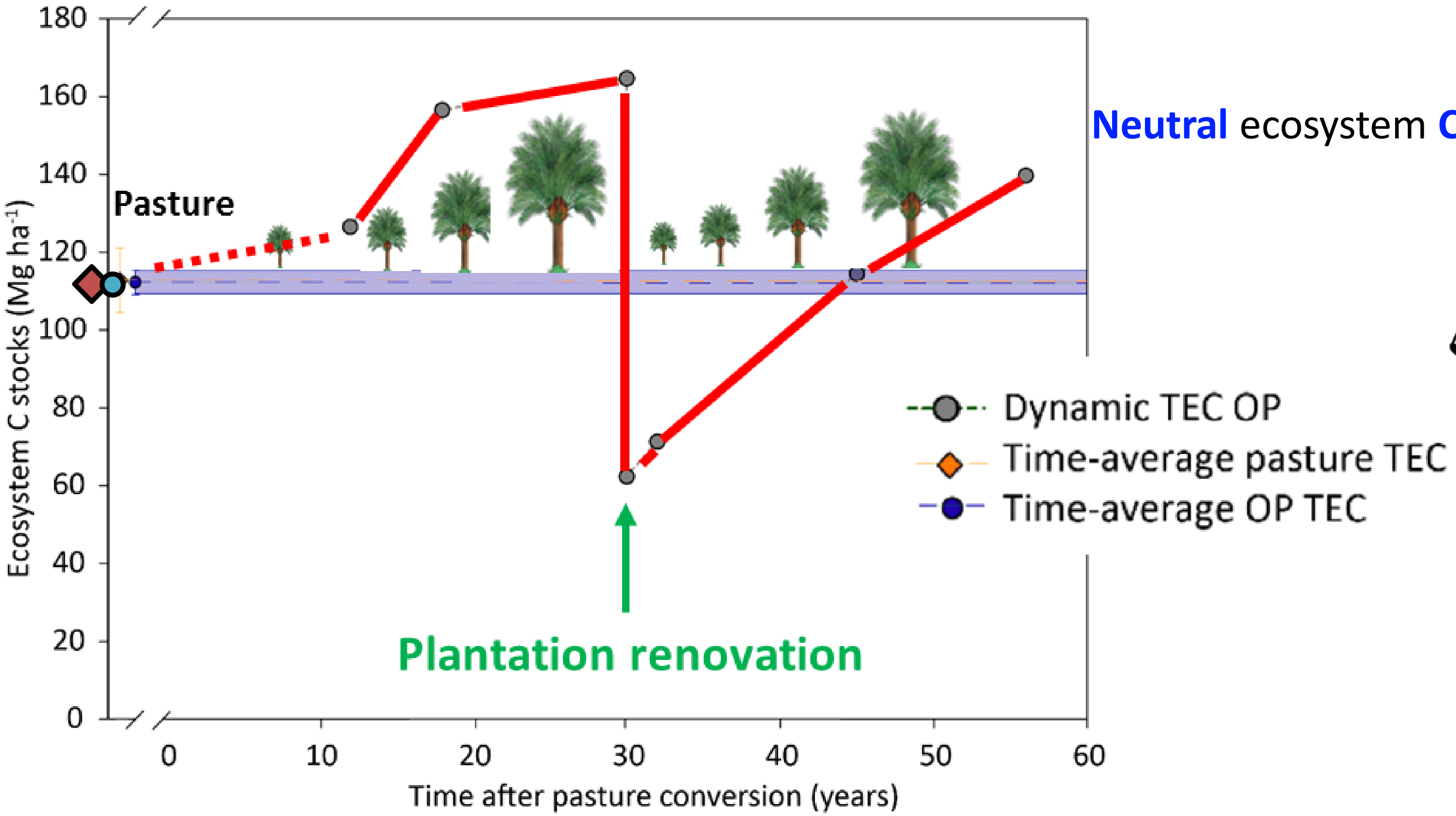
Juan Carlos Quezada, September 2022.

Quezada et al., 2019. Sci. Adv.

Long-term C dynamics

Major Findings

Ecosystem C dynamics in Oil Palm on Pasture



Neutral ecosystem **C balance**

Initial SOC loss, **counterbalanced** C **gains** in OP **biomass**

Avoid C loss of 173 Mg C ha^{-1}

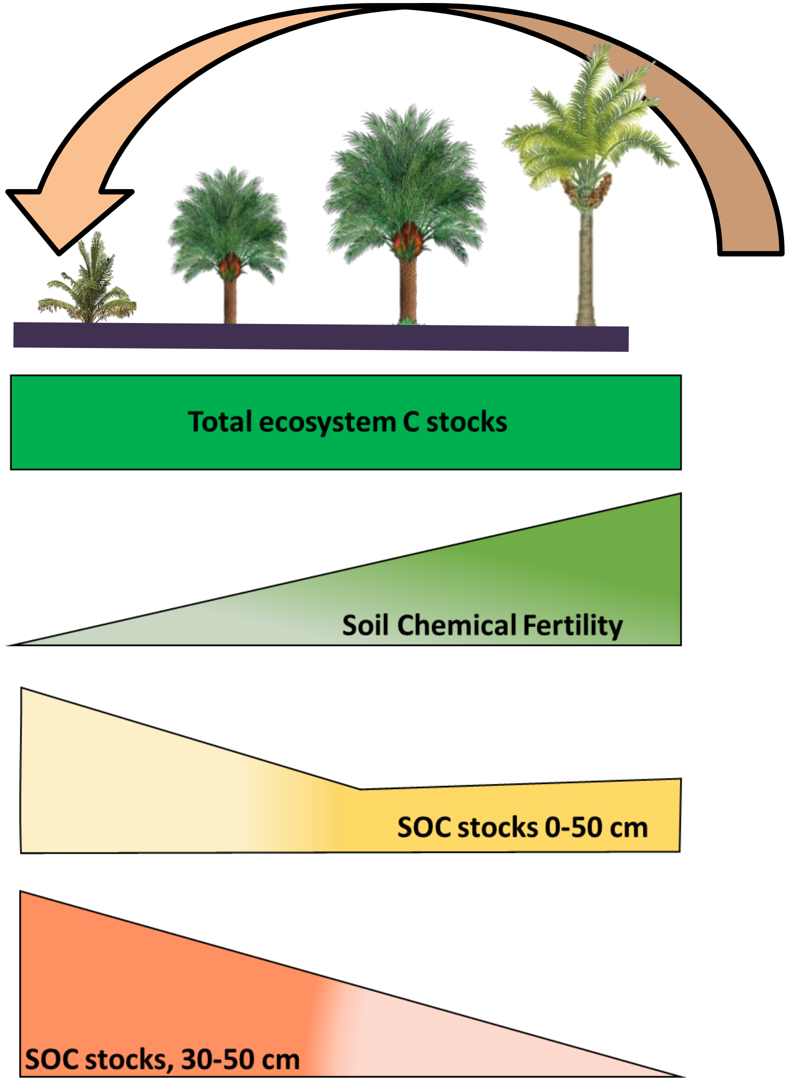
Long-term C dynamics

Ecosystem C dynamics in Oil Palm on Pasture

Take Home Messages

Degraded Pastures

- 2.5 million ha in Los Llanos
- 18 million ha in Cerrados
- 9 million ha Imperata Cylindrica grasslands in Indonesia



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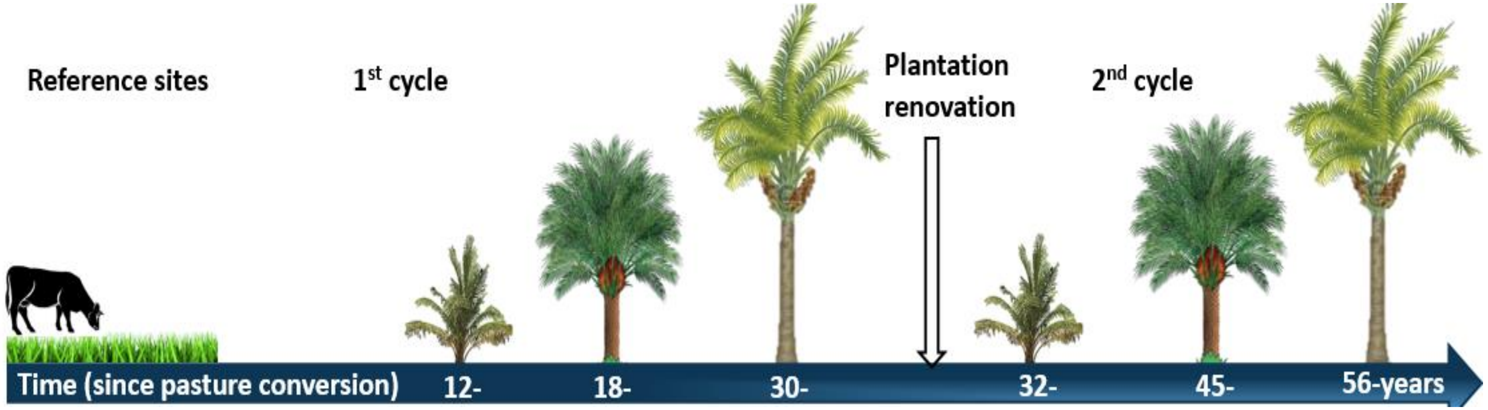
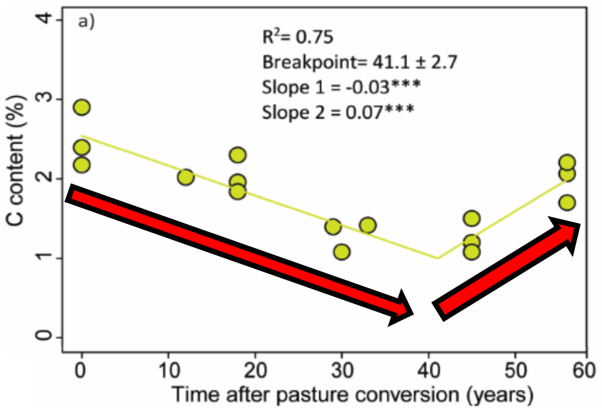
Long-term C dynamics

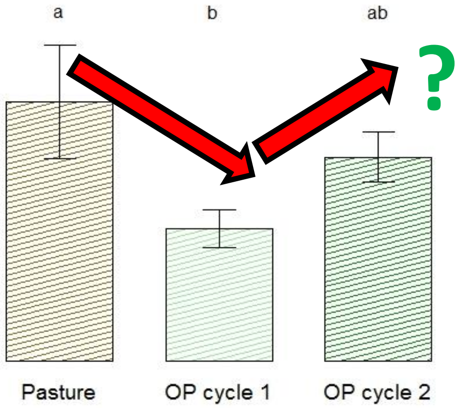
Theme 2, Major Findings



There Will Be ~~No~~ Return to Normal



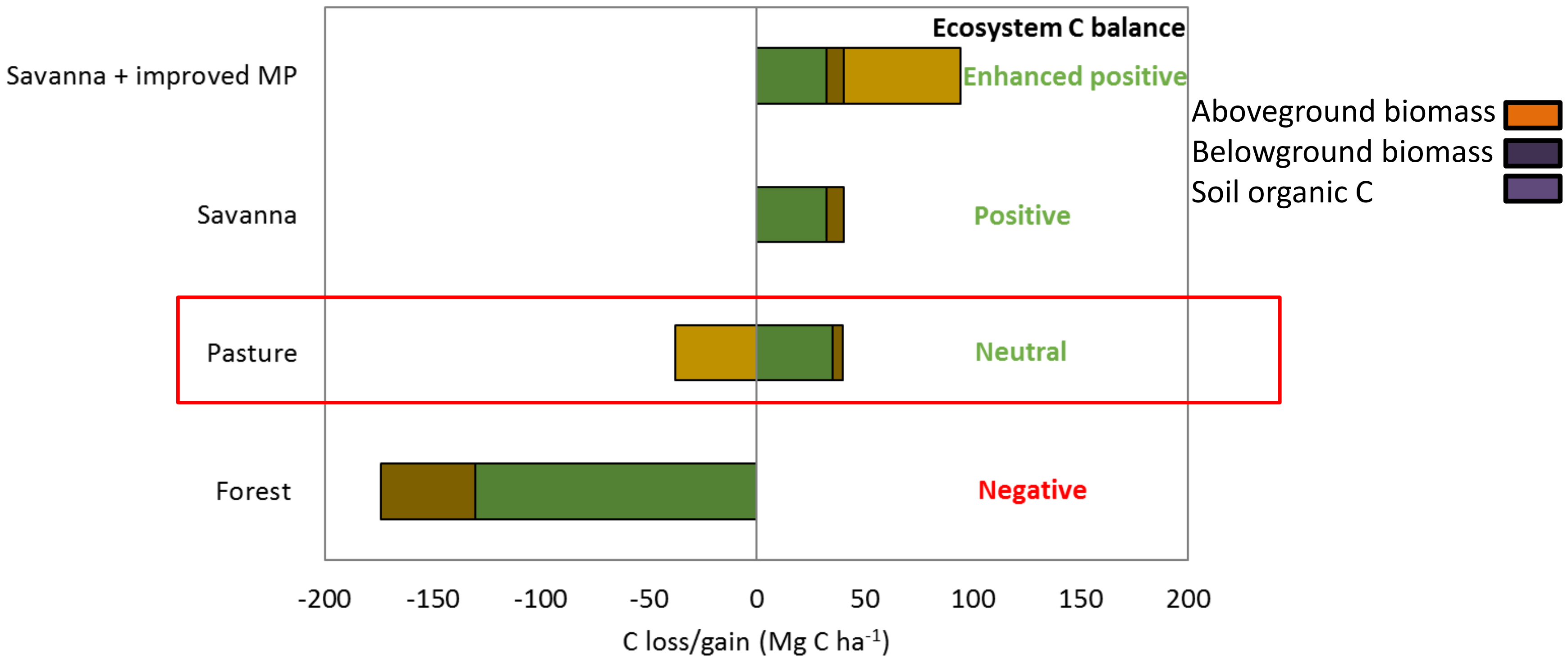
Topsoil C

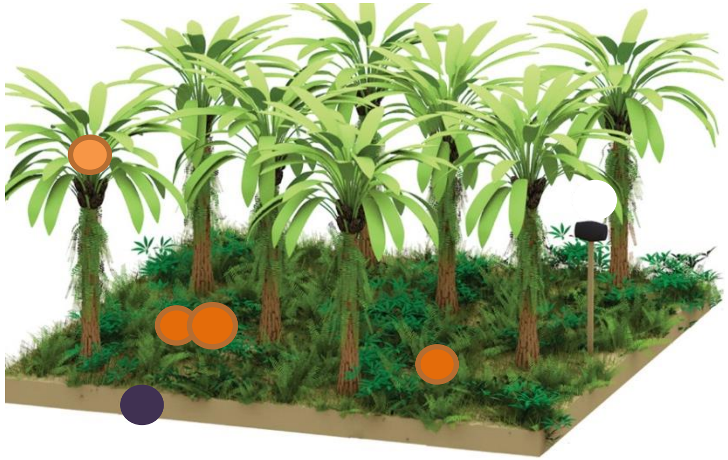


POM, S+C and rSOC

S+C and rSOC: **long-term C storage**
POM: **soil fertility**

Conclusions





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