# Resurrection of indigenous *Acacia koa* forests in Hawaii: An alternative approach to develop management plans

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# Koa Introduction

*Acacia koa* (Gray) is an endemic species and a co-dominant canopy tree with Ohia (*Metrosideros polymorphia*).

Legume, shade intolerant, regenerates in large dense thickets.

Tropical hardwood that acts as pioneer species and remains a dominant canopy species through to forest climax

# Koa Introduction

Historically found in many forest environments from near sea level to 2,300 m, with annual rainfall ranging from 850 to 5,000 mm

Now covers 10% of its original range mostly between 610 m and 2,000 m

Almost all remaining koa forest found in conservation areas

Remnant trees and patches exist on cattle ranch land

# Koa Introduction

There is increasing interest from various groups to re-establish koa forests:

- Ecological: Organisations like The Nature Conservatory and the US National Parks Service want to restore large areas of koa forest.
- Commercial: A number of private and public organisations want to find uses for under-used or unprofitable agricultural land.
- Aesthetic: Gentlemen farmers, rich retirees, and local individuals want more native trees where they live.
- Cultural: Native Hawaiian’s want koa forests for cultural purposes – especially for canoe logs.

# Koa Introduction

- Due to high demand and limited supply, koa now very valuable. However:
  - Never investigated as a commercial species –few permanent data plots exist
  - Exotic species were seen as better options for timber production in Hawaii
  - Koa was a cheap and plentiful right up to the late 1980’s – little interest for regeneration and productivity information until recently
- Very little is known about the ecophysiology and biogeochemistry of a koa forest ecosystem
  - What management strategy would restore koa forests most effectively for ecosystem restoration?
  - What management policies would be the most effective in growing koa for harvest?
  - How do you quickly develop management strategies for the diverse environments throughout Hawaii?

# Koa products




# Koa regeneration
## – responses well to large disturbances

# Typical secondary koa forest

Light

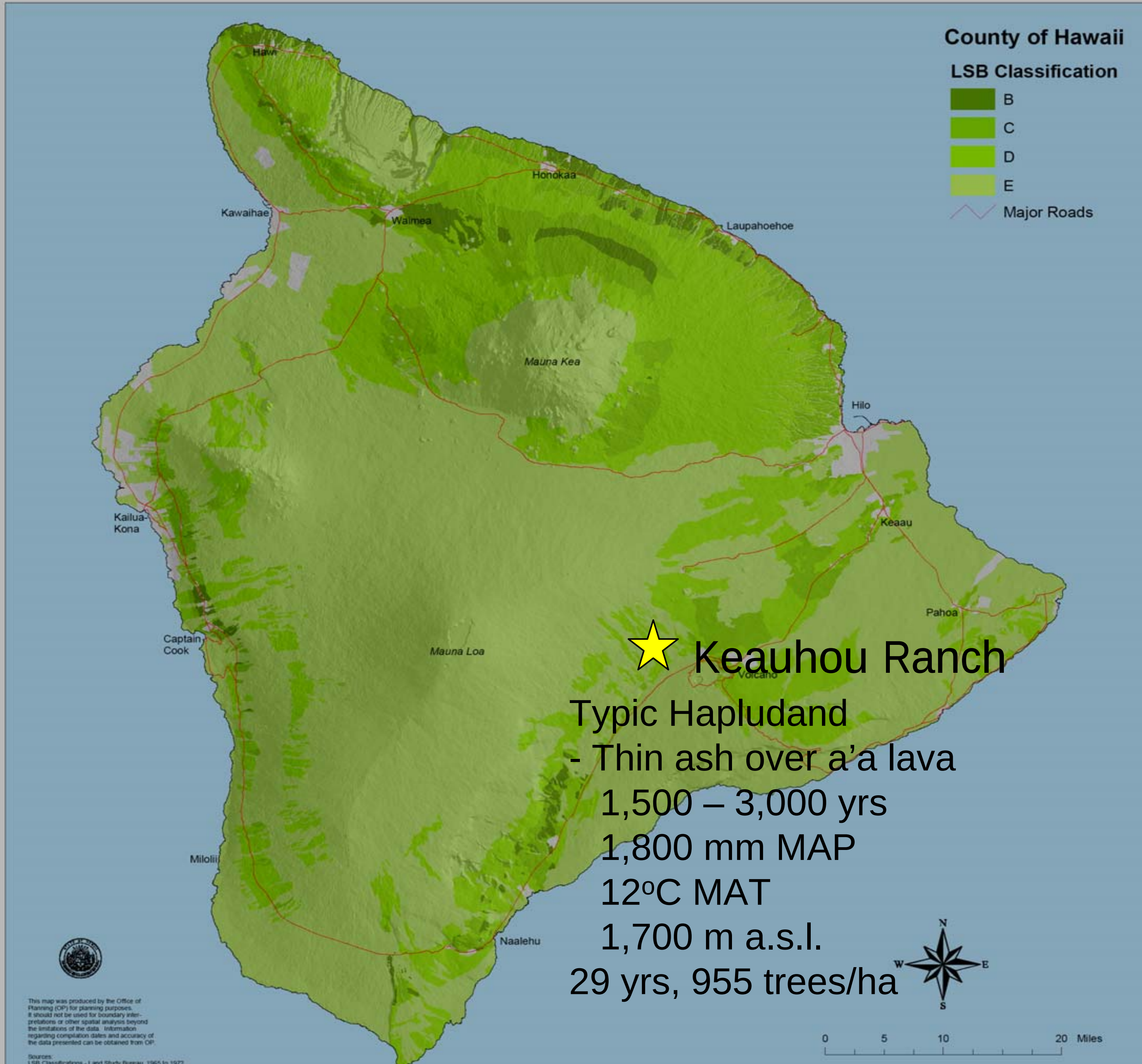
Water

Nutrients

Space

Disease

Primary limitations to tree growth




Keauhou Ranch

Typic Hapludand

- Thin ash over a’a lava
  - 1,500 – 3,000 yrs
  - 1,800 mm MAP
  - 12$^{o}$C MAT
  - 1,700 m a.s.l.

29 yrs, 955 trees/ha

Map from Hawaii Biodiversity and Mapping Program and the State of Hawaii

# Keauhou Ranch Study Site

Study established in 2001 in then 23 yr koa

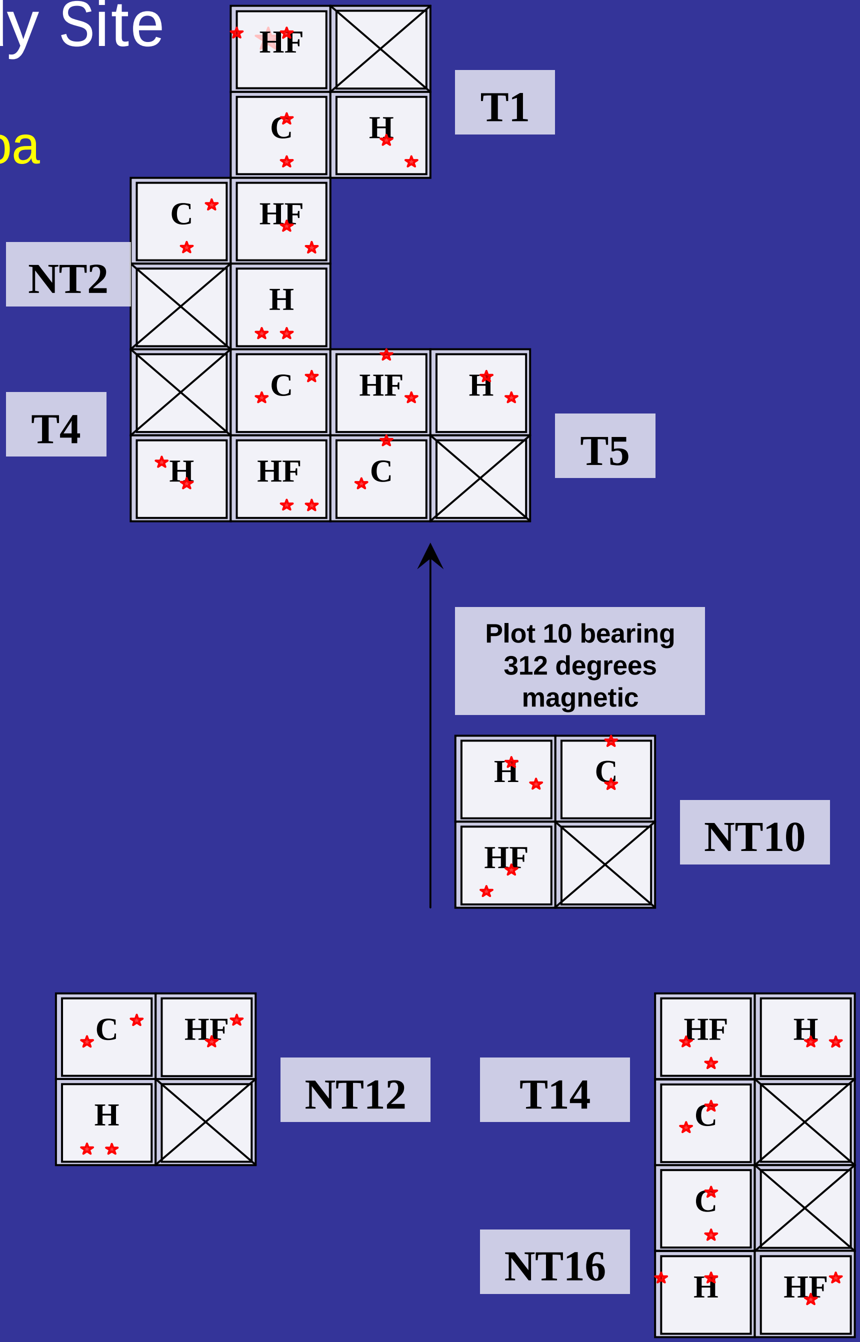
## Split plot design

## Main treatment: Thinning

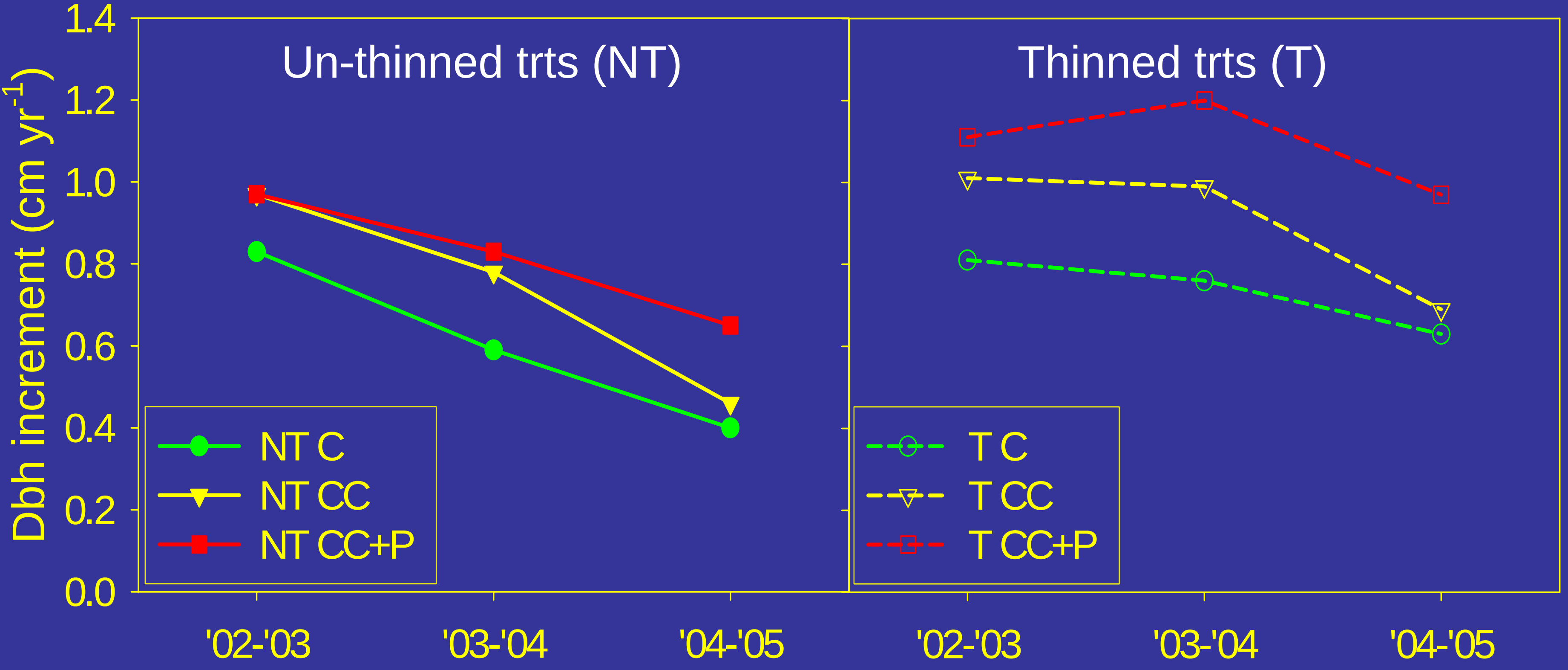
- 60 m x 60 m
- Thin (T, n=4) or un-thin (NT, n=4) koa trees

## Sub treatments: Forest Floor

- 25 m x 25 m
- Control
- Grass competition control (CC or H): Removal of grass species within 2 m radius of crop tree
- CC + Phosphorus fertiliser (CC+P): a total of 750 kg P $ha^{-1}$ over 2.5 yrs



# Annual stem diameter growth of koa crop trees between 2002 and 2005




Dbh = diameter at breast height

Where:

NT = Unthinned   C = Control

T = Thinned   CC = Grass Control

CC+P = CC + P fert.

From Scowcroft *et al.* 2007. Forest Ecology and Management 239: 69-80

Light

Water

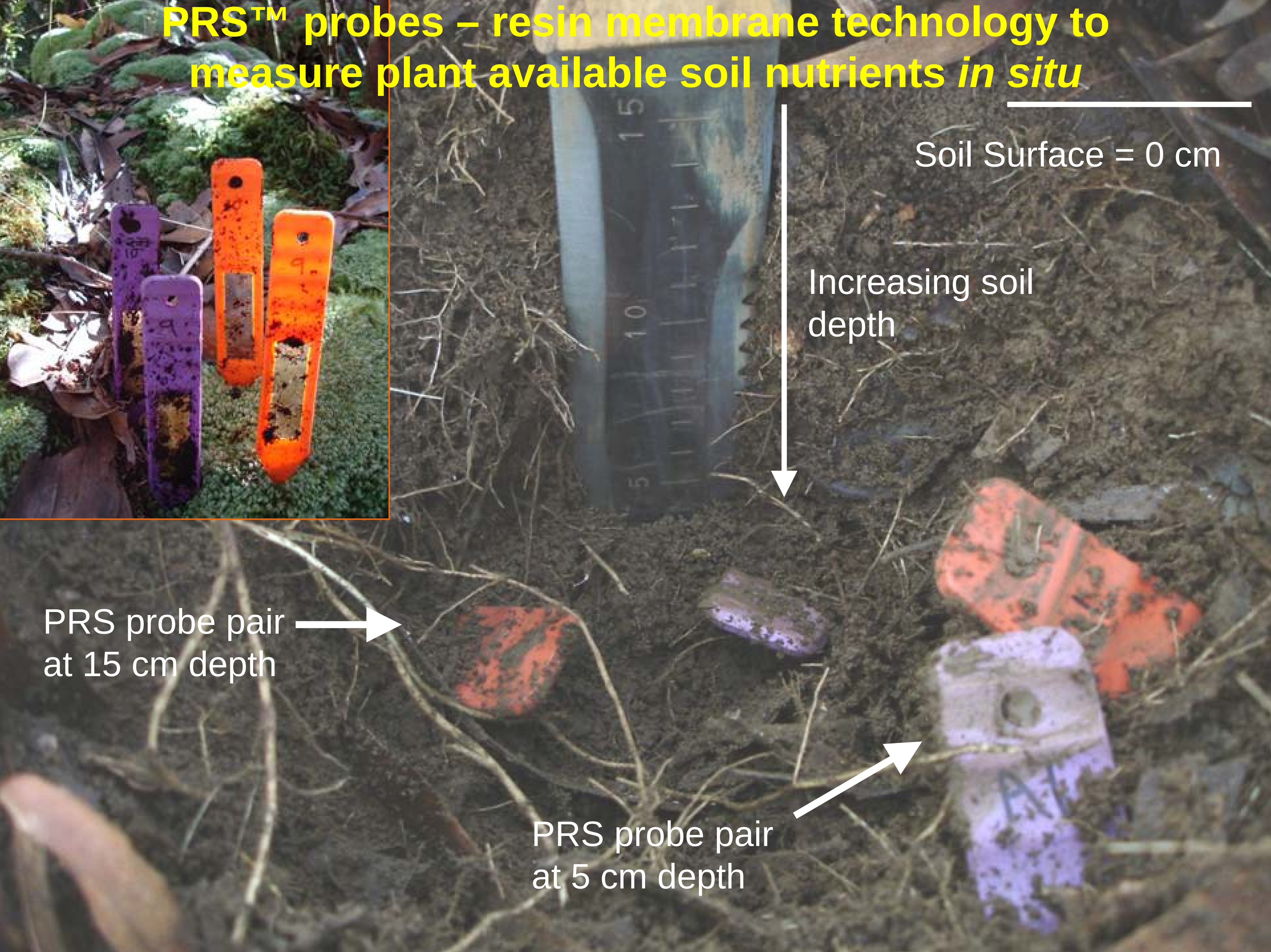
Nutrients

Space

Disease

Primary limitations to tree growth

# PRS™ probes – resin membrane technology to measure plant available soil nutrients *in situ*



# Potential P sorption of Hawaii soils

## Categories of P sorption by mineralogy as measured by P sorption isotherms

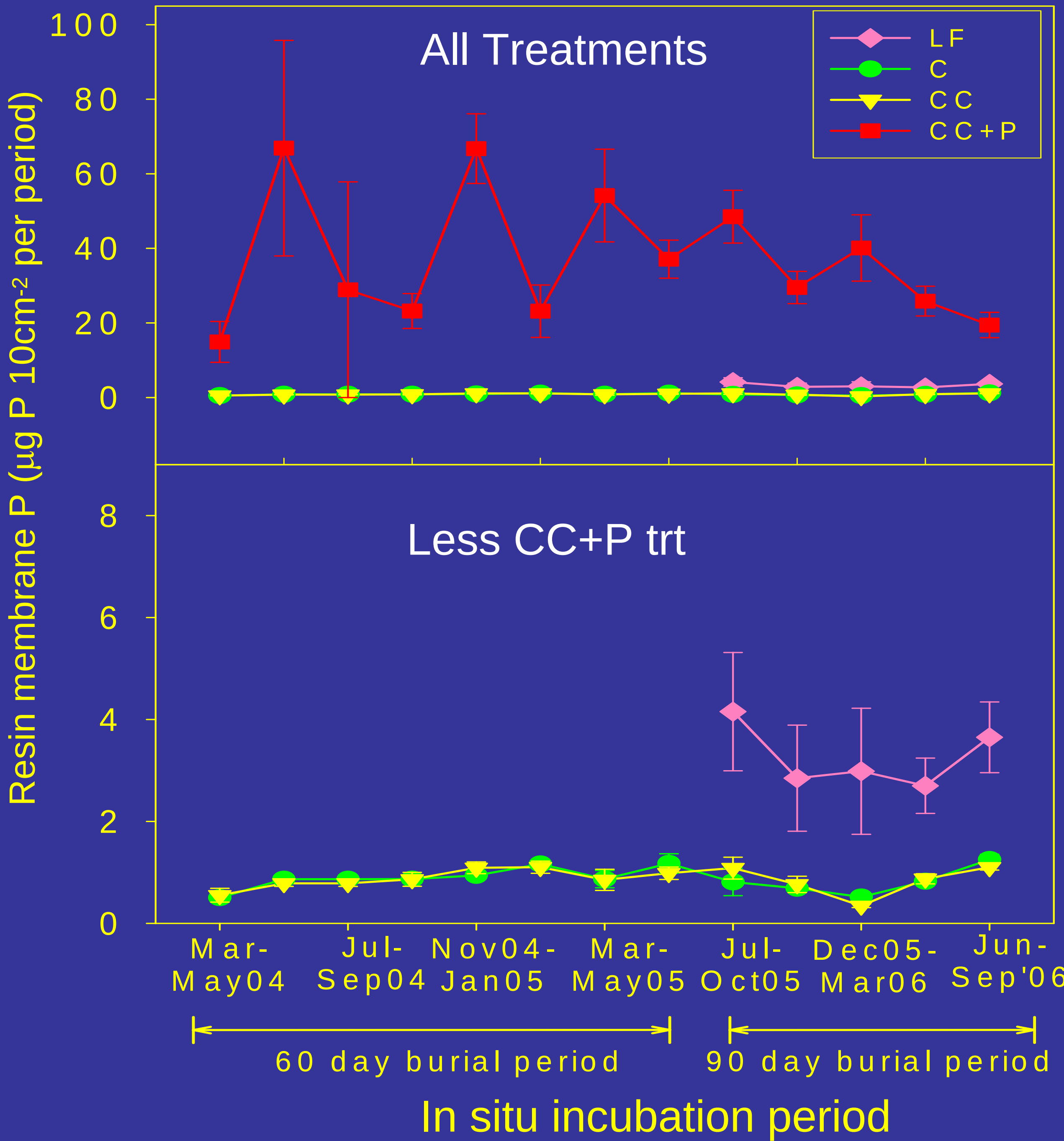
| $PS_{0.2}$ (mg $kg^{-1}$ soil) | Scale | Typical Mineralogy |
|---|---|---|
| <10 | very low | quartz, organic minerals |
| 10-100 | low | 2:1 clays, quartz, 1:1 clays |
| 100-500 | medium | 1:1 clays with oxides |
| 500-1000 | high | oxides, moderately weathered ash |
| >1000 | very high | desilicated amorphous materials |

From Juo and Fox 1977

## Sorption Isotherms of Selected Hawaii Andisols

| | |
|---|---|
| Cultivated Kaiwiki Series (Acrudoxic hydrudand) | 5,673 mg $kg^{-1}$ |
| Uncultivated Kaiwiki Series | 2,138 mg $kg^{-1}$ |
| Maile Series (Acrudoxic hydrudand) | 1,134 mg $kg^{-1}$ |

From Jackman 1994



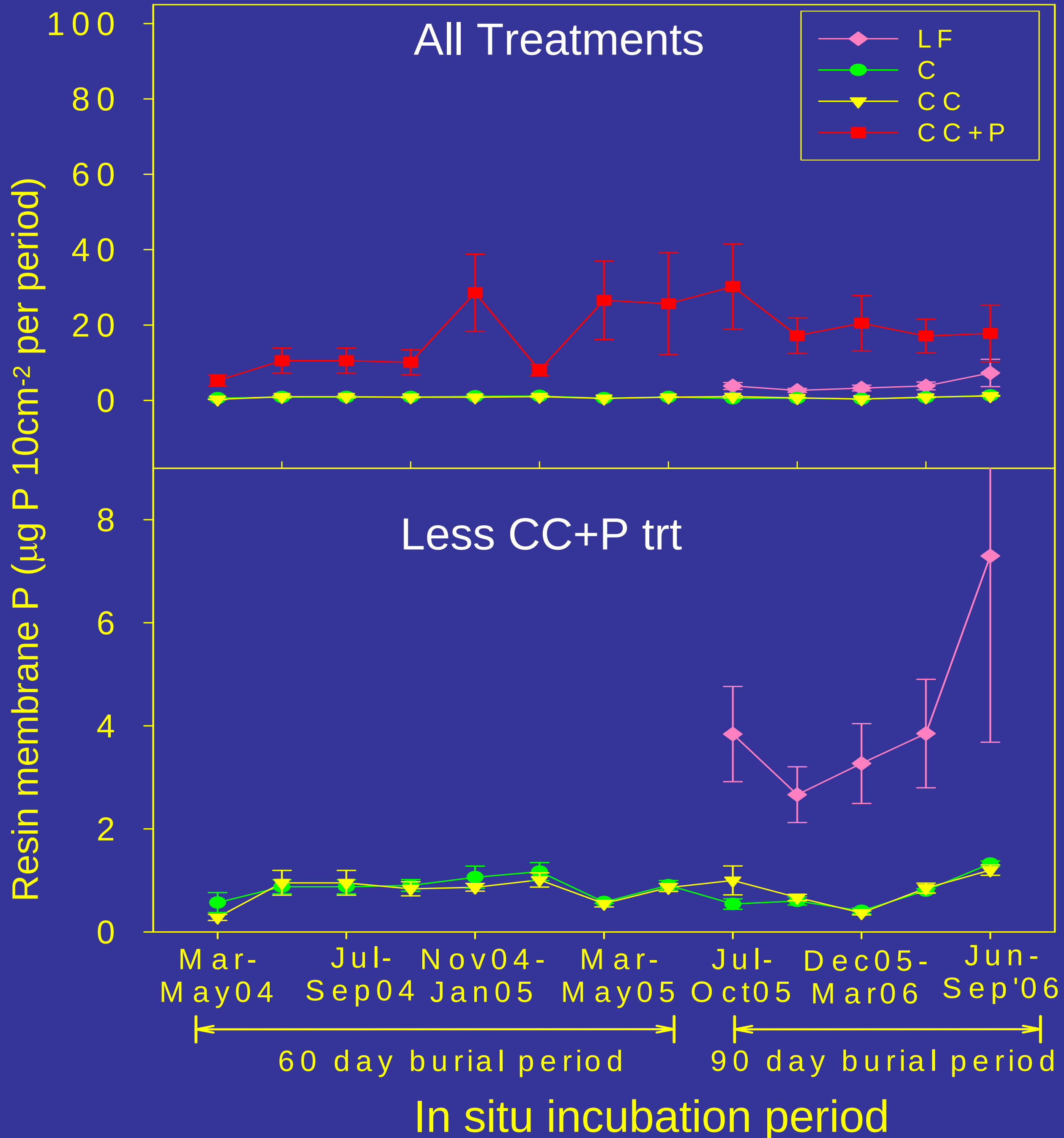

# Soil Labile P measured with PRS™ resin membranes at 5 cm depth - March 2004 and Sept 2006

No significant difference between thinned and unthinned plots

Where:
LF = Laupahoehoe Forest (naturally fertile site)
C = Control
CC = Grass Control
CC+P = CC + P fert.

LF: n=4
C, CC, CC+P: n=8

# Soil Labile P measured with PRS™ resin membranes at 15 cm depth - March 2004 and Sept 2006

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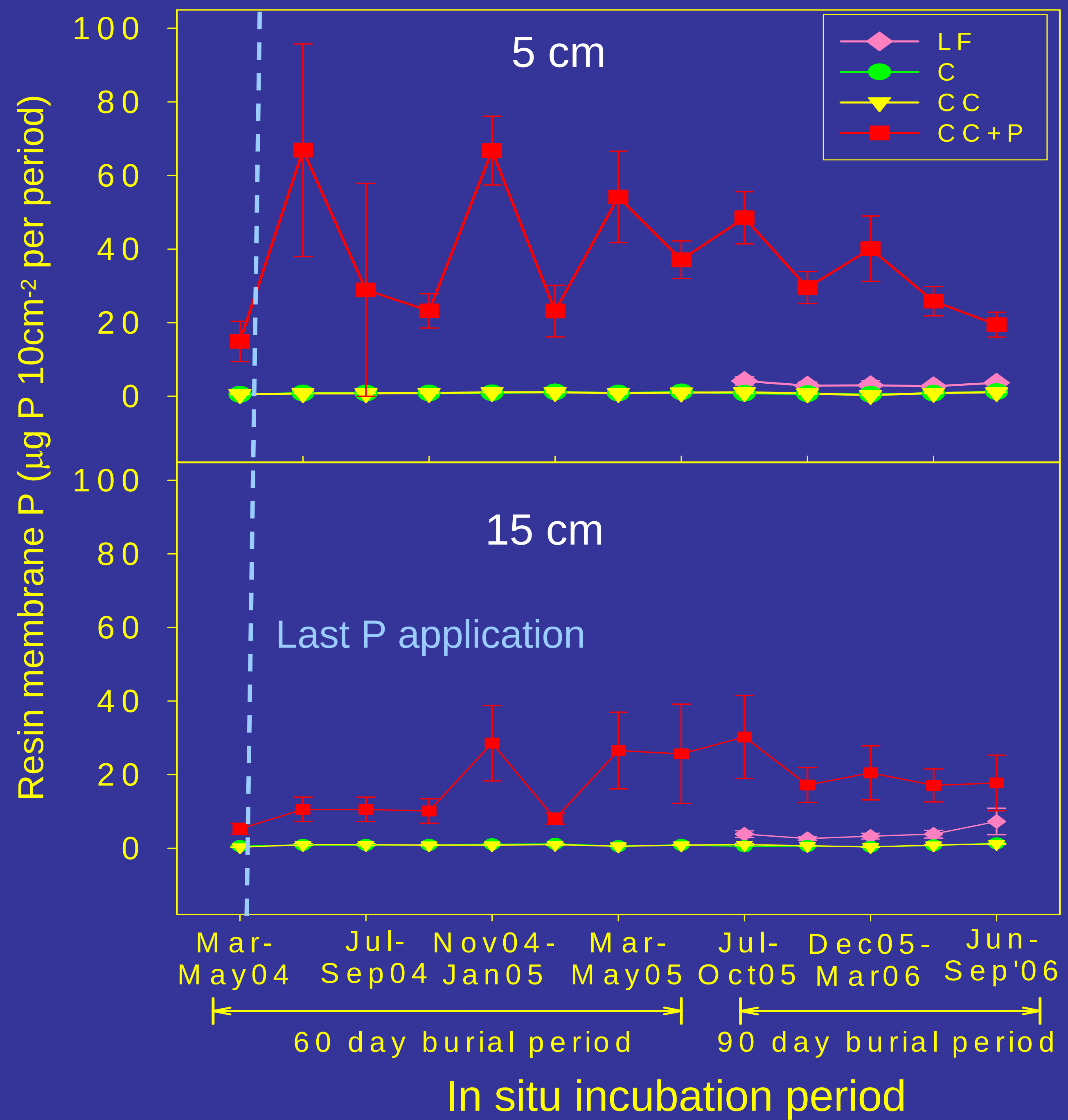


# Soil Labile P measured with PRS™ resin membranes – comparison between both depths

No significant difference between thinned and unthinned plots

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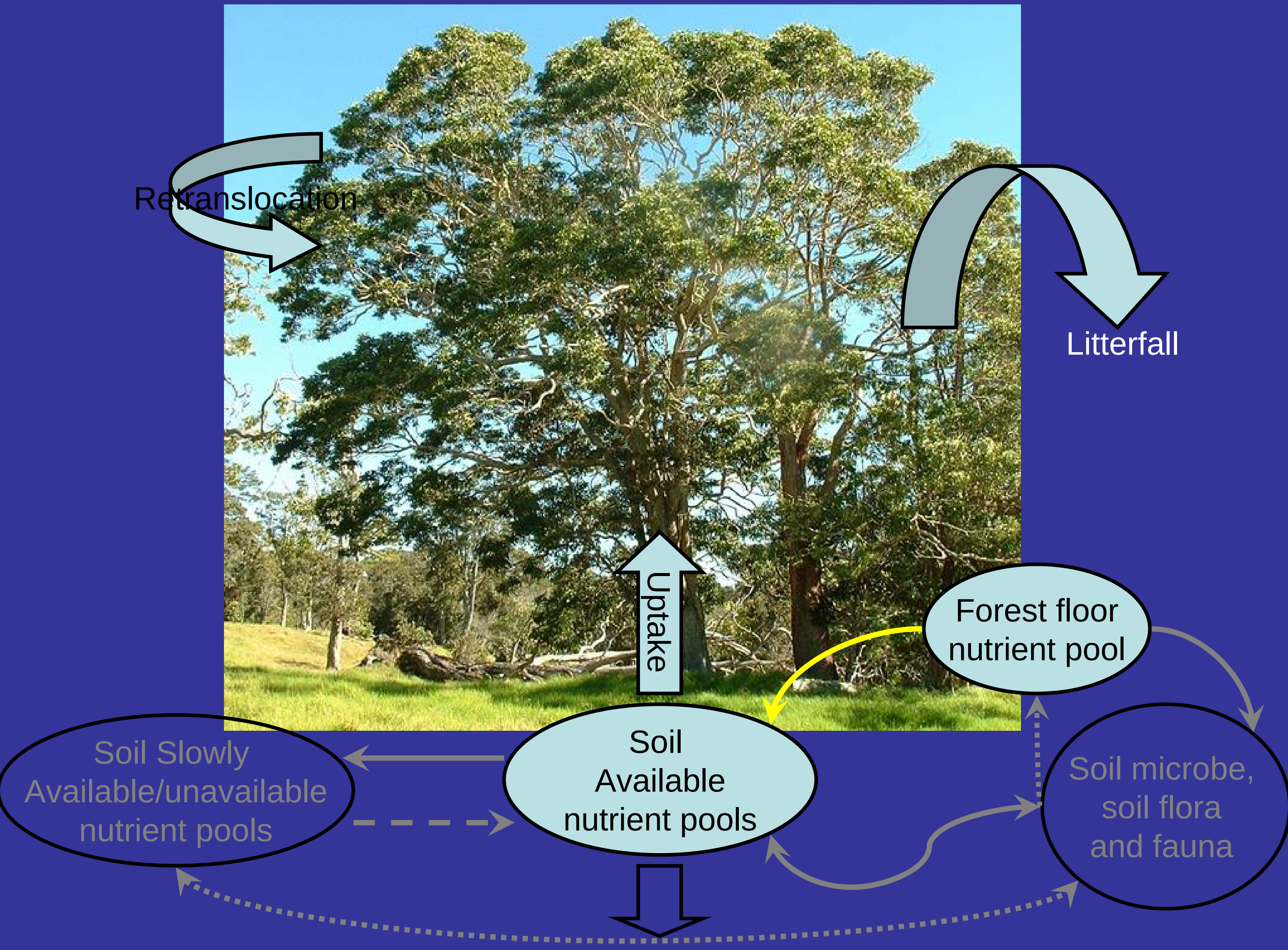
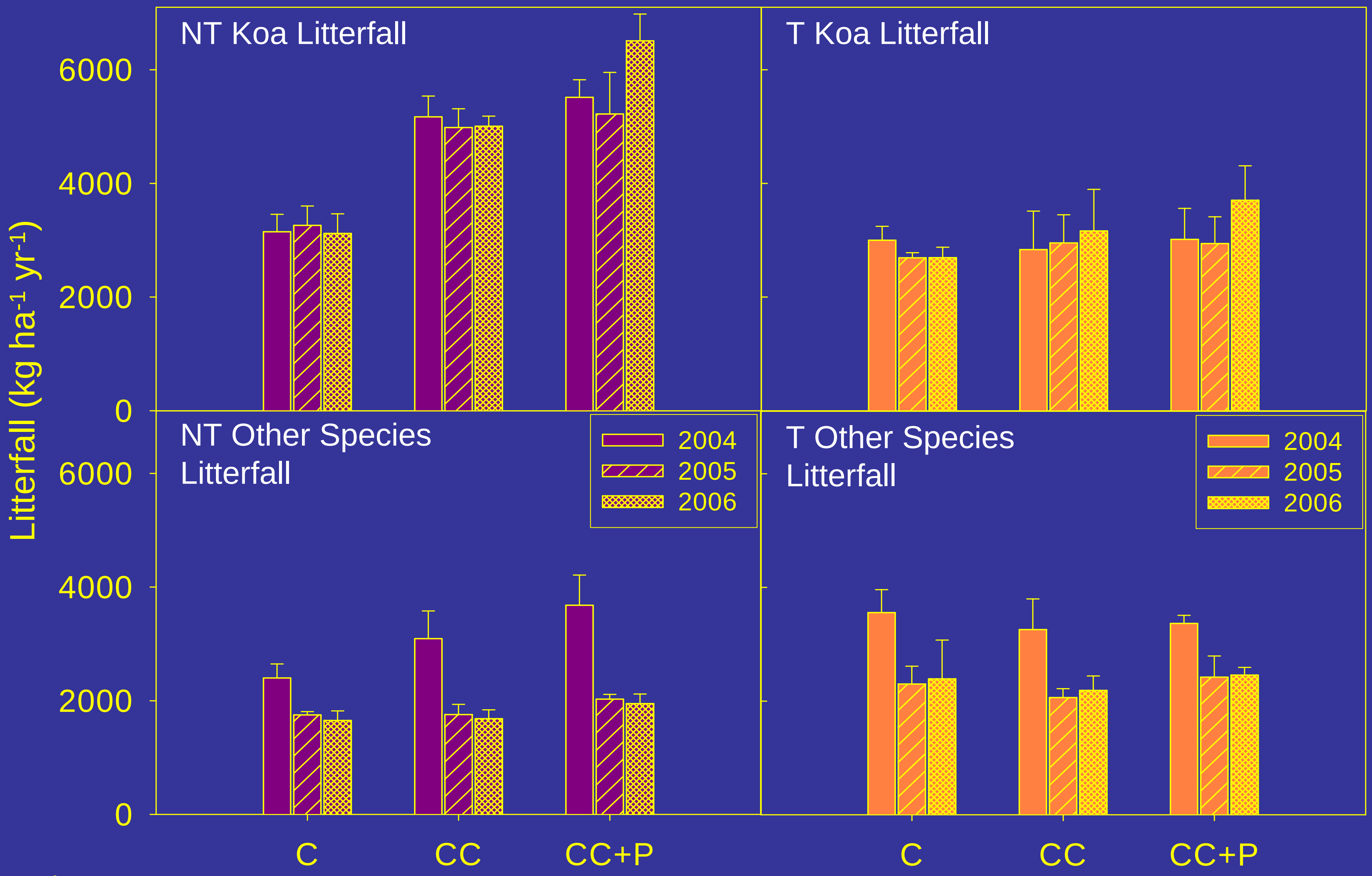


Retranslocation
Litterfall
Uptake
Forest floor nutrient pool
Soil Available nutrient pools
Soil Slowly Available/unavailable nutrient pools
Soil microbe, soil flora and fauna

# Litterfall biomass and nutrient cycling

# Annual Litterfall rates from 2004 to 2006




Where:
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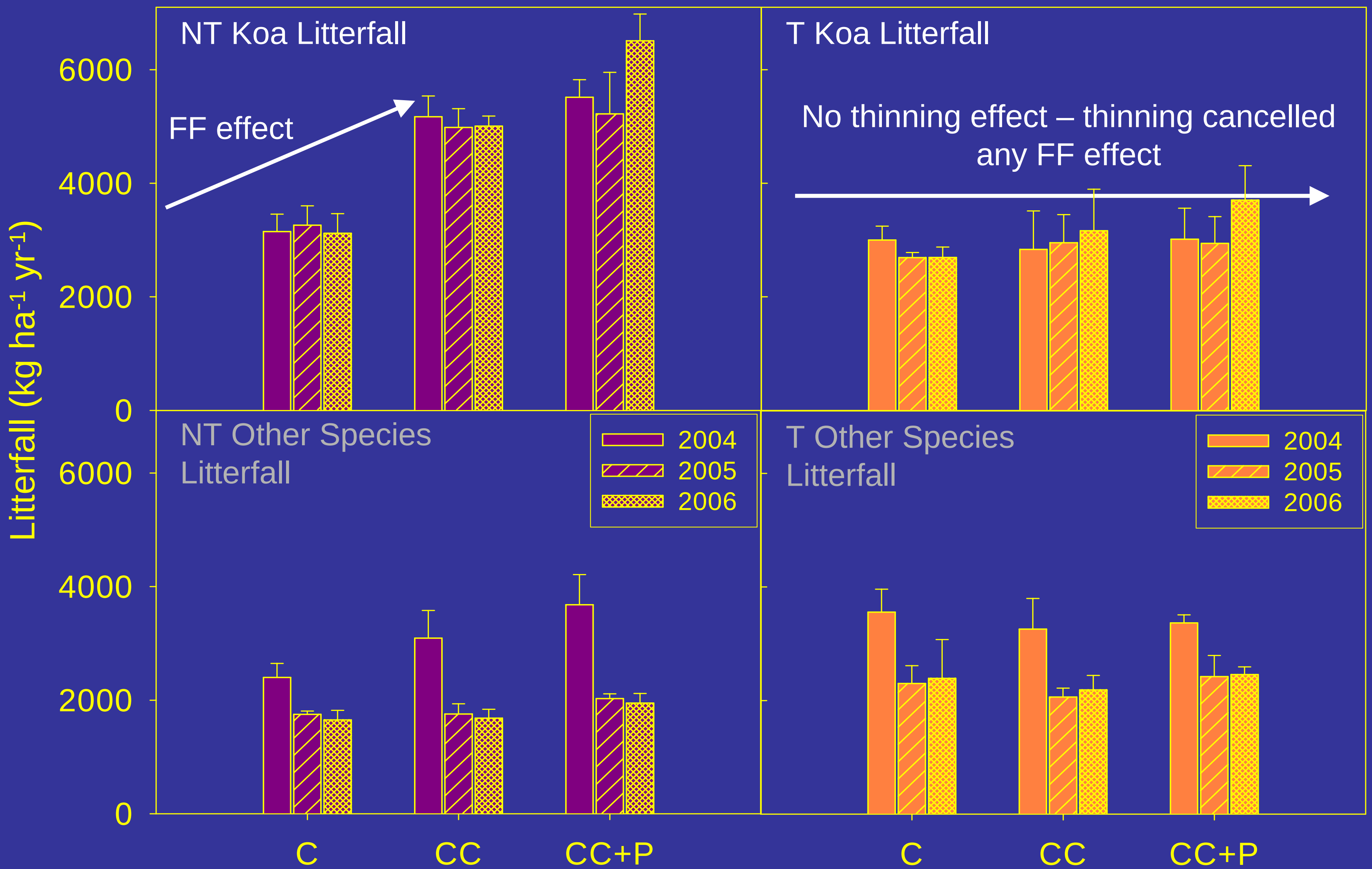
# Annual Litterfall rates from 2004 to 2006

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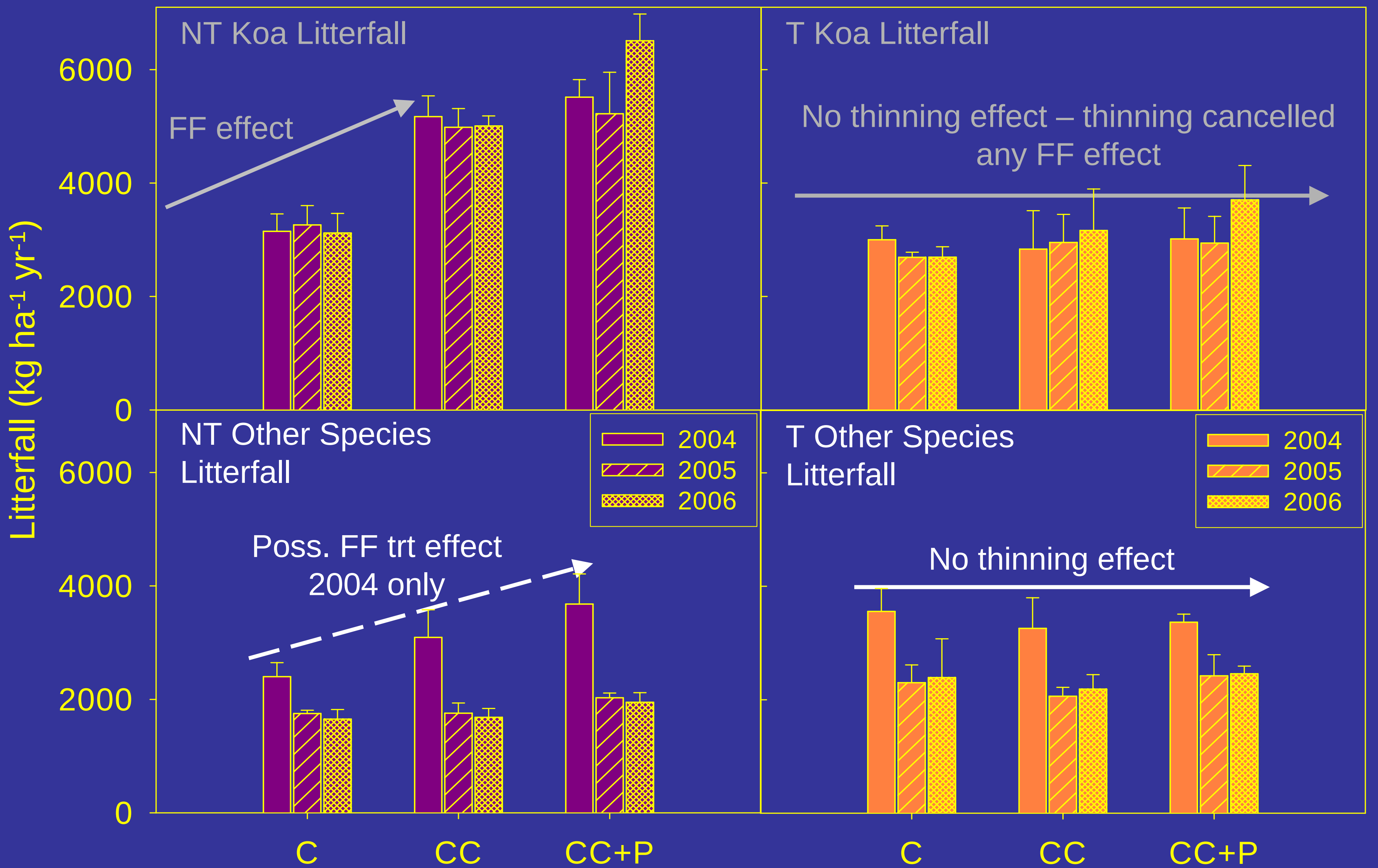


Where:
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n=4

# Litterfall (LF) phosphorus (P) concentration and P content for 2006

| | | Koa LF | | Other spp. LF | | Total LF |
|---|---|---|---|---|---|---|
| | | P Conc. ($g\ kg^{-1}$) | P Content ($kg\ ha^{-1}$) | P Conc. ($g\ kg^{-1}$) | P Content (kg ha-[1]) | P Content ($kg\ ha^{-1}$) |
| NT | C | 0.54 | 1.68 | 0.80 | 1.32 | 2.22 |
| NT | CC | 0.35 | 1.75 | 0.86 | 1.45 | 3.20 |
| NT | CC+P | 0.70 | 4.55 | 1.21 | 2.36 | 6.91 |
| T | C | 0.46 | 1.25 | 1.09 | 2.79 | 4.04 |
| T | CC | 0.56 | 1.77 | 0.92 | 2.01 | 3.78 |
| T | CC+P | 0.70 | 2.61 | 1.38 | 3.47 | 6.08 |

Where:

NT = Unthinned trt
T = Thinned trt

C = Control
CC = Grass Control
CC+P = CC + P fertiliser

n=4

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Where:
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n=4

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| | | Koa LF | | Other spp. LF | | Total LF |
|---|---|---|---|---|---|---|
| | | P Conc. (g $kg^{-1}$) | P Content (kg $ha^{-1}$) | P Conc. (g $kg^{-1}$) | P Content (kg ha-$^{1}$) | P Content (kg $ha^{-1}$) |
| NT | C | 0.54 | 1.68 | 0.80 | 1.91 | 3.59 |
| NT | CC | 0.35 | 1.81 | 0.86 | 2.67 | 4.48 |
| NT | CC+P | 0.70 | 3.87 | 1.21 | 4.46 | 8.33 |
| T | C | 0.46 | 1.39 | 1.09 | 3.87 | 5.26 |
| T | CC | 0.56 | 1.58 | 0.92 | 3.01 | 4.59 |
| T | CC+P | 0.70 | 2.10 | 1.38 | 4.65 | 6.75 |

Where:

NT = Unthinned trt

T = Thinned trt

C = Control

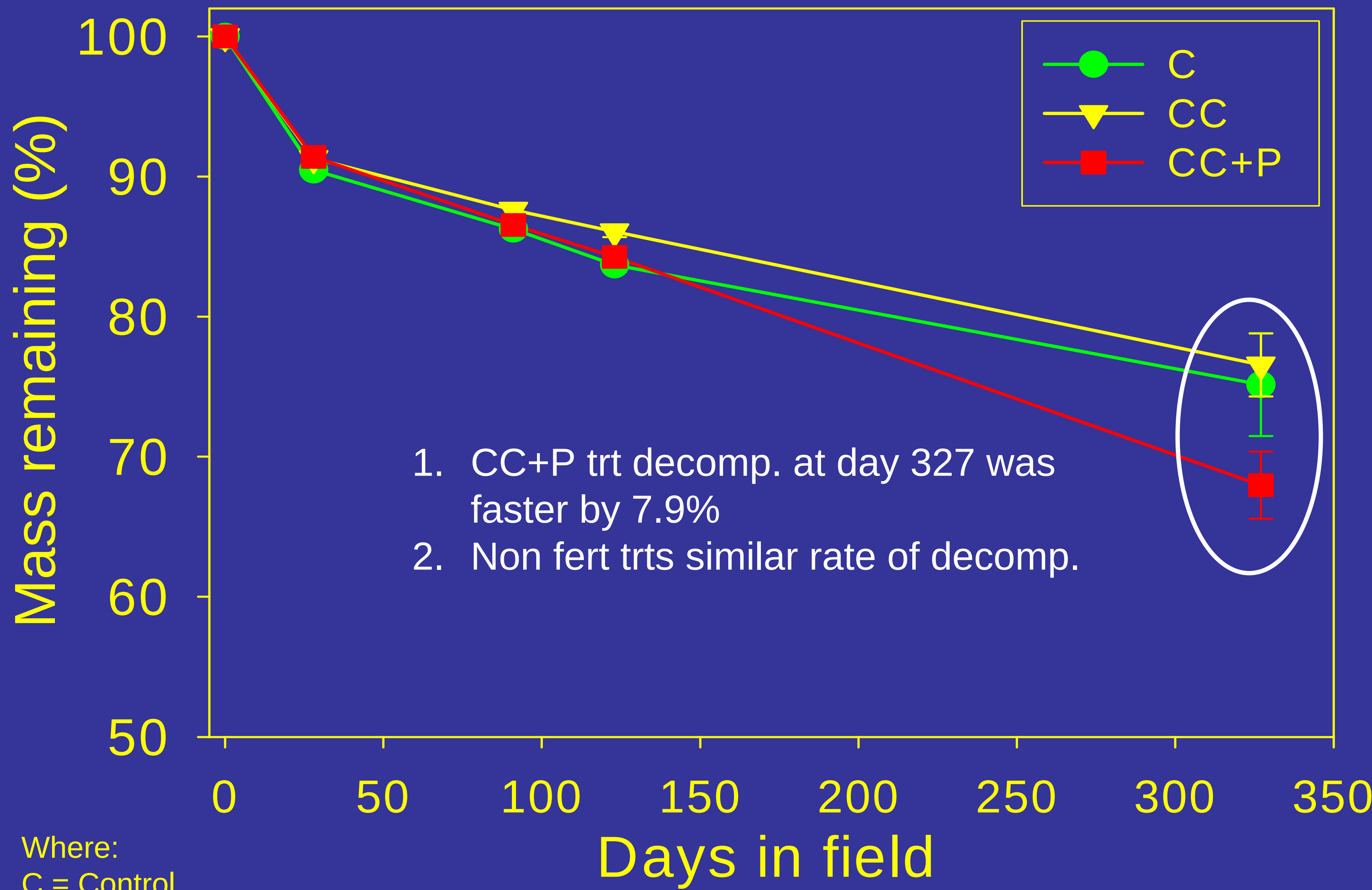
CC = Grass Control

CC+P = CC + P fertiliser

n=4

# Leaf litter decomposition

# Decomposition rates of koa phyllode litterfall in 2007 by trt




Where:
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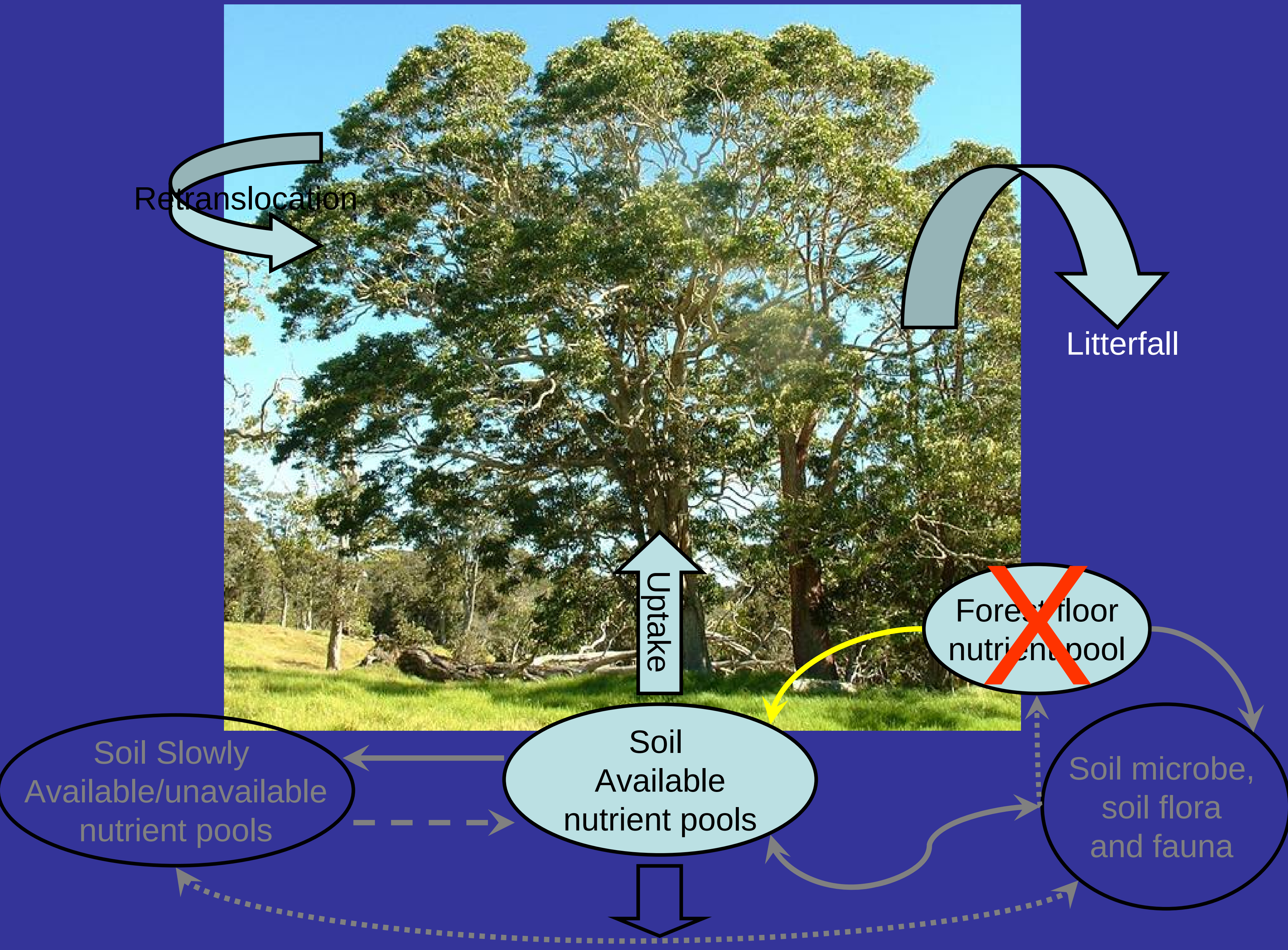
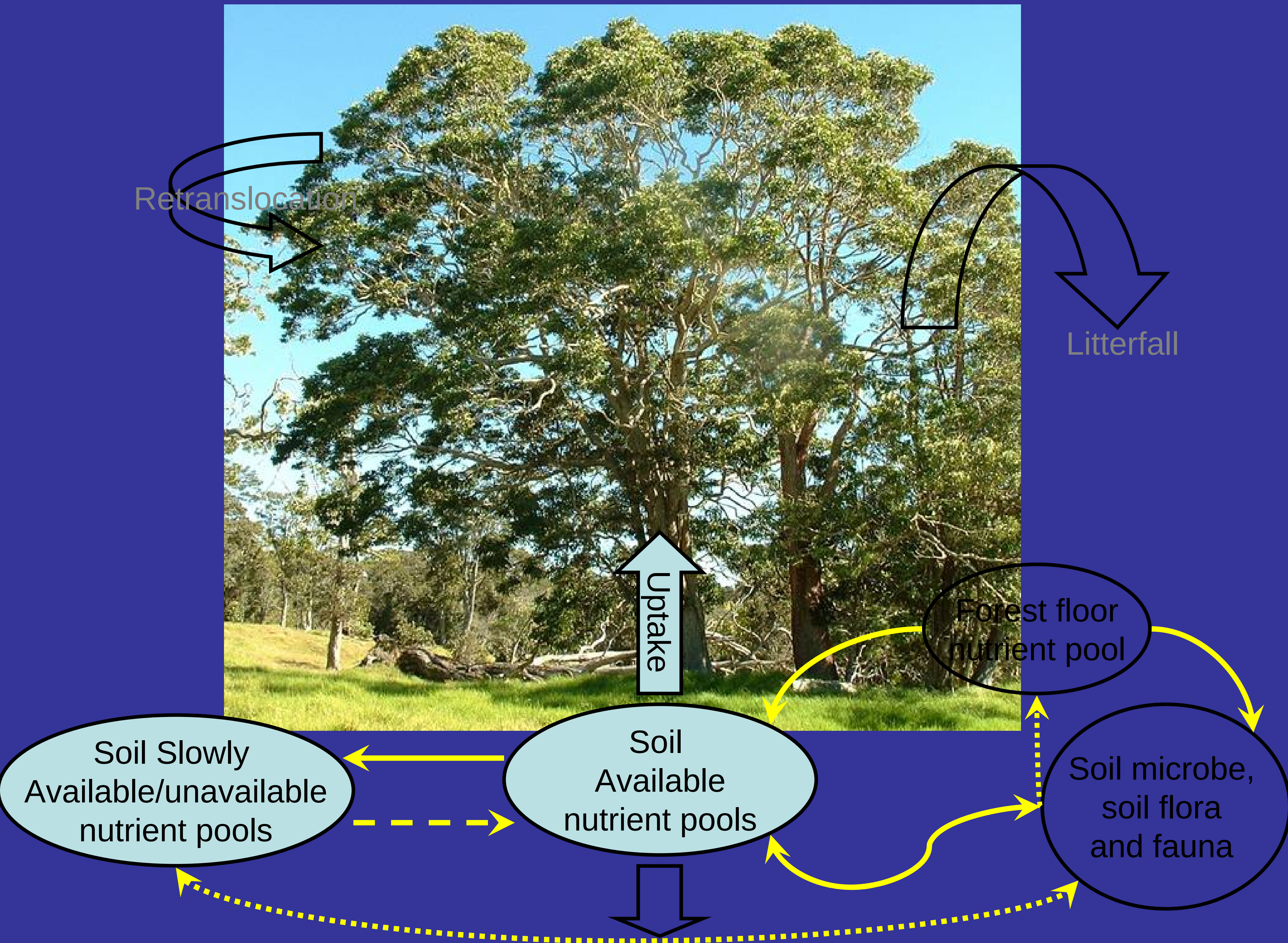
No significant difference between thinned and unthinned plots


Retranslocation
Litterfall
Uptake
Forest floor
nutrient pool
Soil
Available
nutrient pools
Soil Slowly
Available/unavailable
nutrient pools
Soil microbe,
soil flora
and fauna

# Sequential soil phosphorus extraction - The Hedley Fractionation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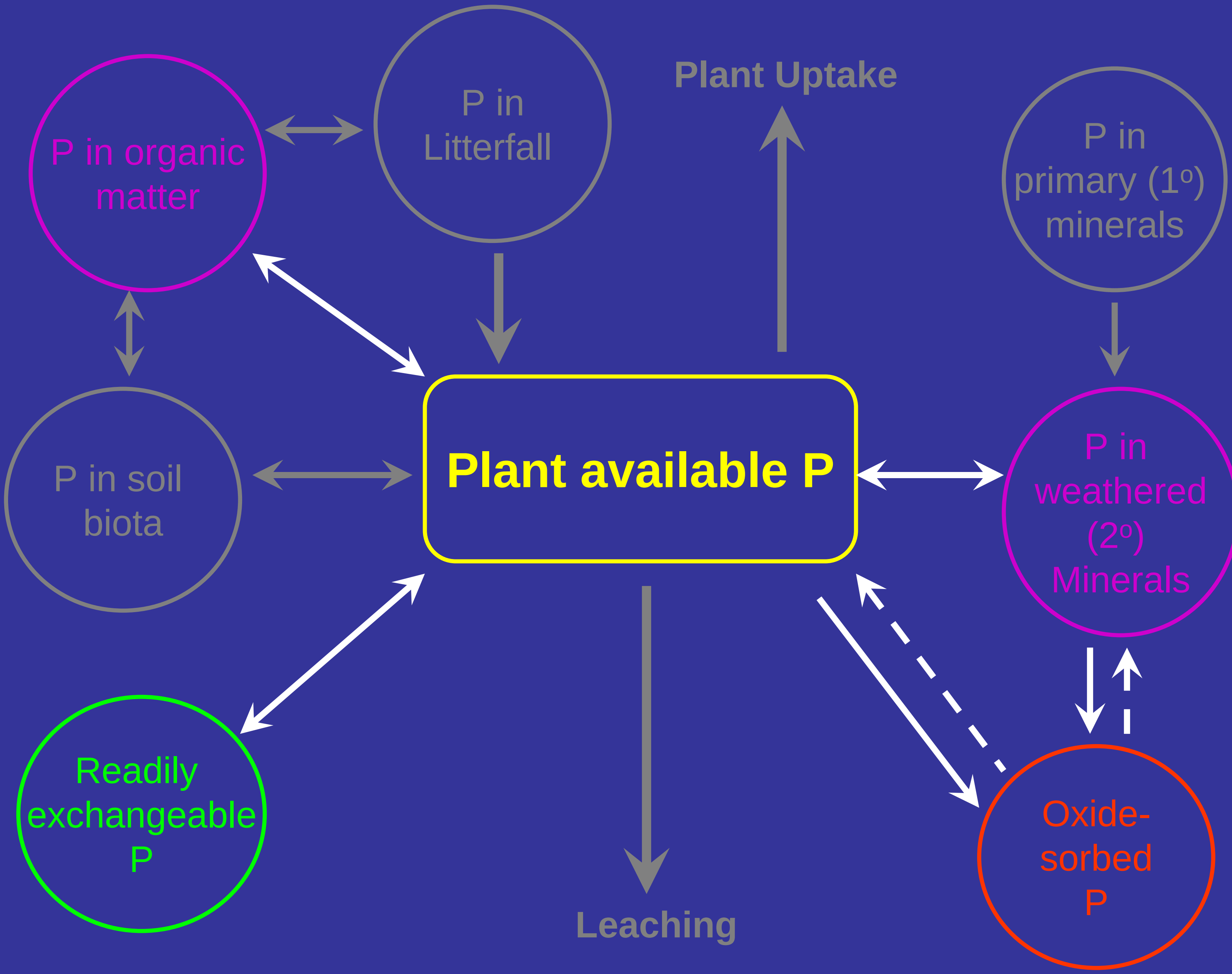
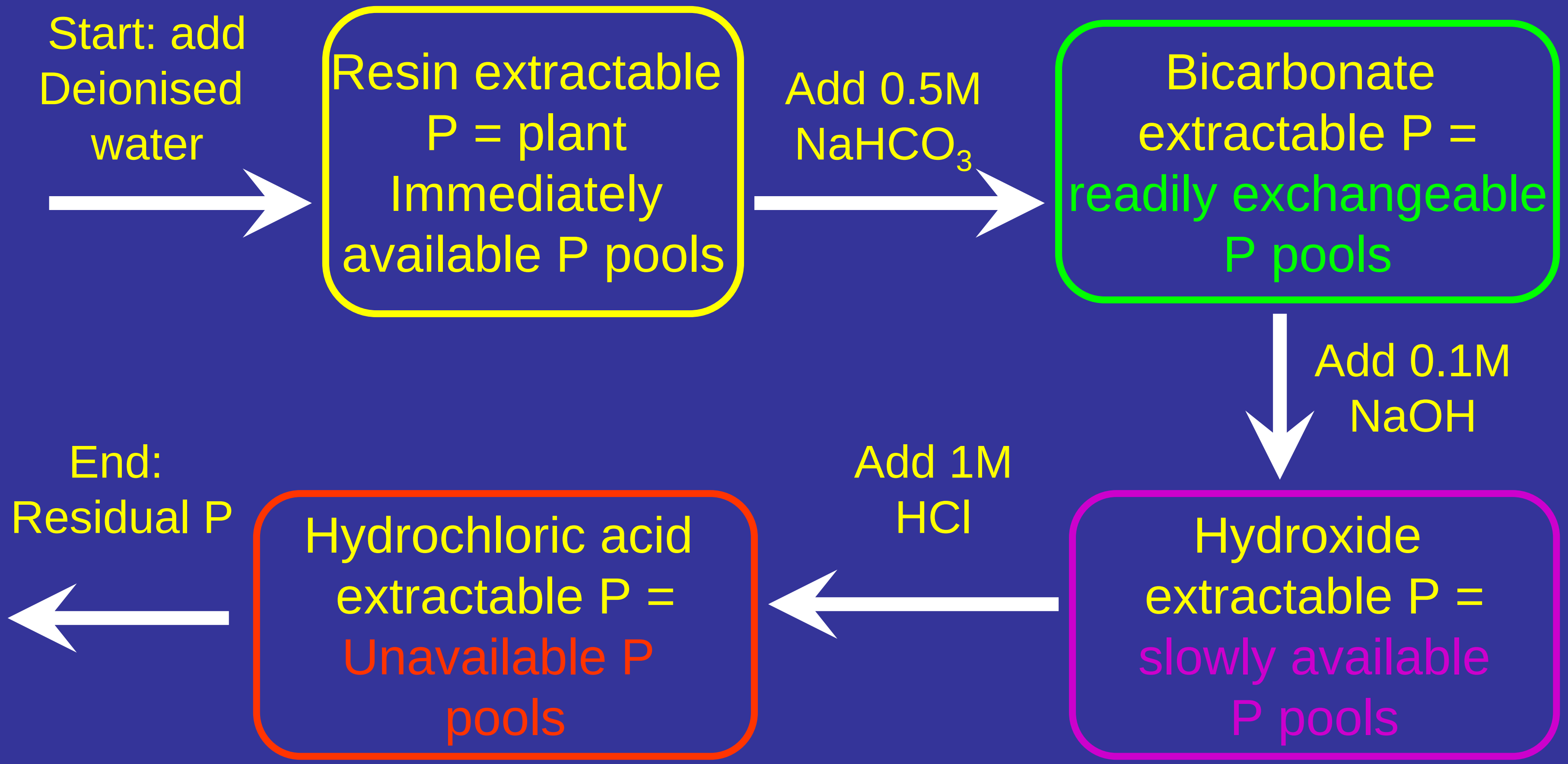
# Phosphorus (P) cycle

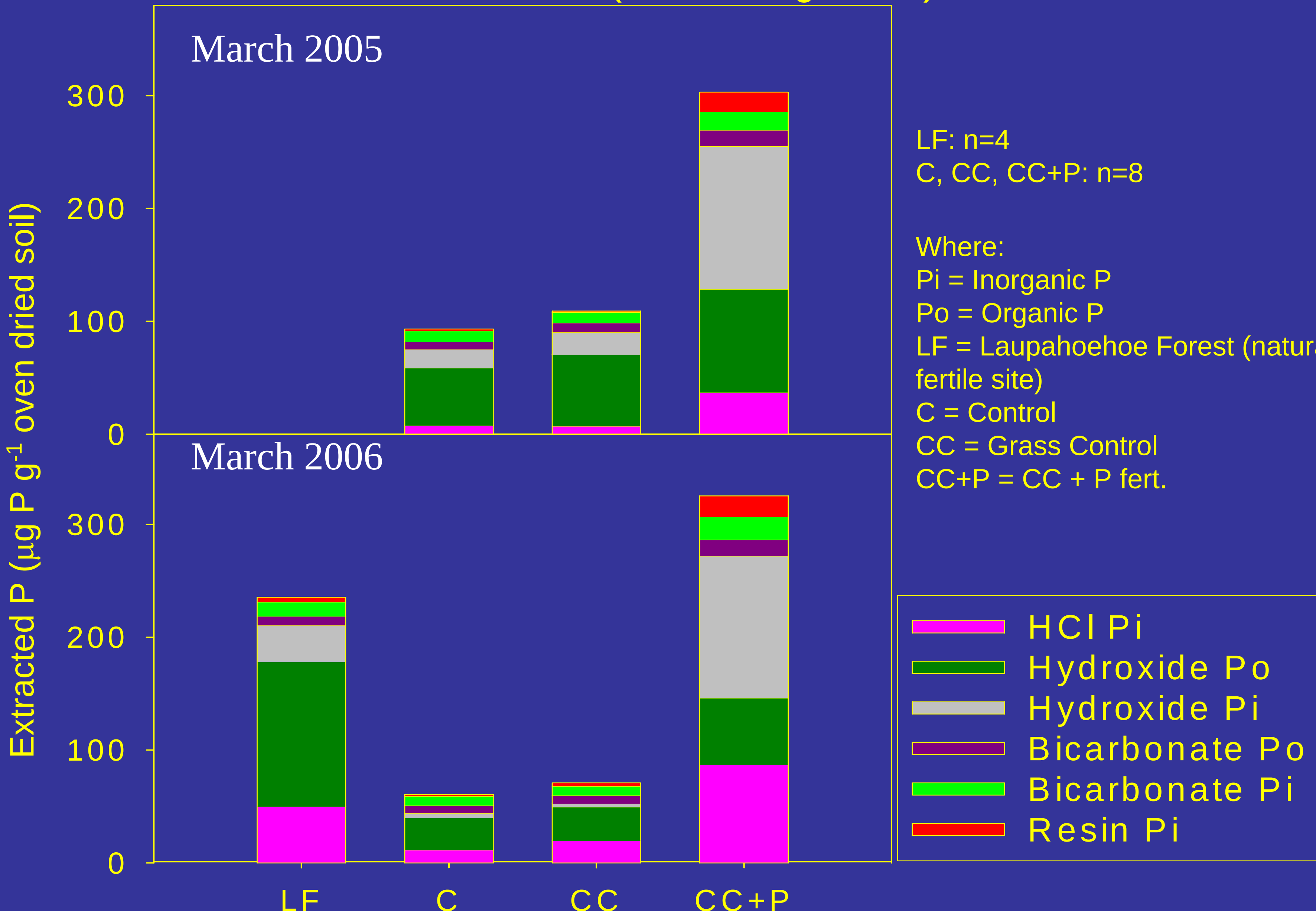


# Hedley Fractionation – sequential extraction of phosphorus (P) from various soil pools by adding stronger and stronger reagents

The stronger the reagent = the less available P is for plant uptake



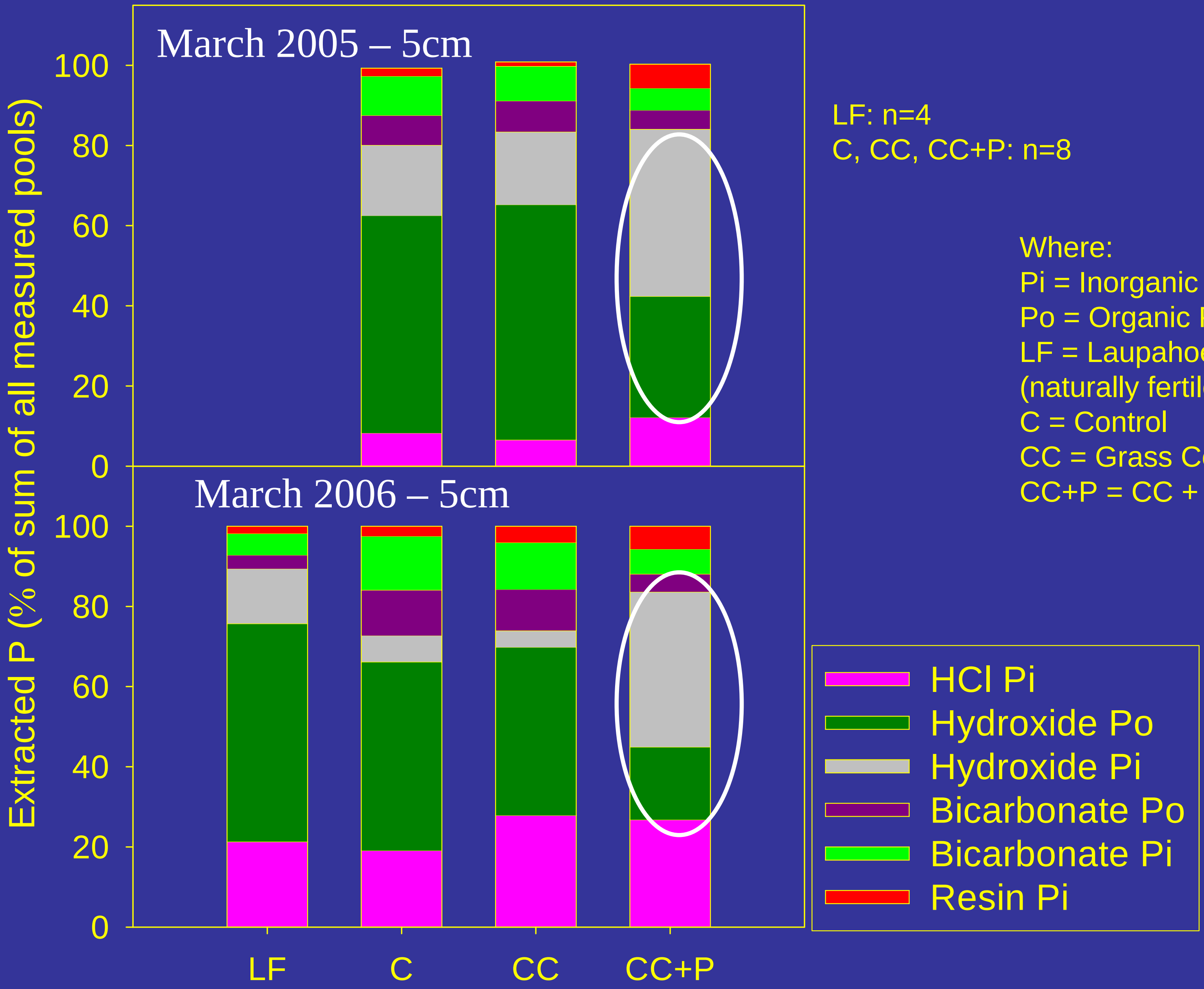
# Hedley fractionation of phosphorus pools at 5 cm soil depth – NT and T trts combined (no thinning effect)




LF: n=4
C, CC, CC+P: n=8

Where:
Pi = Inorganic P
Po = Organic P
LF = Laupahoehoe Forest (naturally fertile site)
C = Control
CC = Grass Control
CC+P = CC + P fert.

# P content per fraction as % of total P extracted

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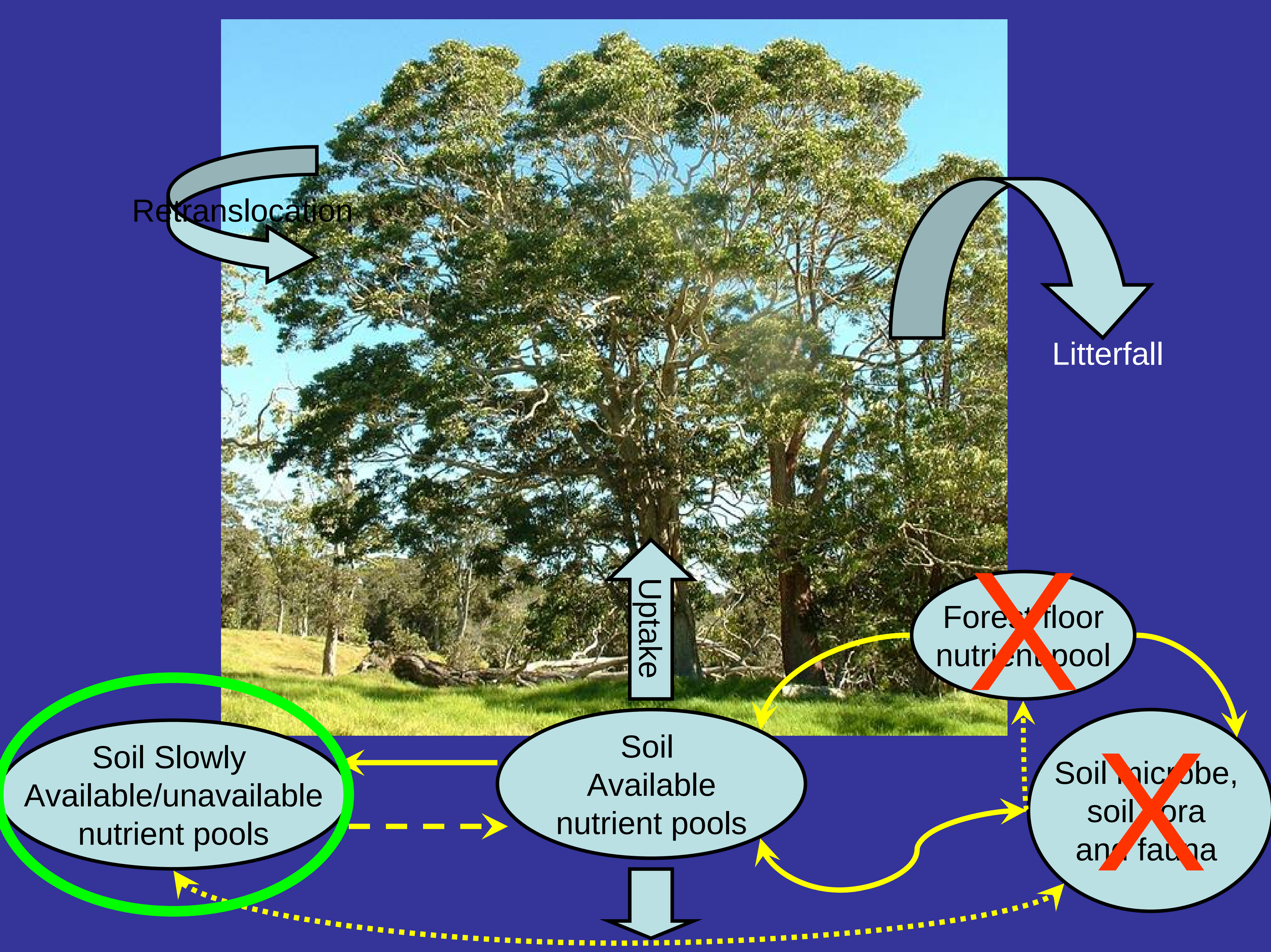

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# Summary

Does phosphorus (P) fertilisation elevate soil P availability in the short term or the long term?

- Yes, elevated for at least the medium term
- Two years after last P application, P availability 40 and 20 times greater at 5 cm and 15 cm depth, respectively
- Despite the very high P sorption capabilities of young volcanic soils, elevated P availability remains 4 years after the last P application

# Summary

## Does the treatments alter phosphorus (P) cycling through the leaf litter?

- Yes, CC+ P fertilisation tripled and almost doubled annual litterfall P content for the Unthinned and Thinned plots, respectively

- 8% increase in koa litterfall decomposition for CC + P fertilisation treatment after 327 days

# Summary

## If soil P availability remains high, what are the primary sources of this extra phosphorus (P)?

- Despite the extra P in the litterfall, this pool could not account for the elevated P levels by a factor of 30 for CC+P fertiliser treatment
- Almost all Hedley P pool fractions was greater for the fertilised treatment
- Largest change was from the NaOH Inorganic P pool - the most likely candidate for the extra soil available P
  - Indications of P being reversibly sorbed from this pool
- Actual mechanism is currently being investigated

# Management Implications

- Koa growth limited by low soil available P on young volcanic soils
- Without additional phosphorus, koa may not be able to take full advantage of additional soil water resources freed up with exotic grass competition control
- Large applications of phosphorus seem not to be required for a koa growth response
  - at least on young volcanic, organic rich soils
  - mechanism currently under investigation. Possibilities:
    - Secondary minerals?
    - Organic matter?
    - SOM coated amorphous minerals?

# Management Implications

- Phosphorus addition seems to provide extra labile soil P for tree uptake from the mineral soil and litterfall
- Phosphorus addition could provide a positive feedback loop for at least 5 years or more
- All information collected from this and other koa studies will be developed into a koa mathematical model based on the Australian process-based model, 3-PG
- Information will be tied into a GIS platform to assess land that has not seen koa for over 100 years and develop appropriate management strategies for each unique site

# Acknowledgements

Much mahalo's for the following organisations for site access, funding, and assistance:

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- DLNR DOFAW Hawaii and Kauai
- Koke'e Museum, Hawaii State Parks
- Garden Isle RC&D
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- Lynn Koehler
- Rodolfo Martinez
- Steve Smith
- Laurie Ho

# David Douglas Monument – Kaluakauka, Island of Hawaii