Nutrition and fertilization of Short-rotation Eucalypt Plantations of High Productivity

José **Leonardo** de Moraes **Gonçalves**[1]

Jean-Paul Laclau[2]

[1] Full Professor
University of São Paulo, Brazil
The "Luiz de Queiroz" College of Agriculture
Department of Forest Sciences

[1] Visiting scientist
CIRAD/UMR Eco&Sols, France
University of São Paulo, Brazil
The "Luiz de Queiroz" College of Agriculture

IUFRO Symposium
Nutrient Dynamics of Planted Forests
27-28 November 2012
Vancouver, WA, USA

Outline

1. Location of plantations
2. Edaphoclimatic and physiographic characterizations
3. Productivity
4. Soil fertility and eucalypt nutrition
   - 3.1 Nitrogen
   - 3.2 Phosphorus
   - 3.3 Potassium
   - 3.4 Calcium and Magnesium
5. Silvicultural practices used to alleviate the nutrient constraints
   - 5.1 Site-species/hybrid matching conformance
   - 5.2 Fertilizer application
   - 5.3 Site preparation
6. Final considerations

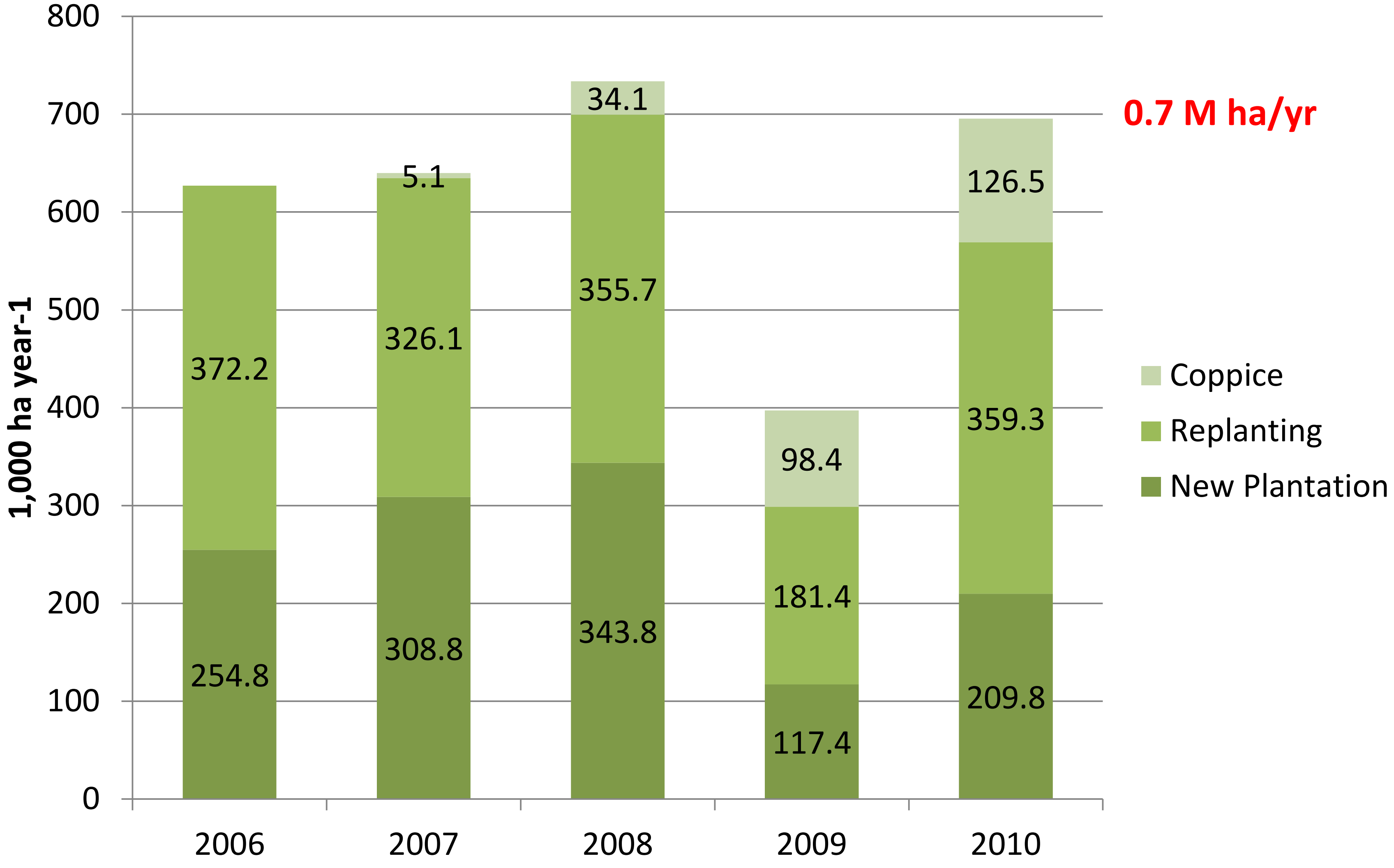
Locations of Plantations

Forest Plantations

4.7 millions ha *Eucalyptus*
1.8 milion ha *Pinus*

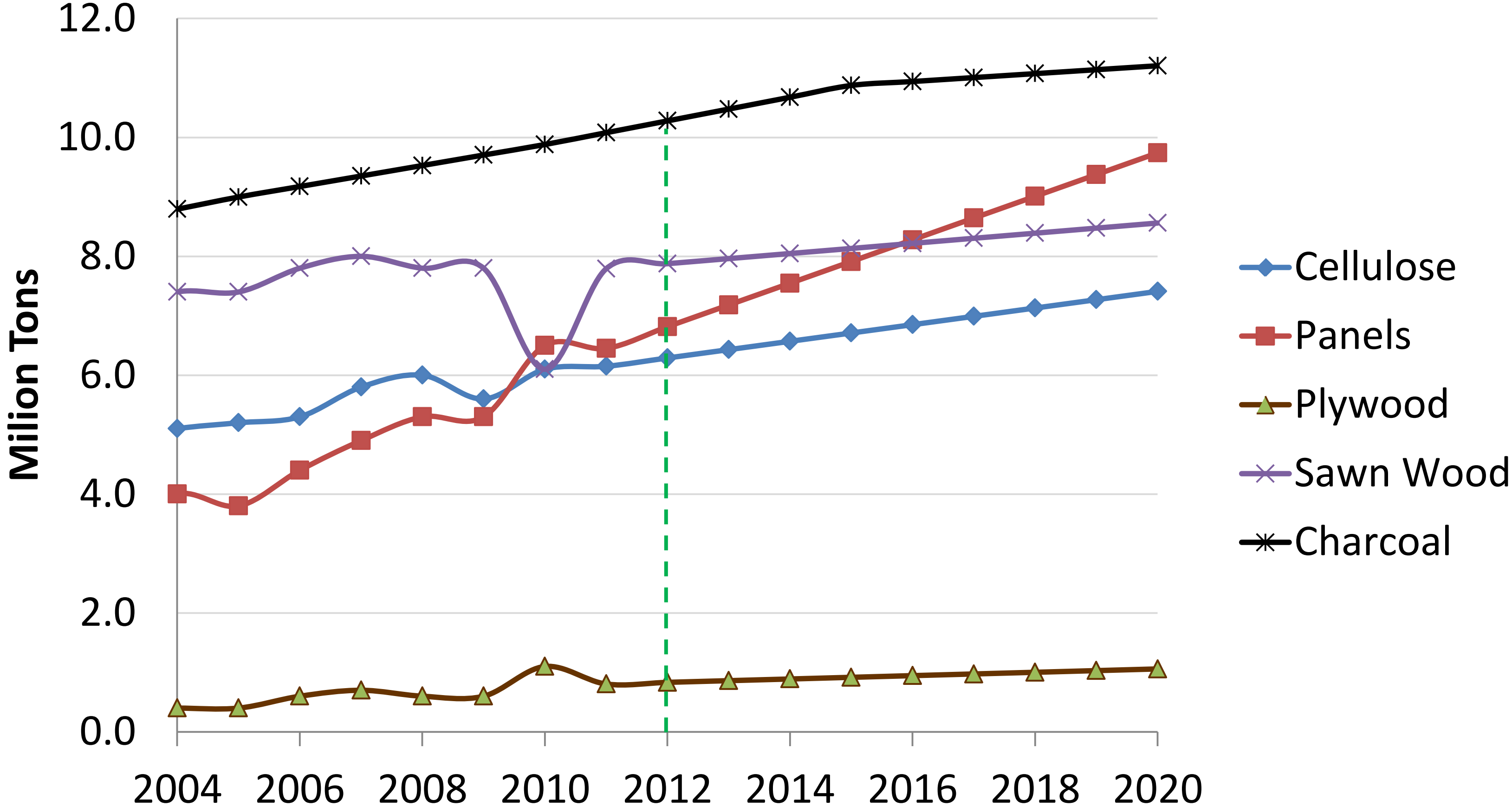
● = 100.000 ha

Silvicultural Systems



Source: ABRAF 2011

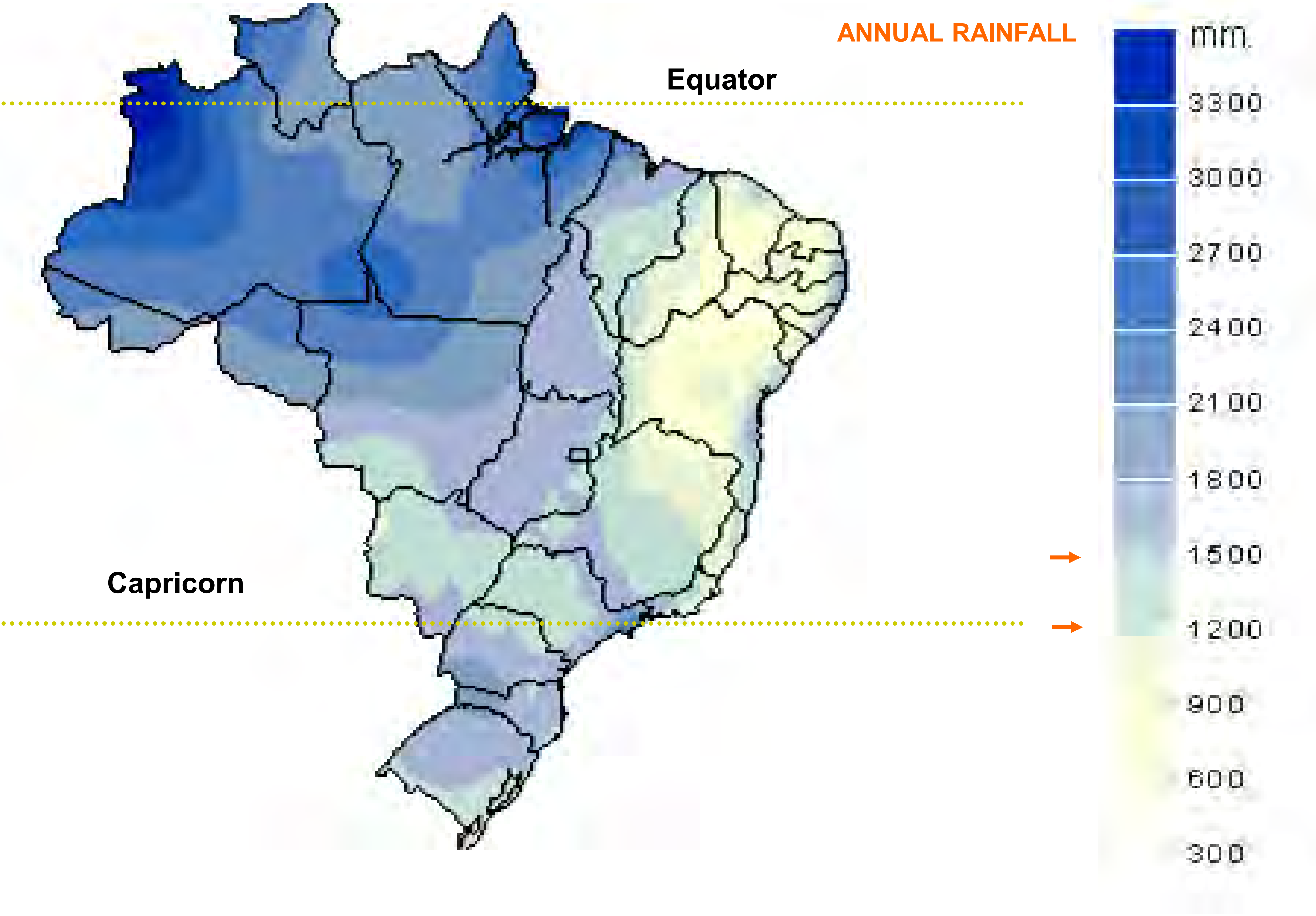
Historic and Projection of the Consumption of Round Wood for Industrial Use



Source: ABRAF, 2011 and AMS, 2009 (modified)

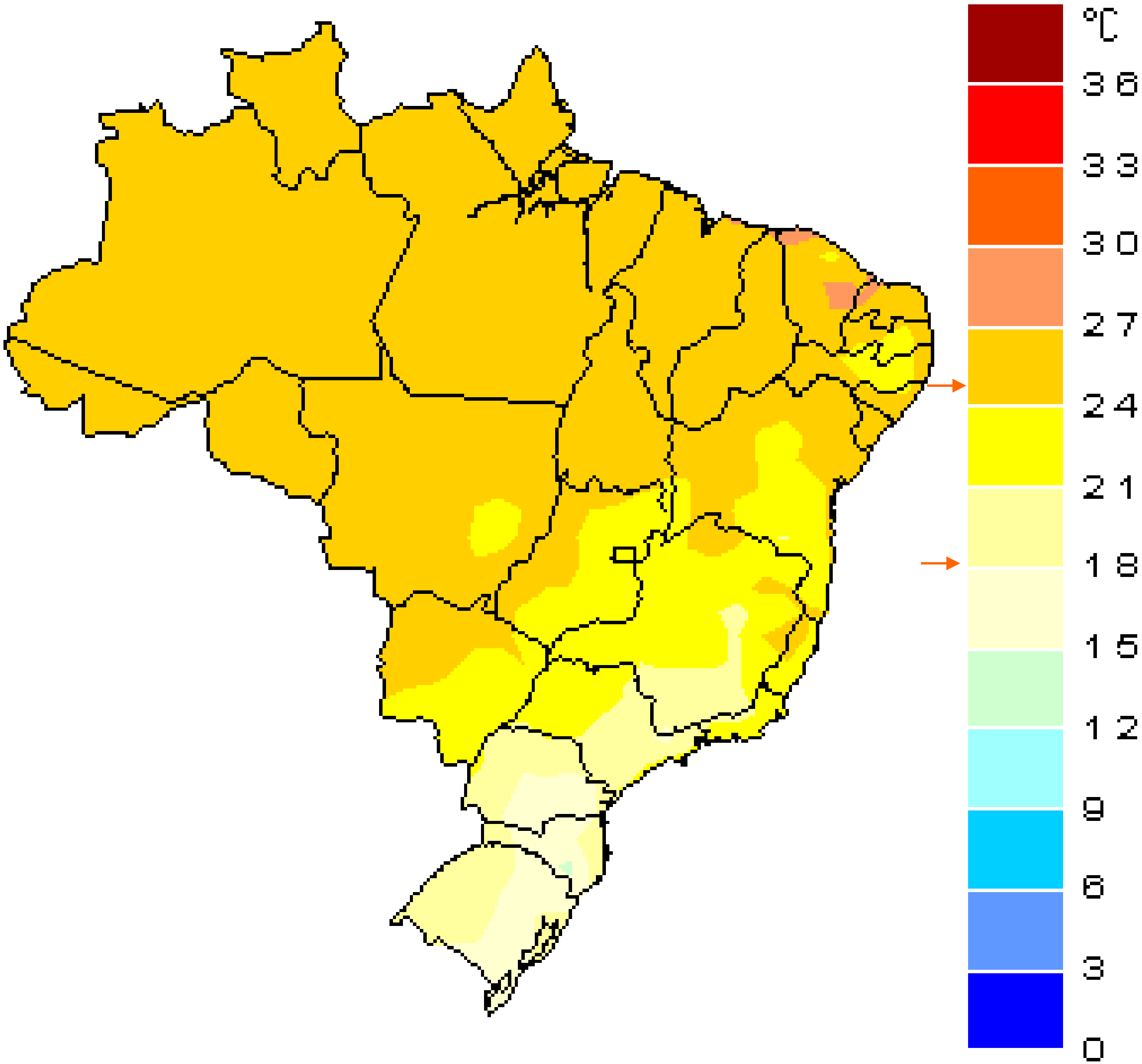

General view of Eucalypt Plantation in Brazil
BIODIVERSITY CONSERVATION
Mosaic of native and exotic species
on landscape
Atlantic forest
eucalypt
VERACEL Cia

Edaphoclimatic and Physiographic Characterizations



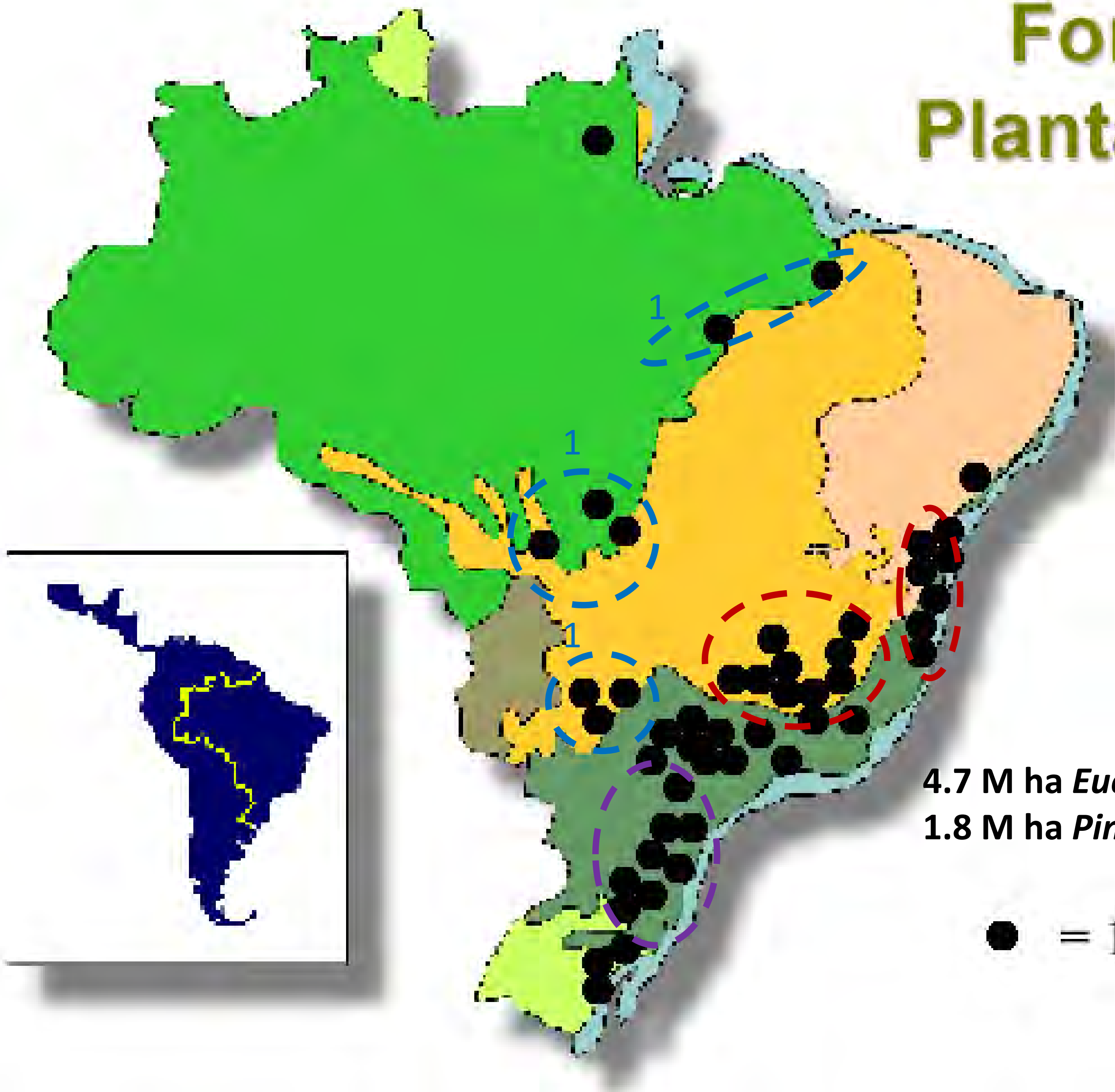
ANNUAL RAINFALL
Equator
Capricorn
mm
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300

ANNUAL AVERAGE TEMPERATURE



Source: INMET 1931/1990

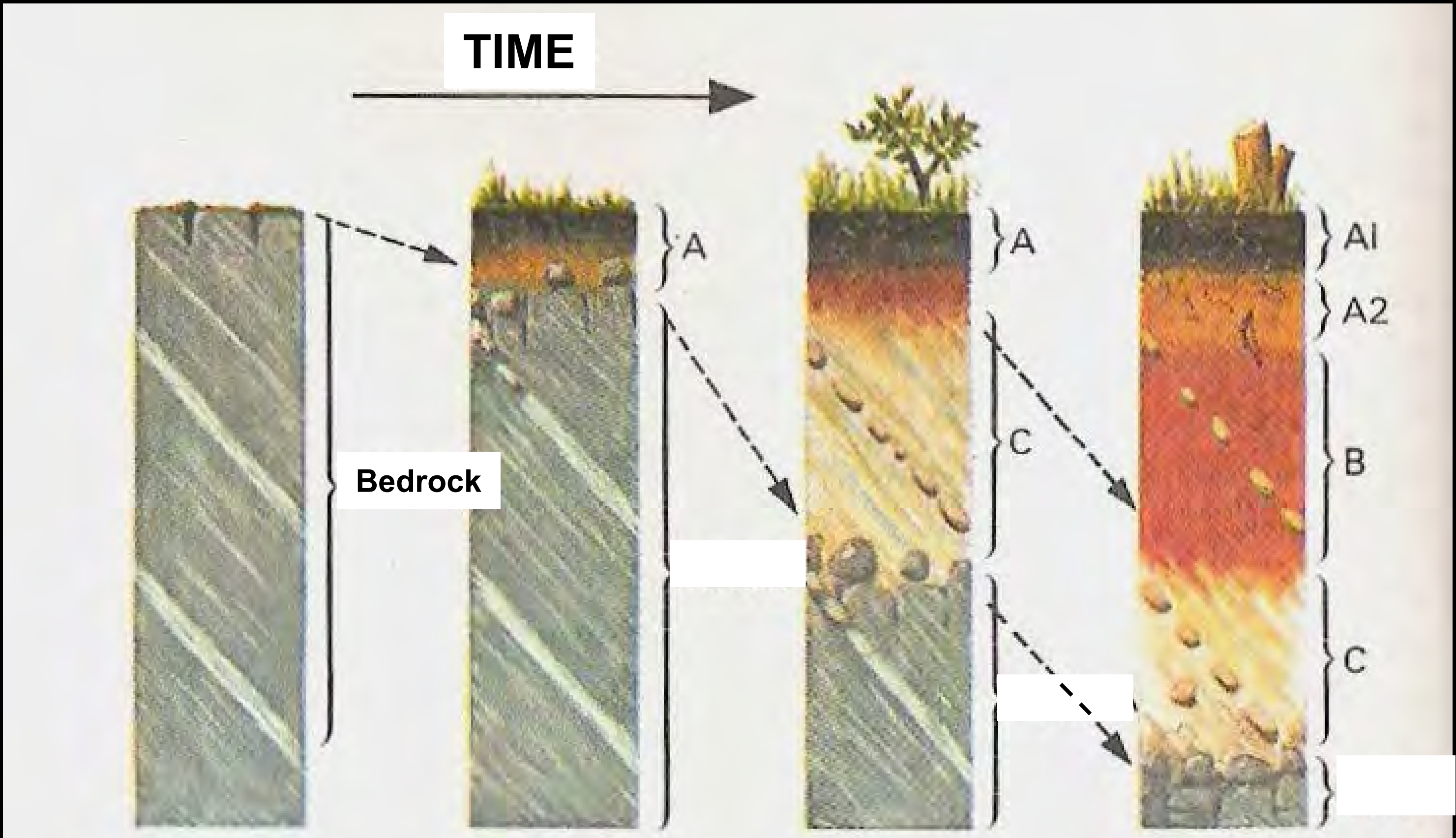
Forest Plantations



4.7 M ha *Eucalyptus*
1.8 M ha *Pinus*

● = 100.000 ha

Time of Soil Formation

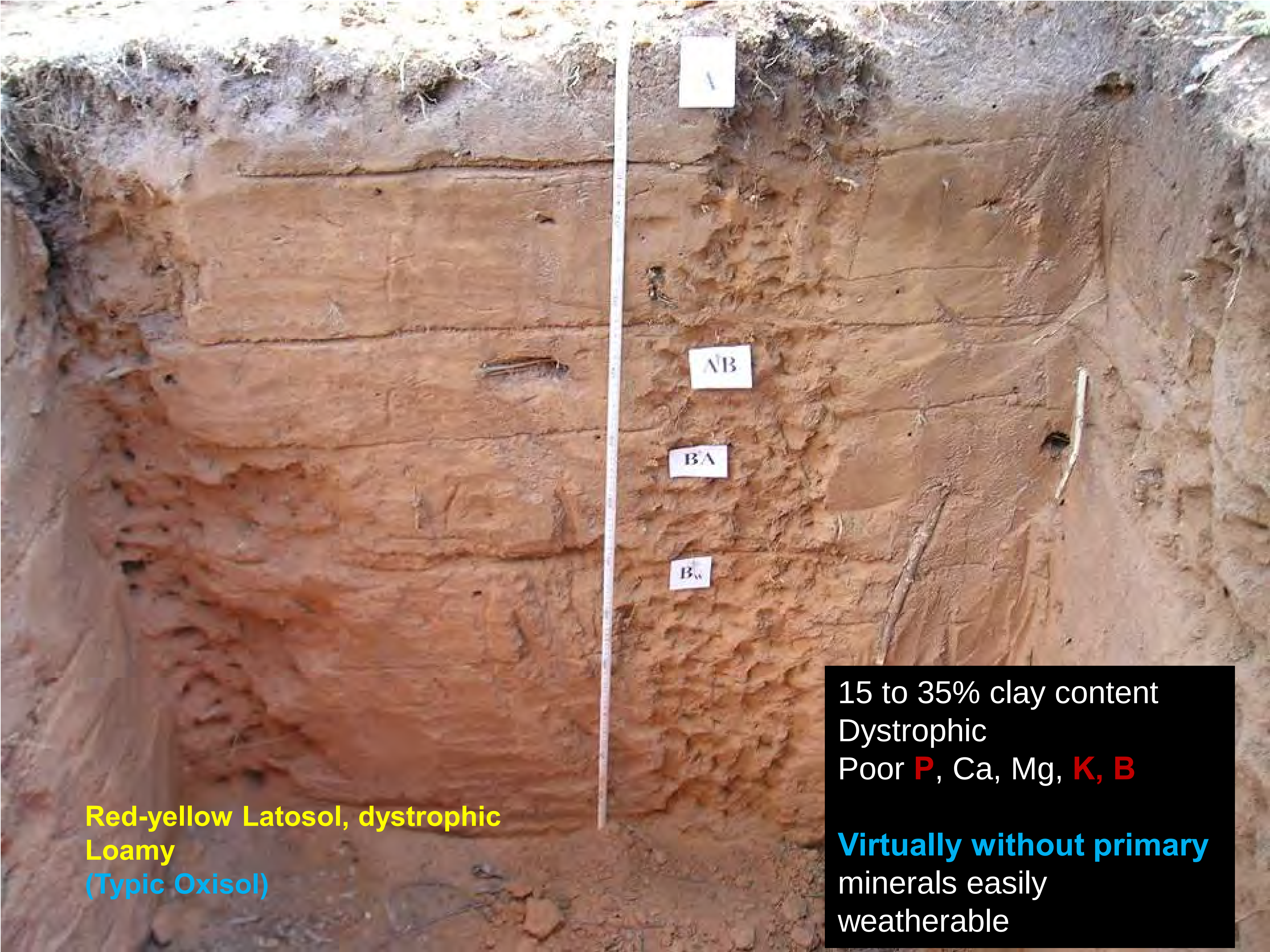


Bedrock newly exposed

New soil (Entisol)

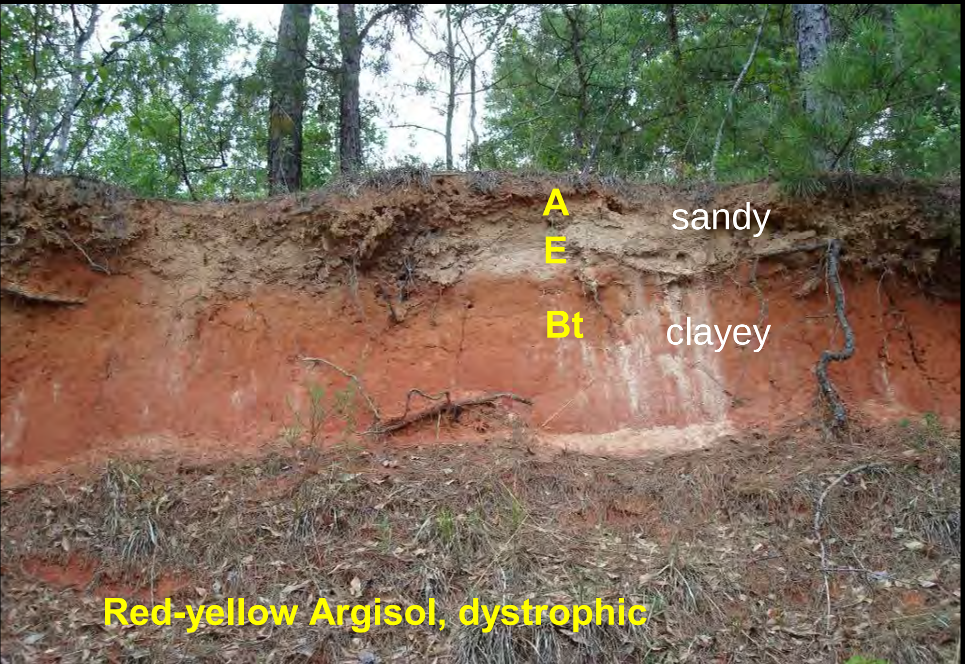
Flat soil (Inceptisol = 14%)

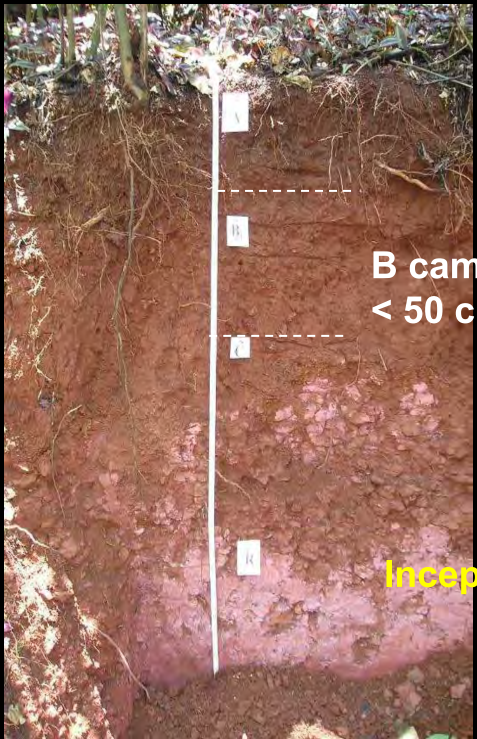
Mature soil (Oxisol = 48%, Ultisol = 26%)


AB
BA
Red-yellow Latosol, dystrophic
Loamy
(Typic Oxisol)
15 to 35% clay content
Dystrophic
Poor P, Ca, Mg, K, B
Virtually without primary
minerals easily
weatherable


Typical Landscape
28 5 2007

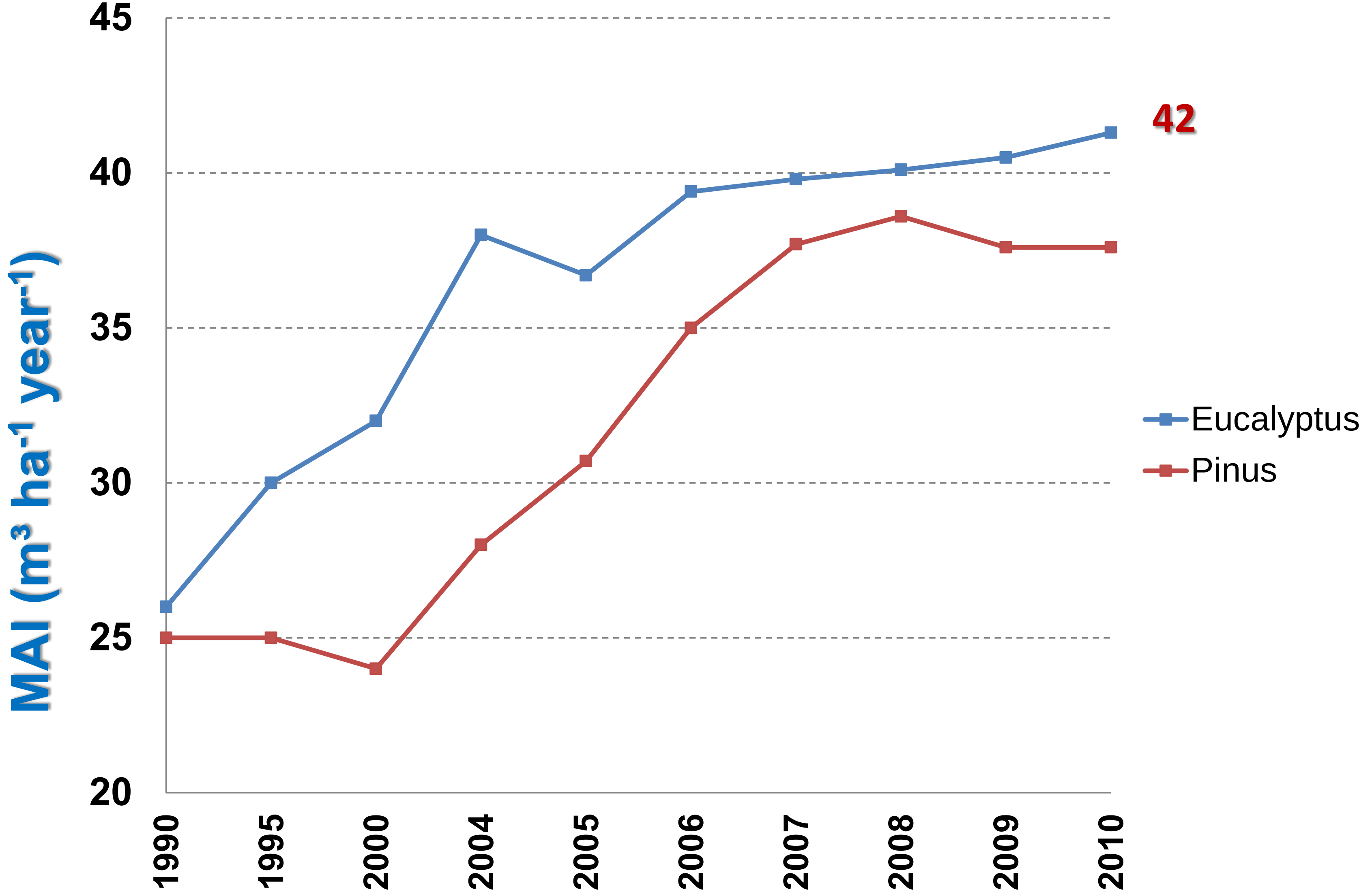
Geology: Atlantic Plateau (pre-Cambrian crystalline rocks)
Relief: hilly-rolling (declivity 13 to 30%)





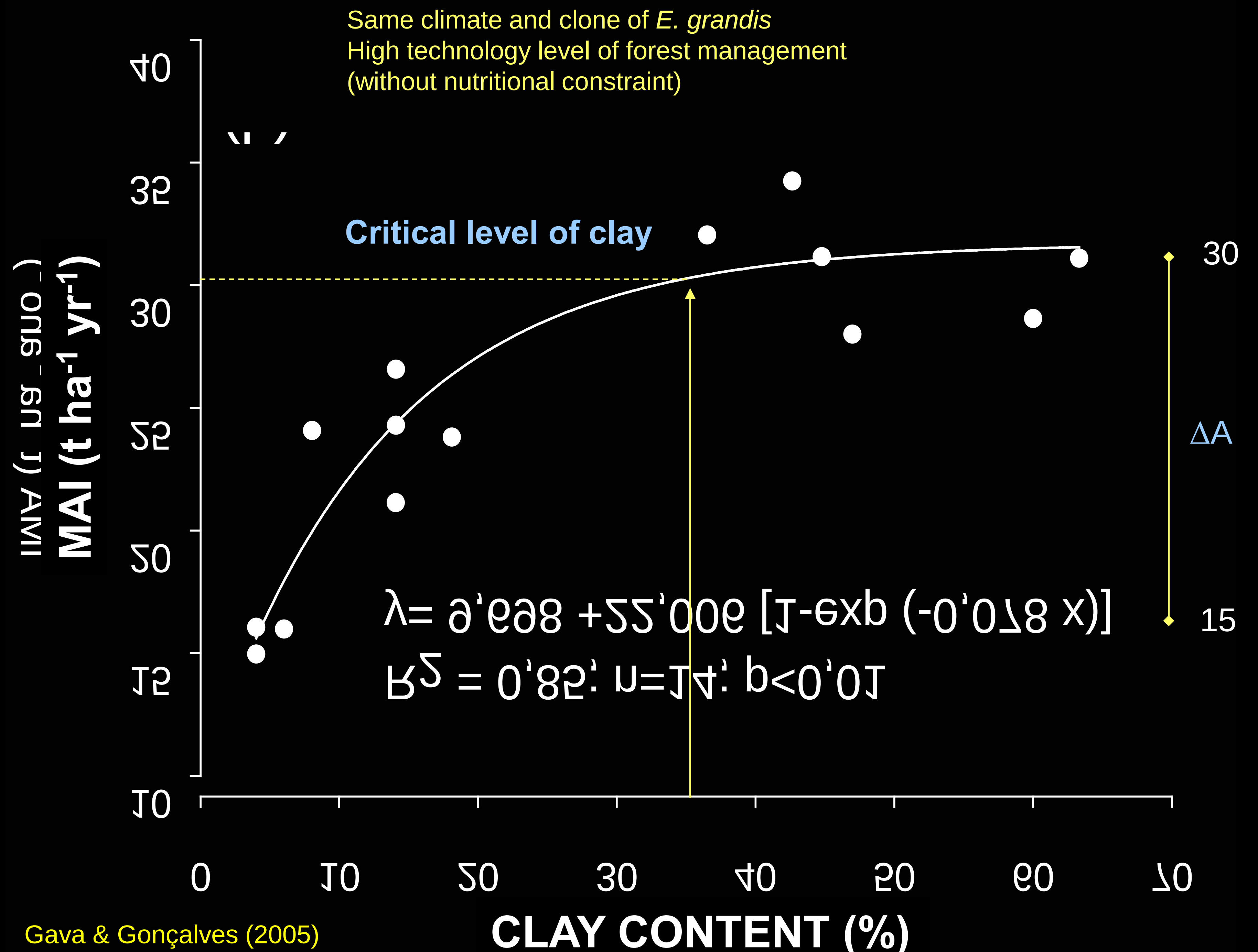
Productivity

National mean productivity (Age 7 years)

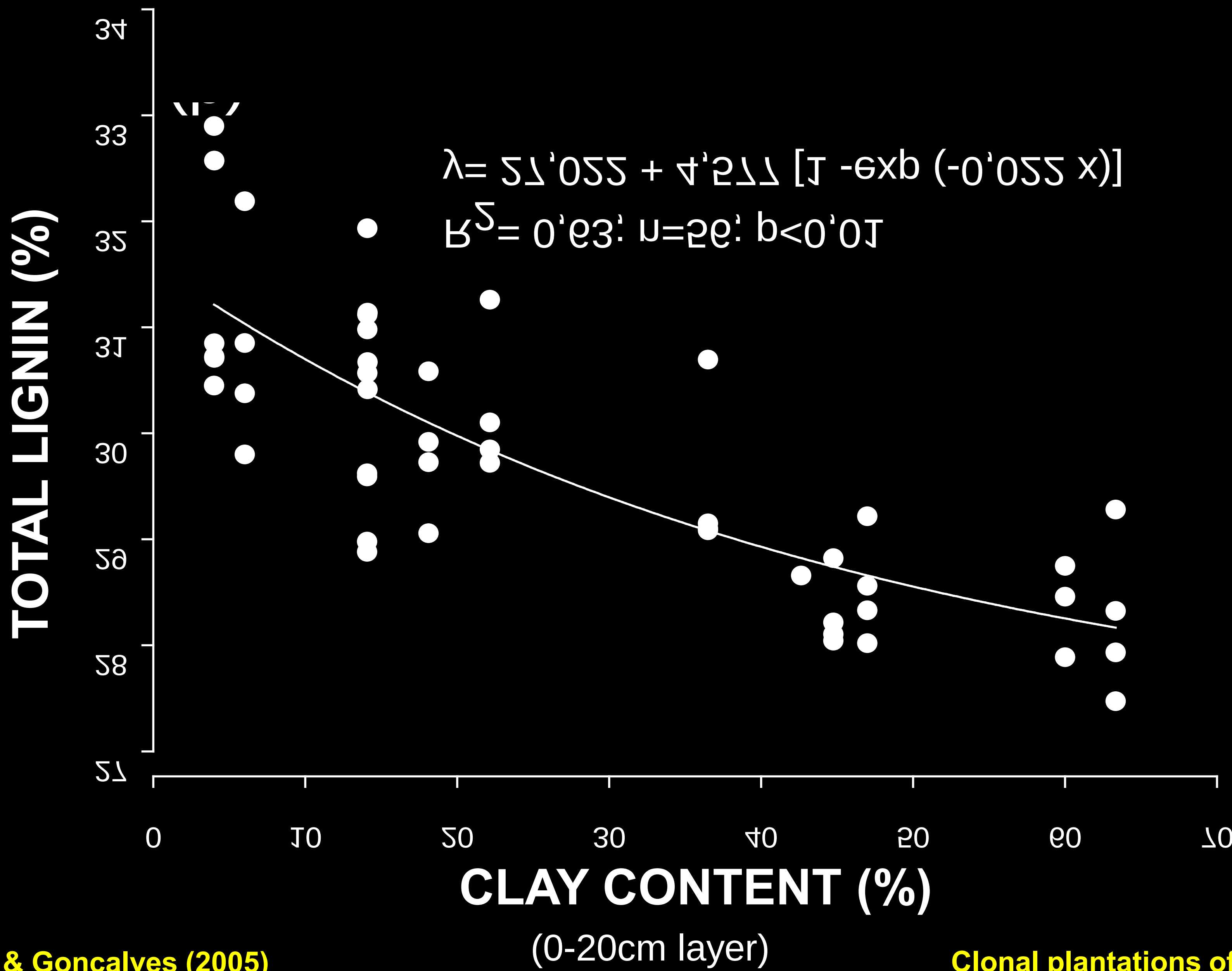


High quality site (5 yr)
E. urophylla x grandis
MAI = 50 m^3 / ha / yr

Poor quality site (5 yr)
E. urophylla x grandis
MAI = 30 m^3 / ha / yr

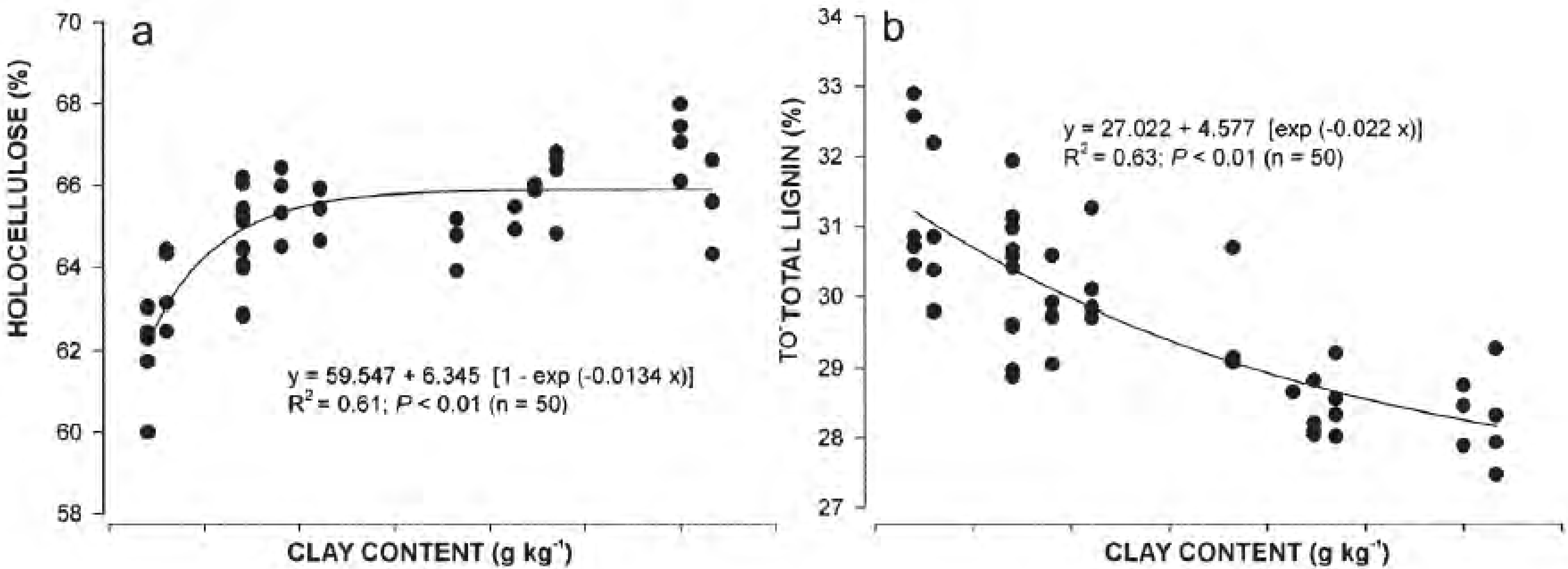


Gava & Gonçalves (2005)



Gava & Gonçalves (2005)

Clonal plantations of *E. grandis*
6.5 to 7.0 year old



Relation between holocellulose (a), total lignin (b) and clay content (0-20 cm layer).

Soil fertility and Eucalypt nutrition

Available Nitrogen in the Soil

Localization (11 sites)

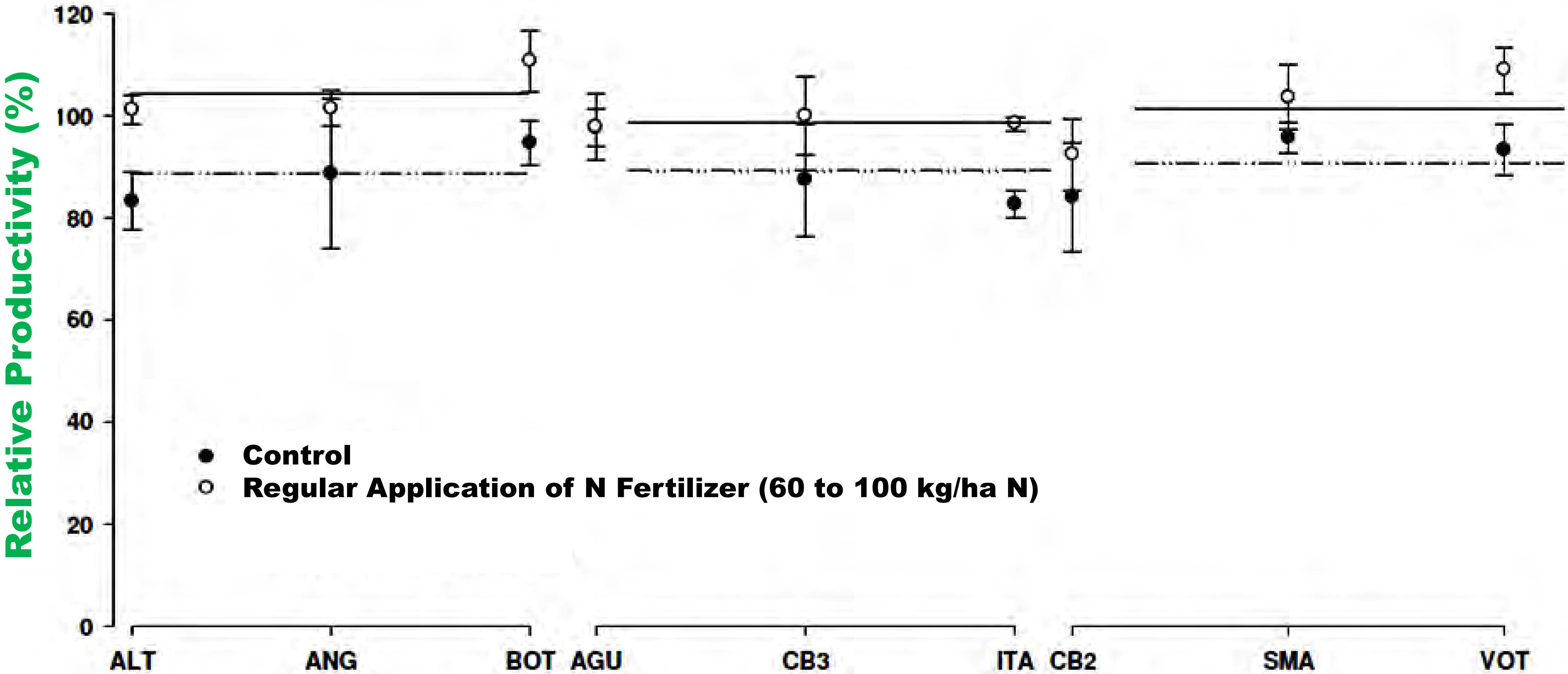
Genotypes: *E. grandis* and *E. urophylla x grandis*
Rainfall: 1200 to 1500 mm
M.A. Temp.: 20 to 21.5°C
M.A. EVT: 900 to 1000 mm
Dry season: < less months

Age: 12 to 24 months

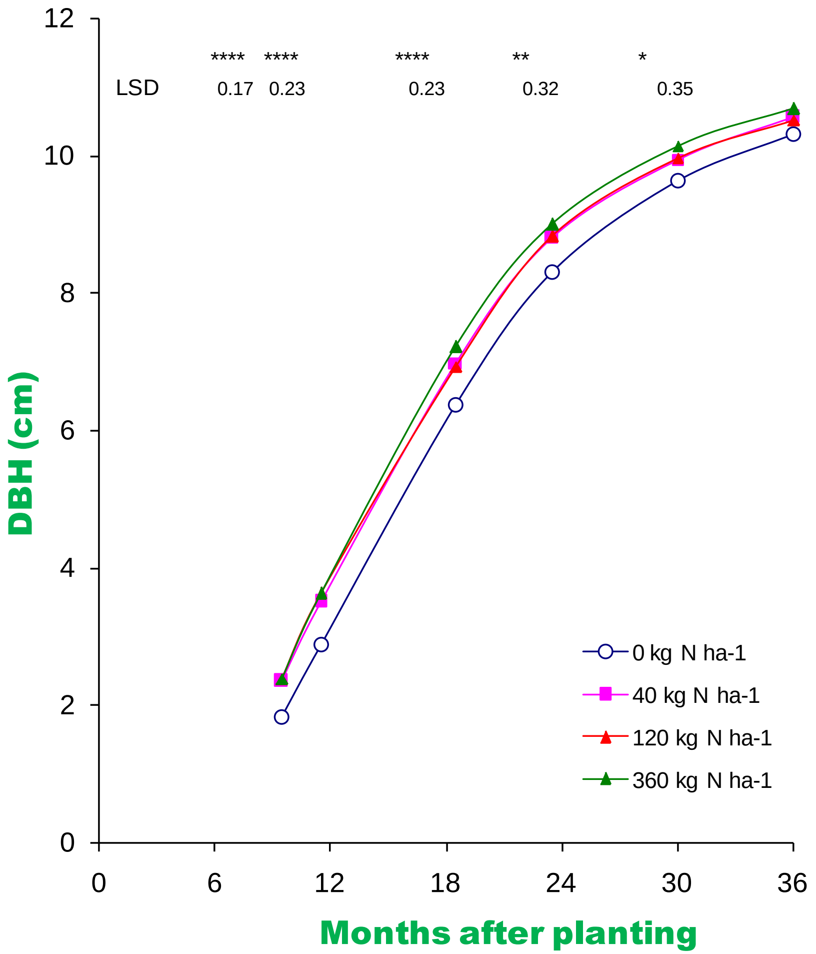
Average

Δ RP(%) = RAN – CTL

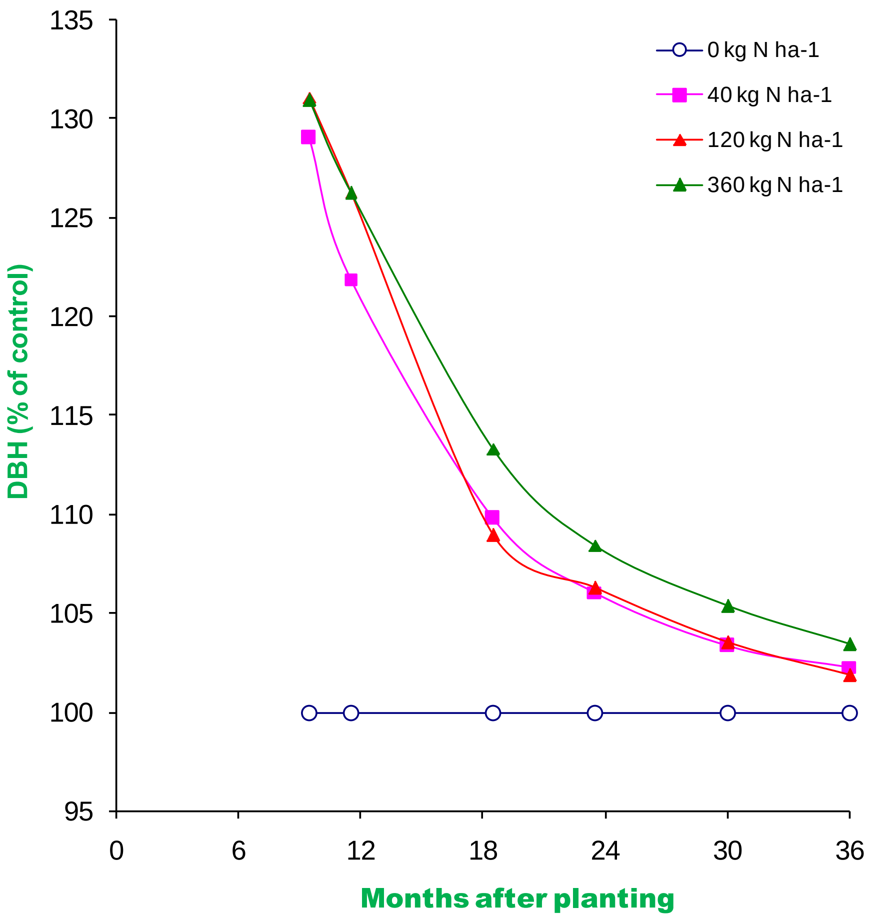
16% **9%** **10%**



Sandy Soils	**Loamy**	**Clayey**
Quartzipsamments	Oxisols	Oxisols
MAI (m^3/ha/yr)		
35 - 45	**40 - 50**	**45 - 55**



LSD
**** 0.17
**** 0.23
**** 0.23
** 0.32
* 0.35
0 kg N ha-1
40 kg N ha-1
120 kg N ha-1
360 kg N ha-1
DBH (cm)
Months after planting



0 kg N ha-1
40 kg N ha-1
120 kg N ha-1
360 kg N ha-1
DBH (% of control)
Months after planting

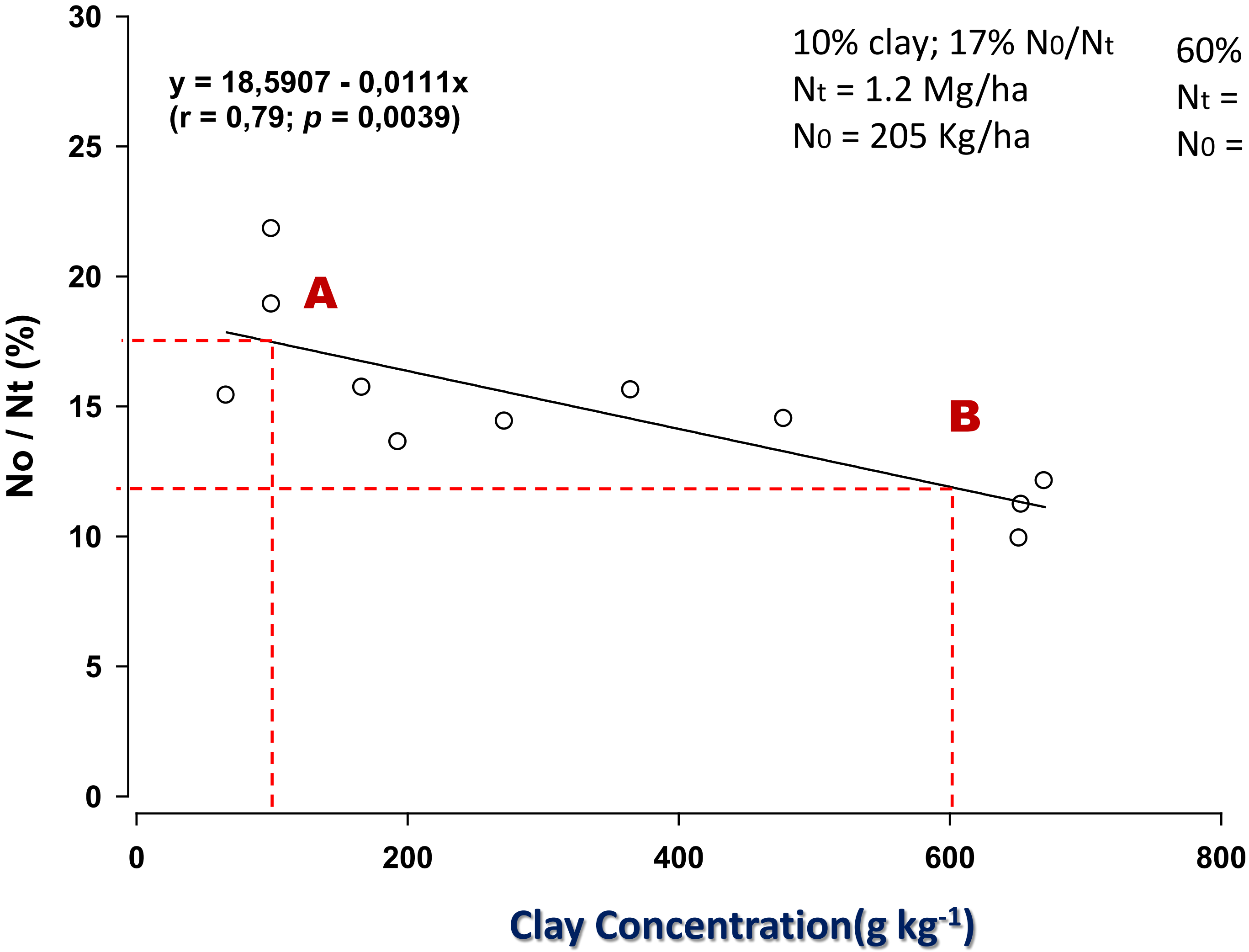
Soil layer: 0-20cm

A

10% clay; 17% N_0/N_t
N_t = 1.2 Mg/ha
N_0 = 205 Kg/ha

B

60% clay; 12.5% N_0/N_t
N_t = 2.9 Mg/ha
N_0 = 360 kg/ha



Potassium

K deficiency

+ K

- K

E. grandis
20 months

Forest Ecology and Management 259 (2010) 1786–1795

Contents lists available at ScienceDirect

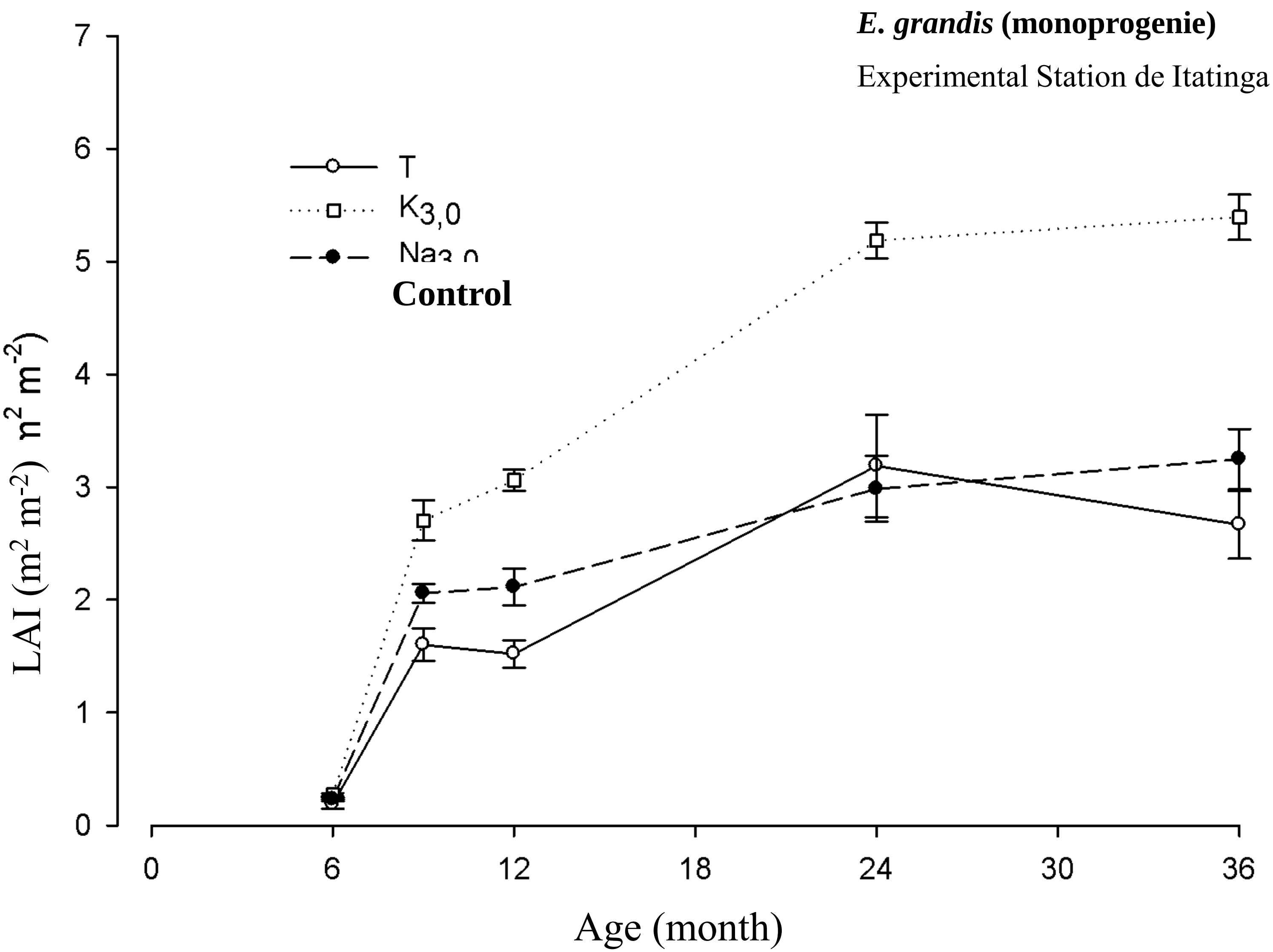
Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

A positive growth response to NaCl applications in *Eucalyptus* plantations established on K-deficient soils

Julio Cesar Raposo Almeida [a,c], Jean-Paul Laclau [b,d,*], José Leonardo de Moraes Gonçalves [c], Jacques Ranger [e], Laurent Saint-André [b,e]

[a] UNITAU, University of Taubaté, Taubaté, Brazil
[b] CIRAD, Persyst, UPR Ecosystèmes de Plantation, F-34398, Montpellier, France
[c] USP, ESALQ, Piracicaba, Brazil
[d] USP, Department of Ecology, São Paulo, Brazil
[e] INRA, Biogéochime des Ecosystèmes Forestiers, Nancy, France

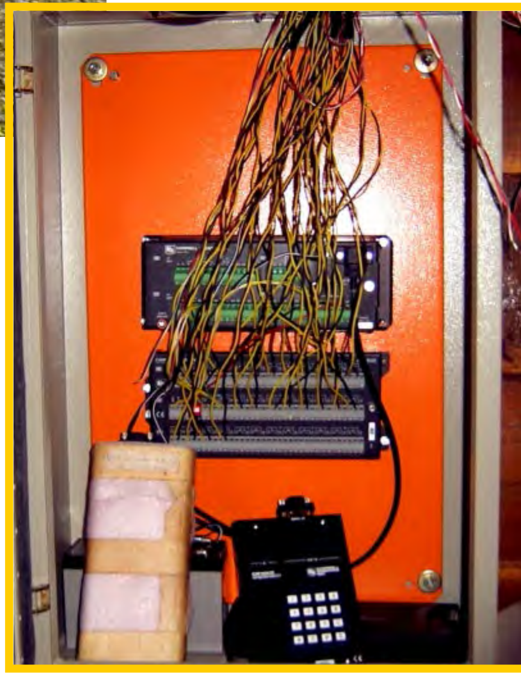


Almeida, Laclau, Gonçalves (2009)

Measurement of sap flow gross (Granier method, 1985)

Sensors

Datalogger



Growth and efficiency of water use

Treatment	Biomass	Water Consumption
	Mg ha^{-1}	**L kg^{-1}**
Control	8	500
K fertilization	21	248

Almeida, Laclau, Gonçalves (2009)

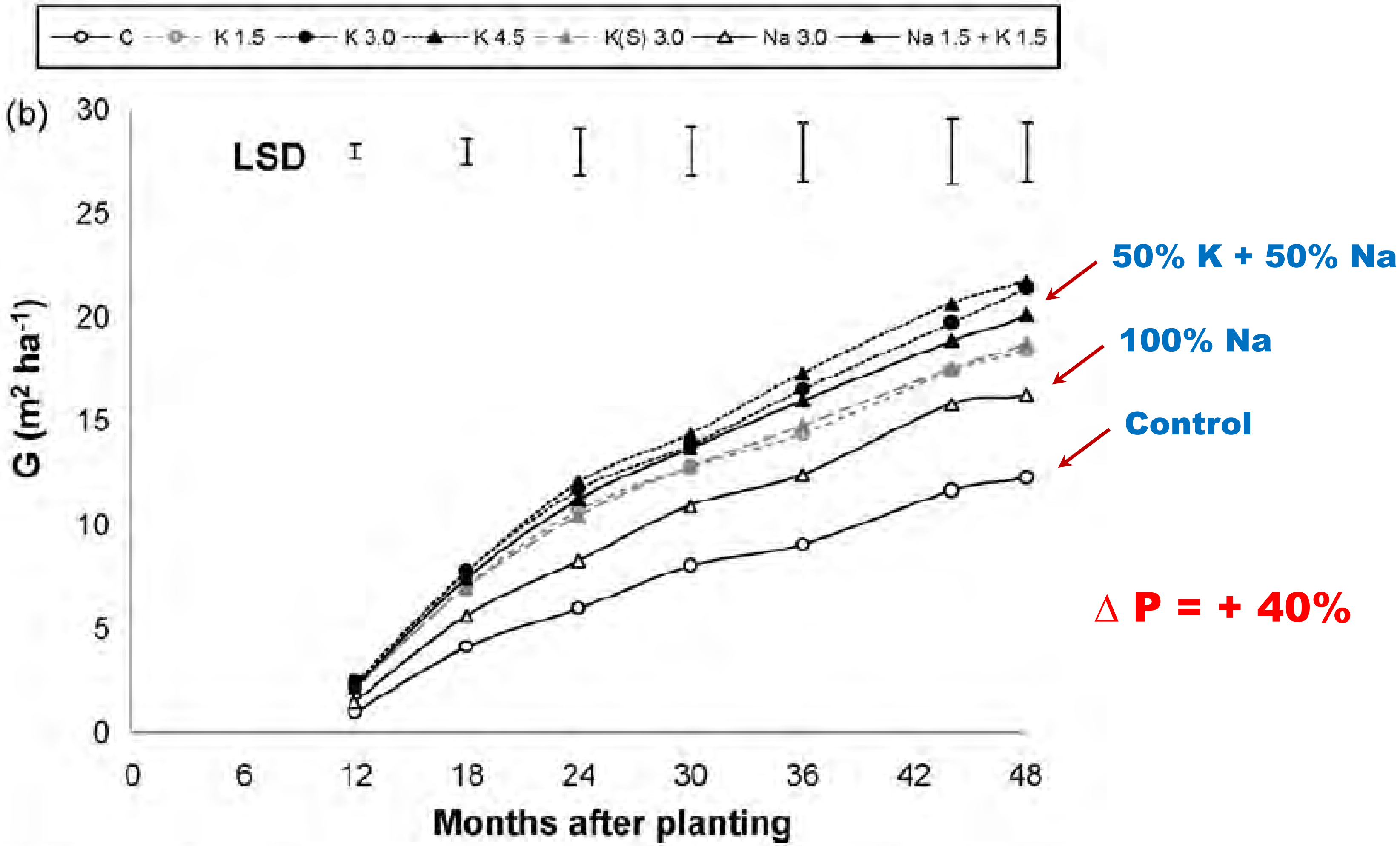


Fig. 1. Effects of K and Na fertilization regimes on height (a) and basal area (b) growth over 3 years after planting. Vertical bars indicate the least significant difference ($P < 0.05$) at each age.

Silvicultural Practices Used to Alleviate the Nutrient Constraints

1. Site-Species/hybrid matching conformance

The main species and hybrids recommended for planting and expected average productivity (**roundwood with bark**) of the planted areas with eucalypts

Climate type (Köppen)	Mean annual rainfall mm yr^{-1}	Mean annual temper. °C	Mean actual ET mm yr^{-1}	Dry season: Nº months	Dry season: Water deficit mm yr^{-1}	Species / hybrid	MAI $m^3 ha^{-1} yr^{-1}$
Cfa, Cfb	1500 – 2500	13 – 20	500 – 800	0 – 1	0 – 50	EUG, Egr, Eur, Cci, Edu, Ebe	35 – 60

Climate type

Cfa = Subtropical, oceanic, fully humid, hot summer

Cfb = …, temperate summer

Genotypes

Egr = *E. grandis;*
Eur = E. urophylla;
Cci = Corymbia citriodora;
Ebe = E. benthamii (frost tolerant)*;*
Edu = E. dunnii (frost tolerant)*;*
EUG = Eucalyptus urophylla x grandis

The main species and hybrids recommended for planting and expected average productivity (**roundwood with bark**) of the planted areas with eucalypts

Type climate	Mean annual rainfall mm yr^{-1}	Mean annual temper. °C	Mean actual ET mm yr^{-1}	Dry season		Species / hybrid	MAI m^3 ha^{-1} yr^{-1}
				Nº months	Water deficit mm yr^{-1}		
Cfa, Cfb	1500 – 2500	13 – 20	500 – 800	0 – 1	0 – 50	EUG, Egr, Eur, Cci, Edu, Ebe	35 – 60
Cwb, Am	**1000 – 1800**	**18 – 20**	**800 – 1000**	**2 – 3**	**50 – 100**	**EUG, Eur**	**35 – 45**

Climate type

Cwb = Subtropical, humid, dry winter, temperate summer

Am = Tropical, monsoon

The main species and hybrids recommended for planting and expected average productivity (**roundwood with bark**) of the planted areas with eucalypts

Type climate	Mean annual rainfall mm yr^{-1}	Mean annual temper. °C	Mean actual ET mm yr^{-1}	Dry season Nº months	Dry season Water deficit mm yr^{-1}	Species / hybrid	MAI $m^3\ ha^{-1}\ yr^{-1}$
Cfa, Cfb	1500 – 2500	13 – 20	500 – 800	0 – 1	0 – 50	EUG, Egr, Eur, Cci, Edu, Ebe	35 – 60
Cwb, Am	**1000 – 1800**	**18 – 20**	**800 – 1000**	**2 – 3**	**50 – 100**	**EUG, Eur**	**35 – 45**
Cwa, Aw	1000 – 1800	20 – 24	1000 – 1200	3 – 5	100 – 200	EUG, Eur, EGC, EUC, Eca, Ete	**35 – 45**

Climate type

Cwa = Subtr., humid, dry winter, hot summer

Aw = Tropical, dry winter

Genotypes (*highly drought tolerant*)

Ete = E. tereticornis;

EGC = E. grandis x camaldulensis;

EUC = E. urophylla x camaldulensis;

Eca = E. camaldulensis;

The main species and hybrids recommended for planting and expected average productivity (**roundwood with bark**) of the planted areas with eucalypts

Type climate	Mean annual rainfall mm yr^{-1}	Mean annual temper. °C	Mean actual ET mm yr^{-1}	Dry season Nº months	Dry season Water deficit mm yr^{-1}	Species / hybrid	MAI m^3 ha^{-1} yr^{-1}
Cfa, Cfb	1500 – 2500	13 – 20	500 – 800	0 – 1	0 – 50	EGU, Egr, Eur, Esa, Eci, Edu, Ebe, EUG	35 – 60
Cwb, Am	**1000 – 1800**	**18 – 20**	**800 – 1000**	**2 – 3**	**50 – 100**	**EGU, Egr, Eur**	**35 – 45**
Cwa, Aw	1000 – 1800	20 – 24	1000 – 1200	3 – 5	100 – 200	EGU, Eur, EGC, EUC, Eca, Ete	35 – 45
Aw	**1000 – 2000**	**24 - 26**	**1100 - 1500**	**5 – 7**	**200 – 400**	**EGC, EUC, ETB, Eca, Ete, Ebr, EUT**	**25 - 35**
As, BSh	700 - 1500	23 - 27	600 - 1000	> 7	> 400	planting is not feasible	

2. Application of fertilizers

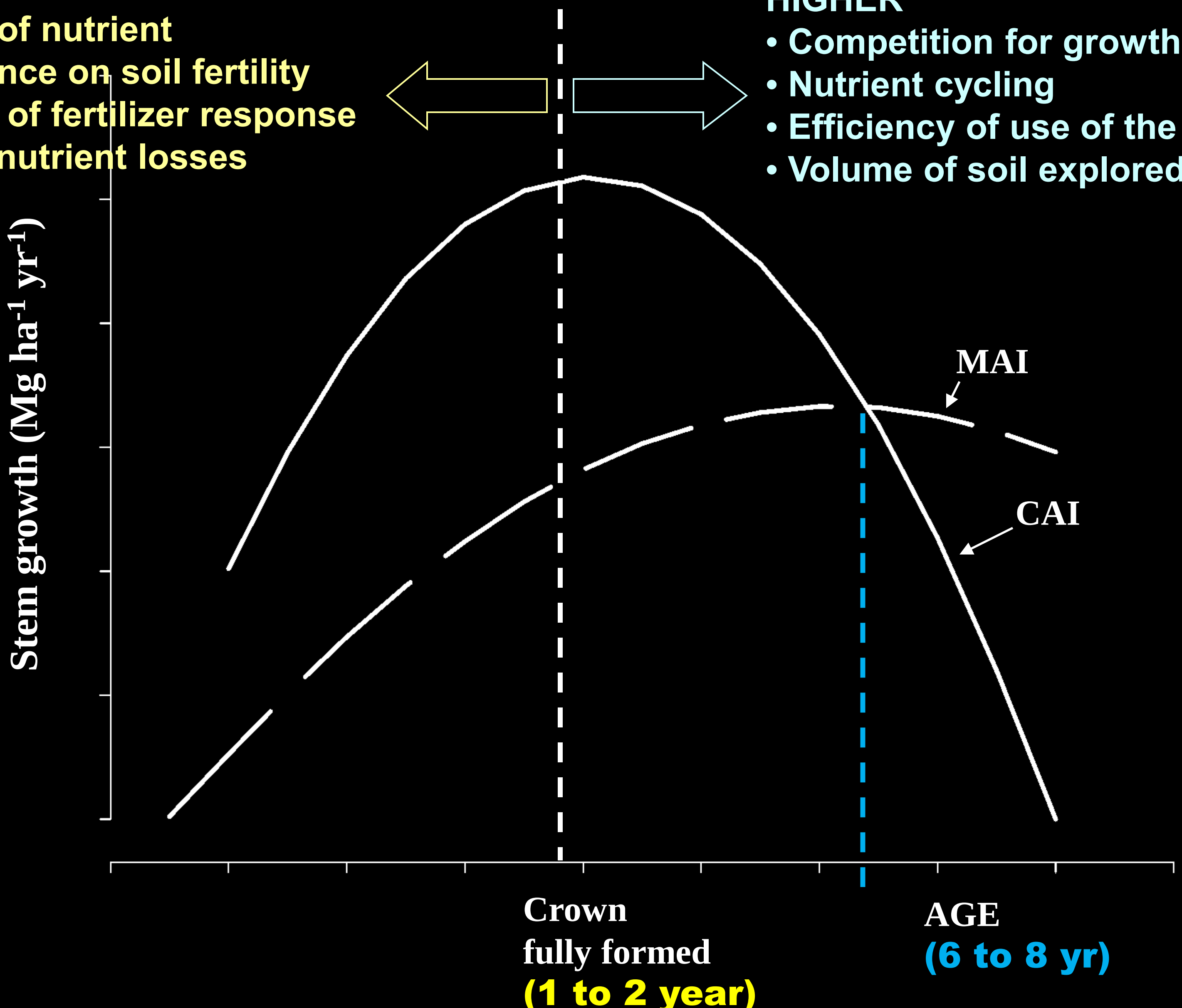
There are significant yield gains in response to fertilization in most eucalypt plantations in Brazil;

Gains in productivity attributed to mineral fertilizers are quite variable and high, but in general , they represent **at least 30% to 50% on average**;

Especially in soils with low fertility, continuous nutrient removal by crops consecutively increases the potential response to fertilizer application;

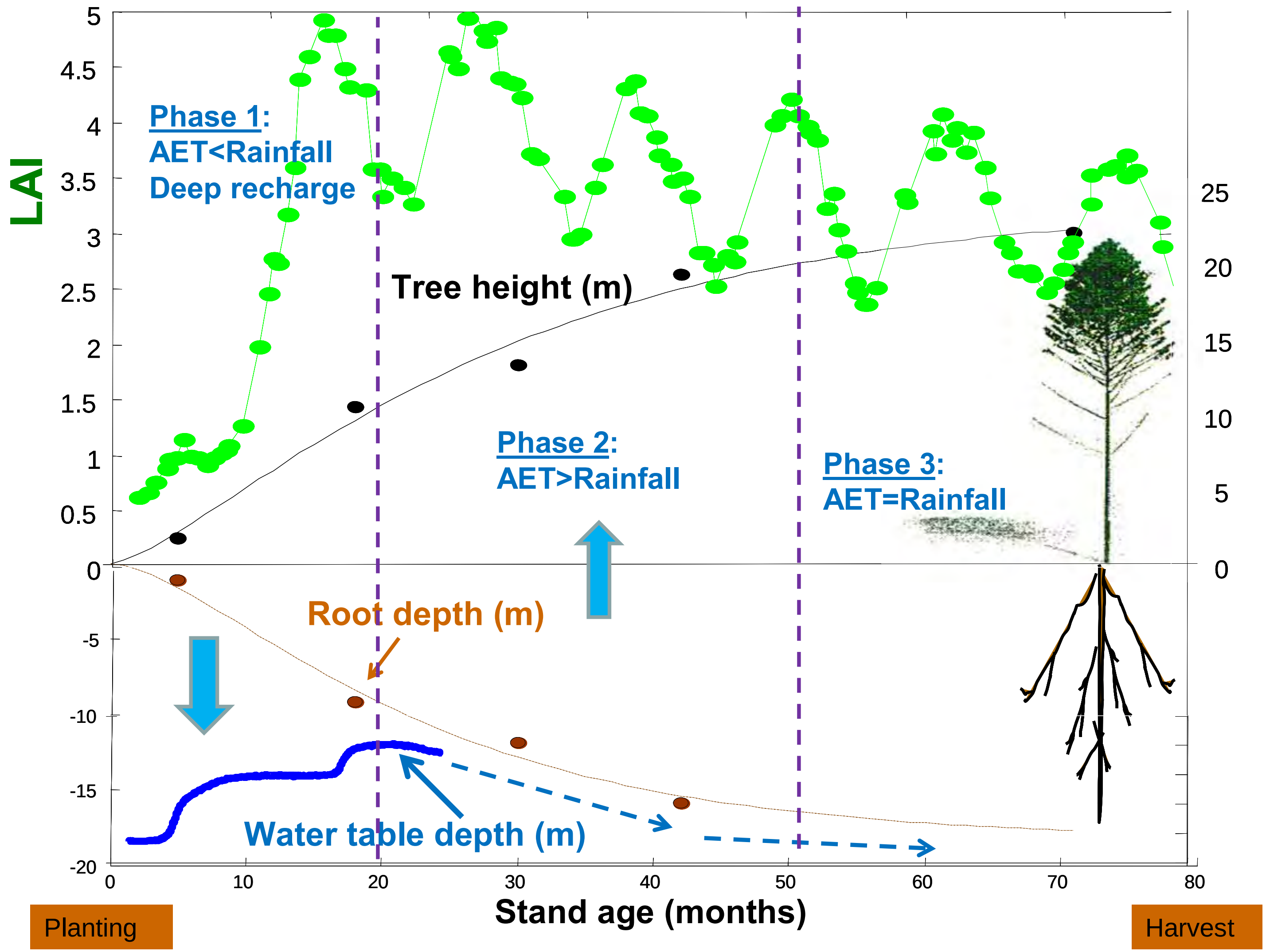
HIGHER
- Demand of nutrient
- Dependence on soil fertility
- Potential of fertilizer response
- Risks of nutrient losses

HIGHER
- Competition for growth factors
- Nutrient cycling
- Efficiency of use of the nutrients
- Volume of soil explored by roots



Nutritional stages of a forest stand as it develop

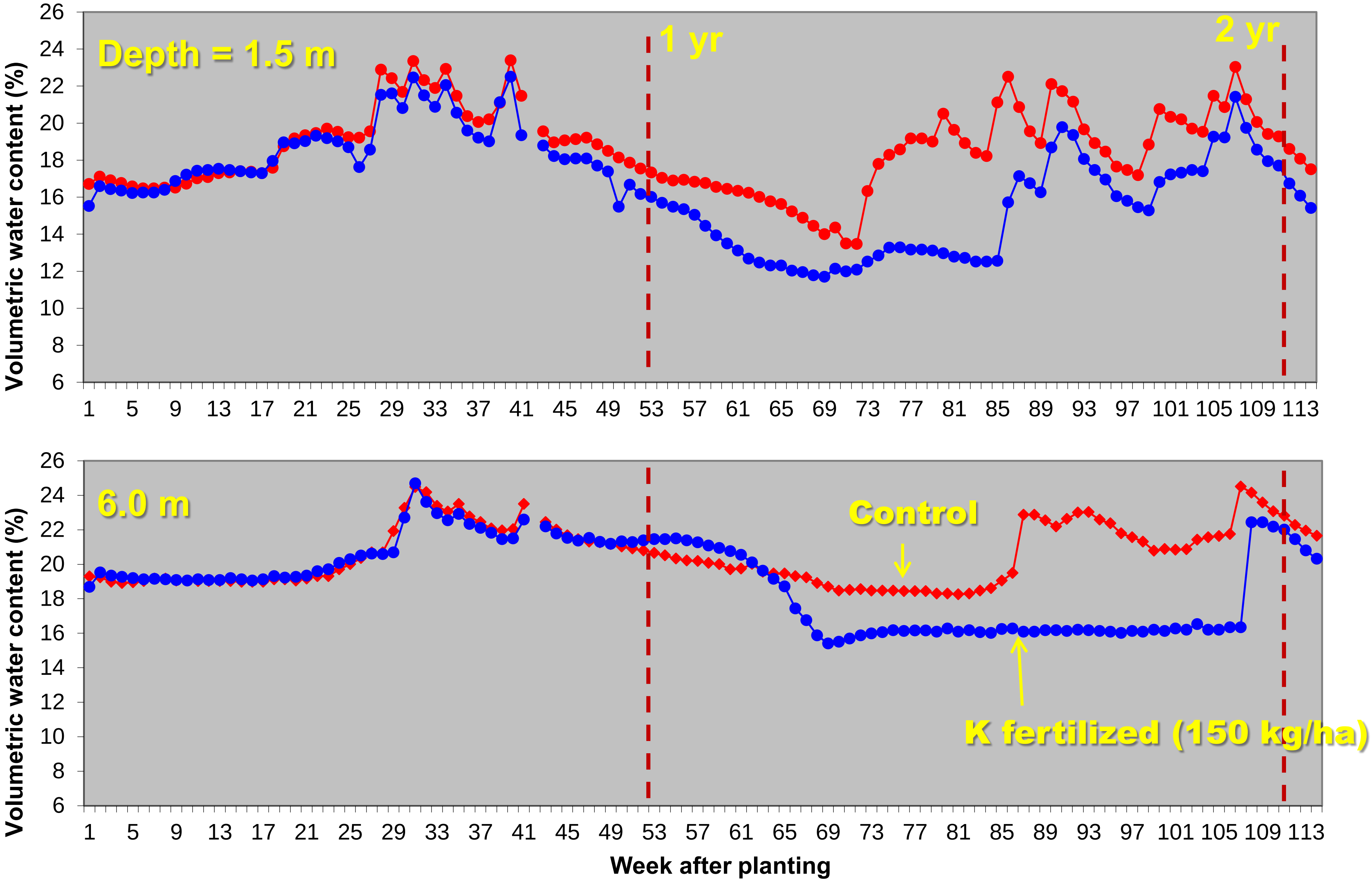
A very dynamic water balance troughout the rotation



Laclau et al. (2012)

E. grandis

Loamy oxisol (20% clay)



Laclau et al. (2012)

Phosphorus Fertilization

Application of P Fertilizer at planting

- ✓ Low soluble Sources (whole rate)
  - low risk of leaching
- ✓ Part of N and K application (as a starter)


Fertilizers more common
4-28-6 (MAP, KCl)
6-30-6 (idem)

Lateral little pits
(Clayey soils)

Prevent

- Leaching
- Fixing
- Weed competition

High precision of application

High operational yield

Continuous bead planting line
(Loamy and Sandy soils)

layer 0-20 cm

Clay Content	**P-resin (mg kg^{-1})**				**Exchangeable K ($cmol_c$ kg^{-1})**		
(%)	**0-2**	**3-5**	**6-8**	**> 8**	**0 – 0.08**	**0,09 – 0.18**	**> 0.18**
	Rate of P_2O_5 (kg ha^{-1})				**Rate of K_2O (kg ha^{-1})**		
< *15*	40	40	10-20	10-20	100	40	10-20
15-35	50	40	30	10-20	120	60	10-20
> *35*	70	50	30	10-20	120	60	10-20

Gonçalves et al. (2011)

Seedling little or no strained

Nitrogen and Potassium Fertilization

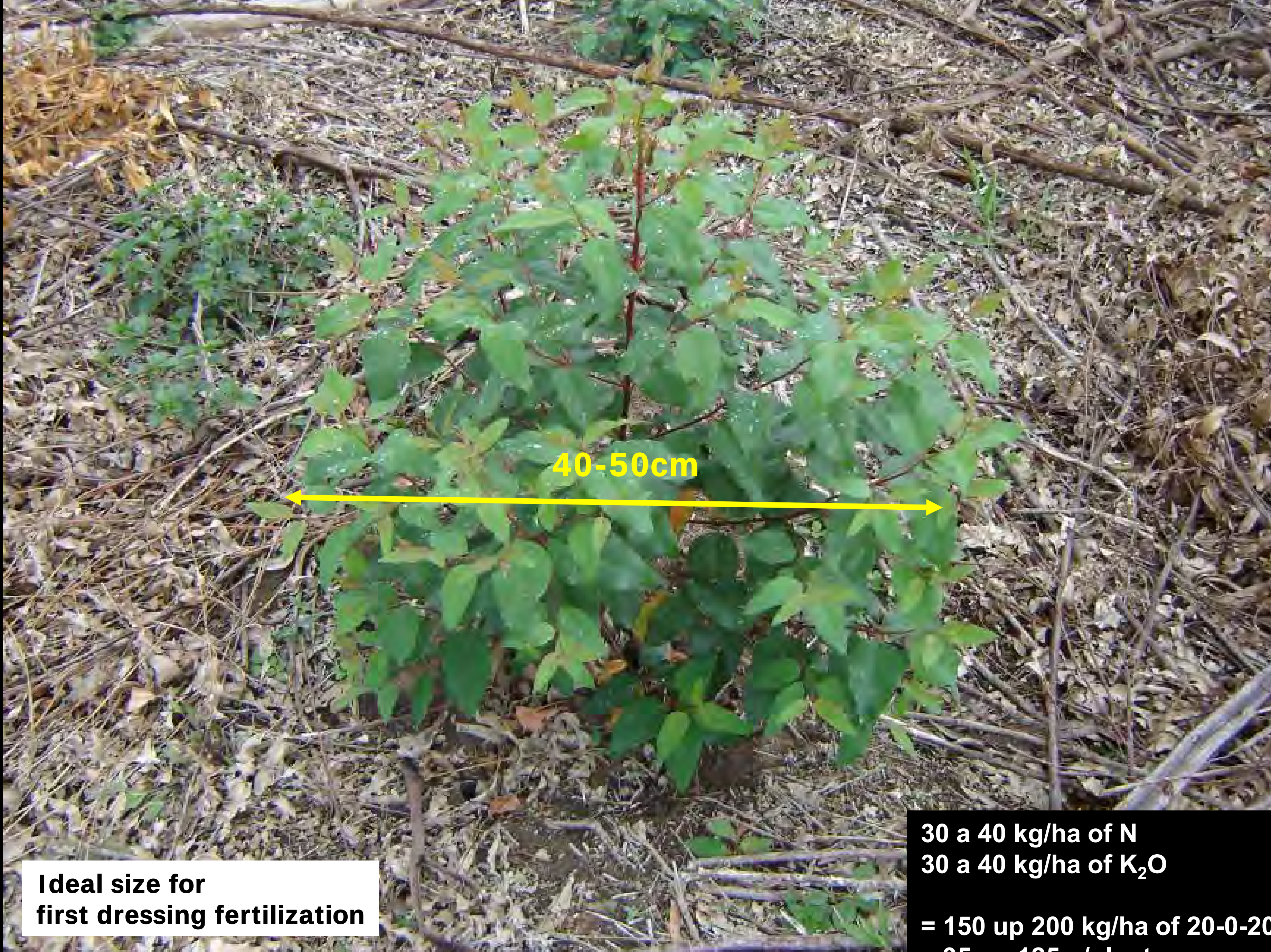
Dressing Fertilization

- ✓ Highly soluble Sources (split 2 or 3 times)
- ✓ N, K and B (according to rhythm of crown and root formation)

N fertilizer prescription

Soil layer 0-20 cm

SOM (g kg^{-1})	Rate of N (kg ha^{-1})
0 - 20	60
21 - 50	40
> 50	20



Ideal size for first dressing fertilization

30 a 40 kg/ha of N
30 a 40 kg/ha of K_2O

= 150 up 200 kg/ha of 20-0-20
= 95 up 125 g/plant


Ideal size for
second dressing fertilization

At this stage

Increase competition for light and water

✓ low fertilizer response

3. Site Preparation

Old Technology

(1960 to 1980)

Eucalyptus

Biomass pre-burn: 20-45 t ha^{-1}

post-burn: 85-90% less

N: 200-310 kg ha^{-1}

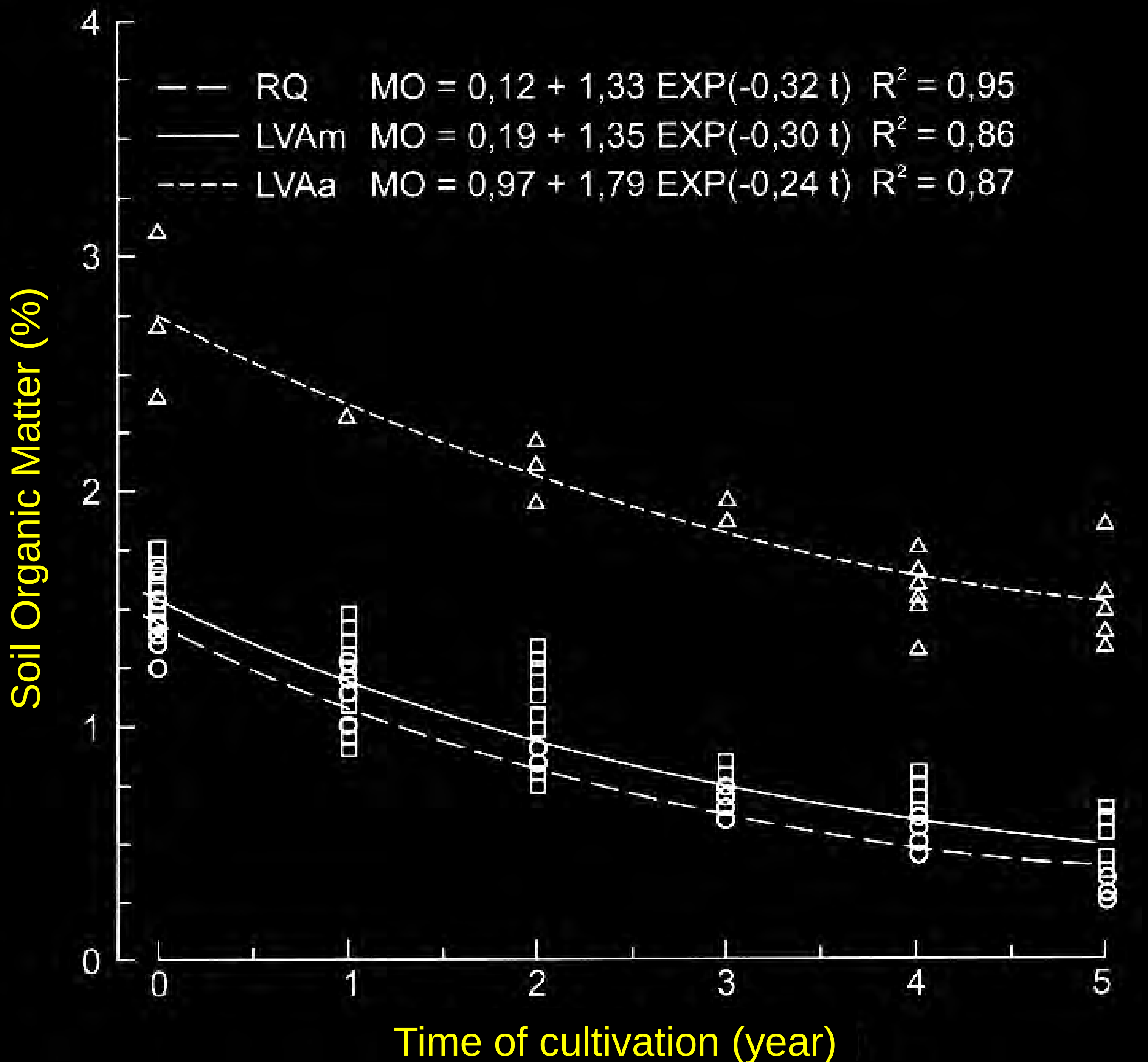
85-90% less

P: 25-35 kg ha^{-1}

35-60% less

Bedding

Native vegetation: savanna (“Cerrado”)
Intensive tillage: plowing and harrowing



Silva et al. (1994)

“MINIMUM CULTIVATION”

New technology (since 1988)

- Established in Brazil in the late eighties.
- Currently, about 90% of the plantations are established in this system.

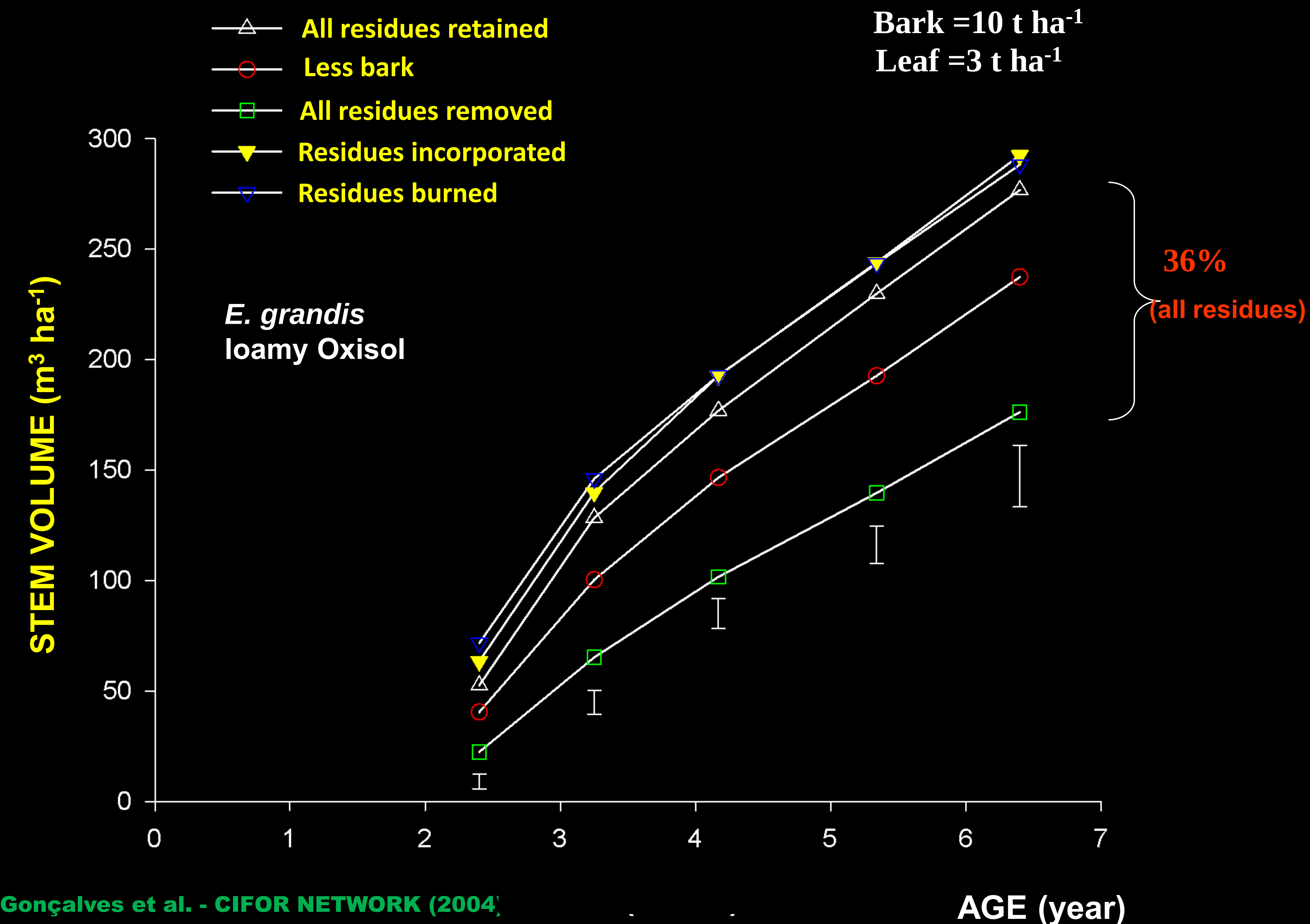
3.1 Maintenance of plant residues on the Soil

(litter layer and harvest residues)

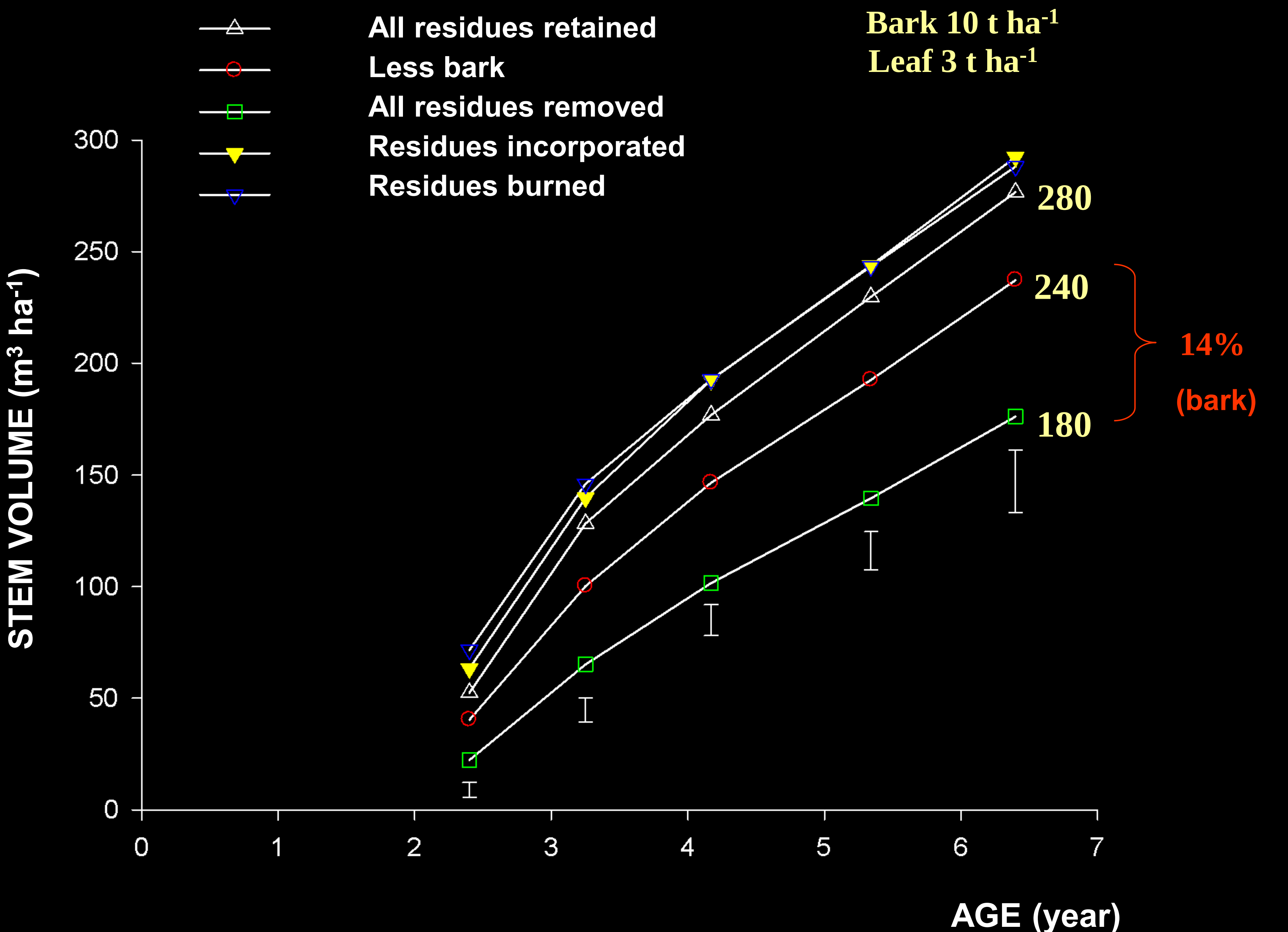
Residue retention after harvesting

Removal of residues in the planting strip before subsoiling


Oxisol, clay (50%)



Gonçalves et al. - CIFOR NETWORK (2004)


All residues retained
Less bark
All residues removed
Residues incorporated
Residues burned
Bark 10 t ha-1
Leaf 3 t ha-1
280
240
180
14%
(bark)
STEM VOLUME (m3 ha-1)
AGE (year)
0
50
100
150
200
250
300
0
1
2
3
4
5
6
7

60 months of age

Causal Effect	Volume Reduction %		
leaf + branch)	12	21	
bark	8		
litter	1		
N	4	53	← High nutrient deficiency
P	13		
K	31		
Lime	5		

3.2 Soil Preparation

Limited at planting rows

- **Subsoiling**
- **Pit digging**

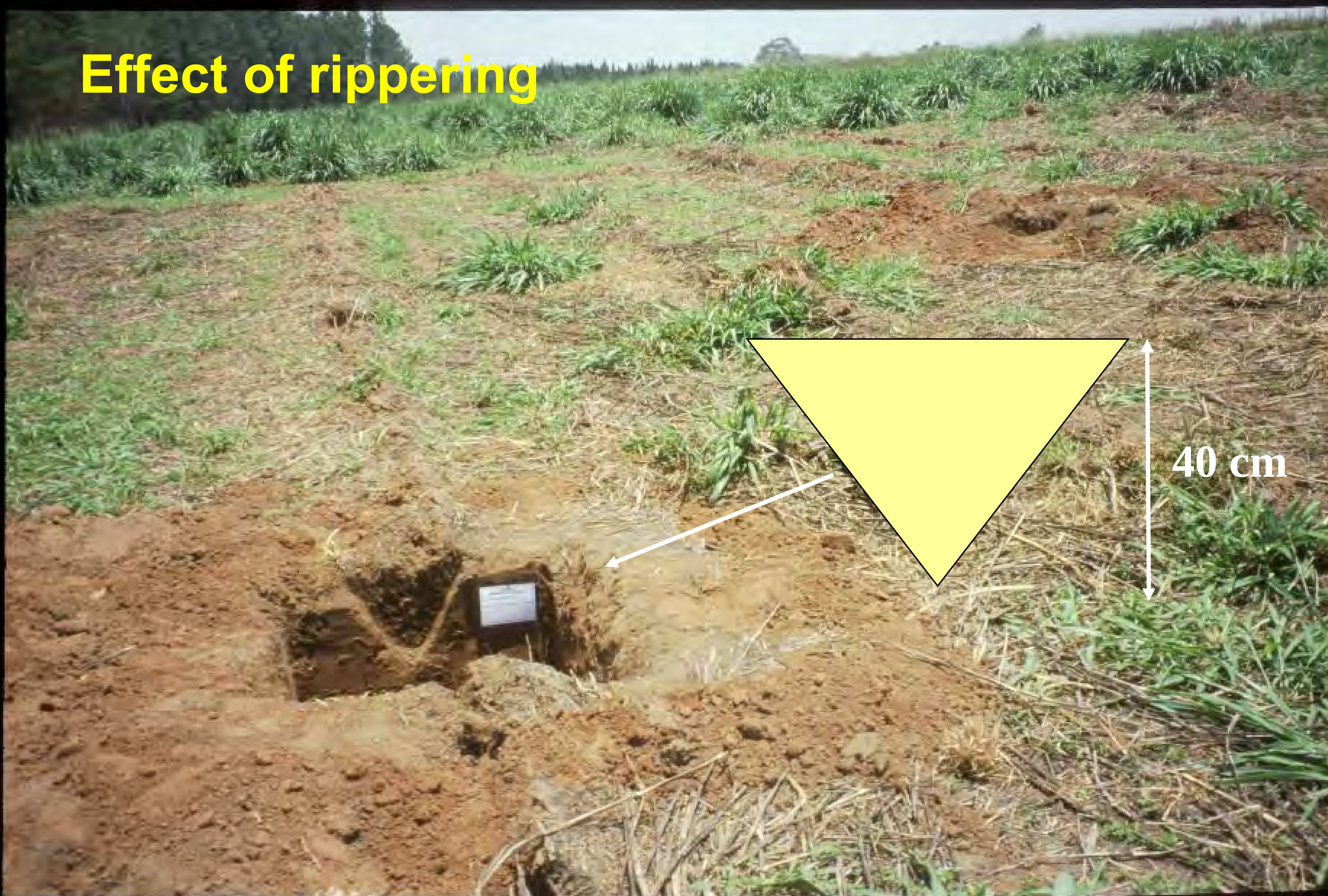
Soil Preparation

1) Areas with

- Low to medium water deficit
- Friable soils


Yield = 1.5 h ha^{-1}
Subsoiler (= Ripper)
29 3 2004


planting row
1 m
29 3 2004

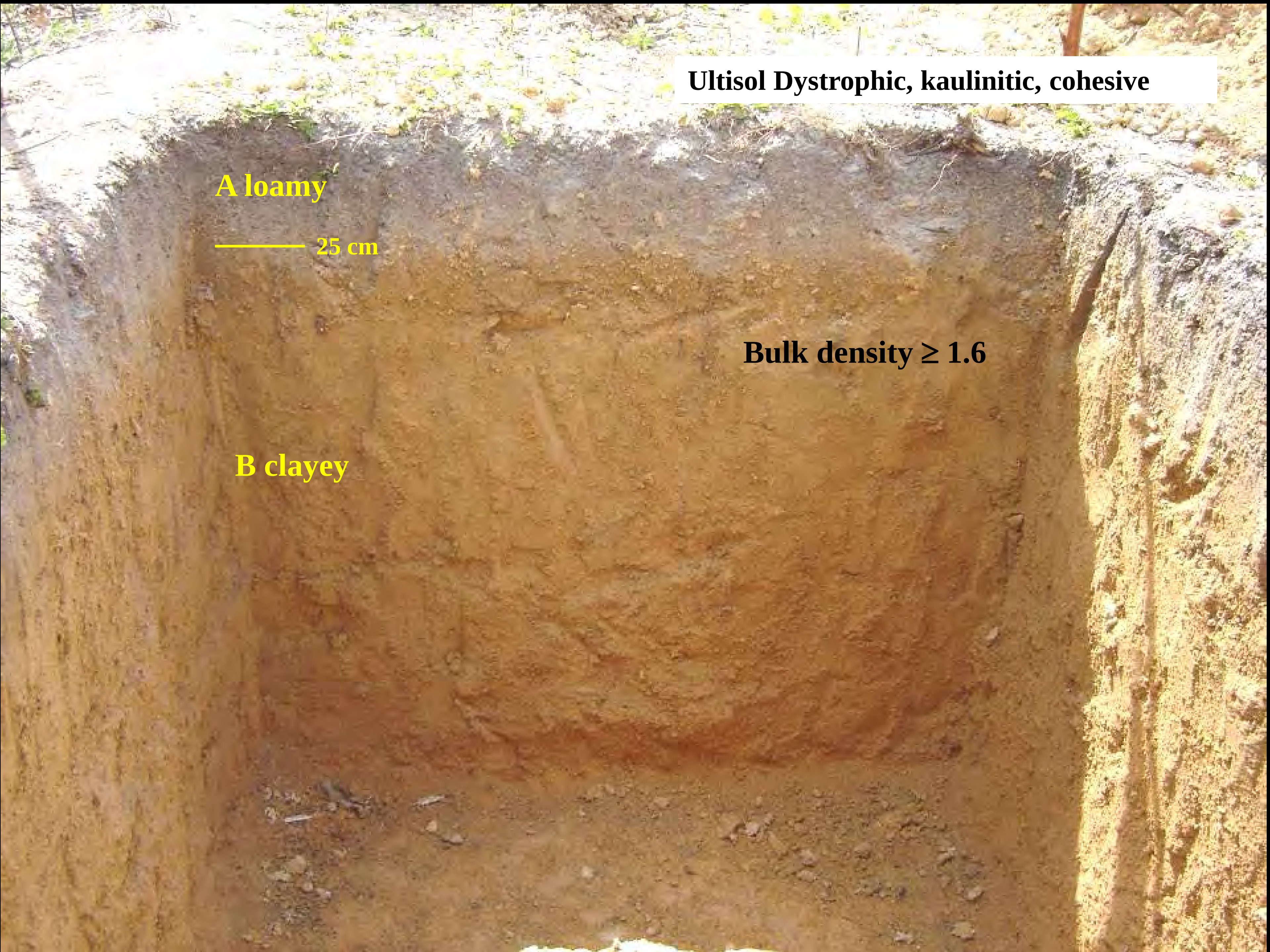

Effect of rippering
40 cm


INCLUIR PROF E LARGURA

Soil Preparation

2) Areas with

- High water deficit
- Cohesive soils


Ultisol Dystrophic, kaulinitic, cohesive
A loamy
25 cm
Bulk density ≥ 1.6
B clayey


CATERPILLAR
Heavy machine
Riperring at 80-100 cm

Soil structure: cohesive

Bulk density: ≥ 1.6 g cm^{-3} (predominantly clay)

Drought: severe (5 to 7 months per year)


Crown helps to carry
the rainfall
Higher infiltration
Soil Volume Per Tree
• 1.5 m³/tree
• Spacing: 3 x 2m
Low infiltration
Ds = 1.6

Final Considerations

1

The Brazilian experience has shown that despite repeated short-rotation cropping, continuous gains in productivity of eucalypts are possible. The increase rate has been steady for over 40 years, indicating the large-scale productivity gain through improved genotype and silviculture.

2

Across a range of sites, the maintenance of crop residues has been found be a key management factor that significantly influences soil fertility and plant nutrition and site quality.

3

Replacing nutrients removed in harvest are key elements of sustaining site productivity.

4

Measurements of yield in successive rotations suggest, so far, there is no widespread evidence that plantation forestry is unsustainable in narrow sense. In the few cases where yield decline has been reported poor silvicultural practices appear largely responsible.

Thank You