O Uso da Agua e a Produtividade de Clones de *Eucalyptus* no Brasil

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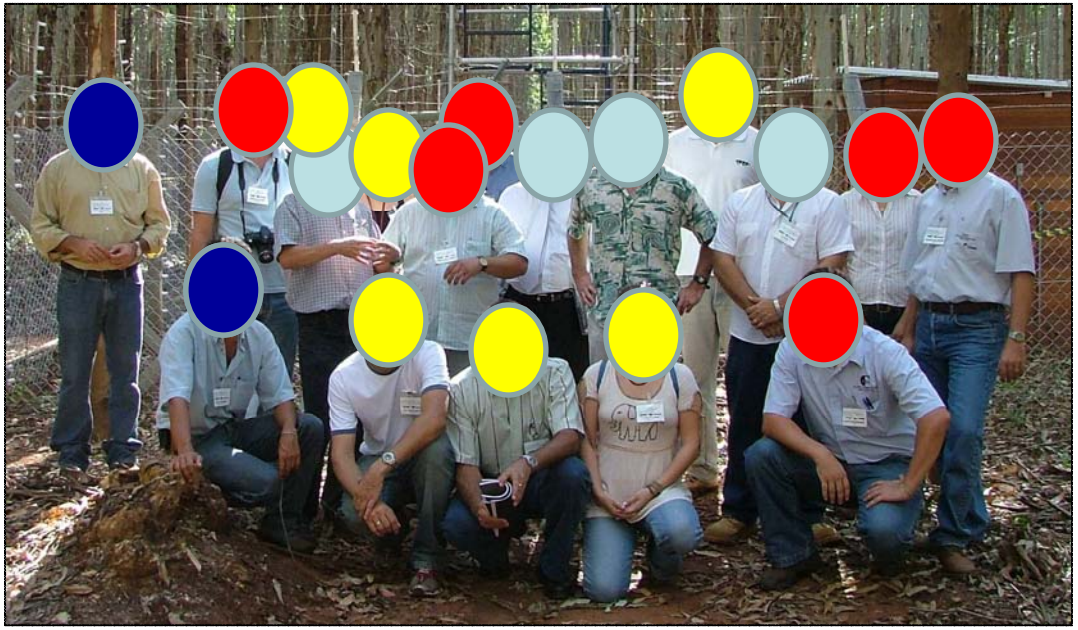
2º Seminário de Recursos Hídricos da Bacia do Paraíba do Sul: Recuperação de Áreas Degradadas, Serviçoos Ambientais e Sustentabilidade

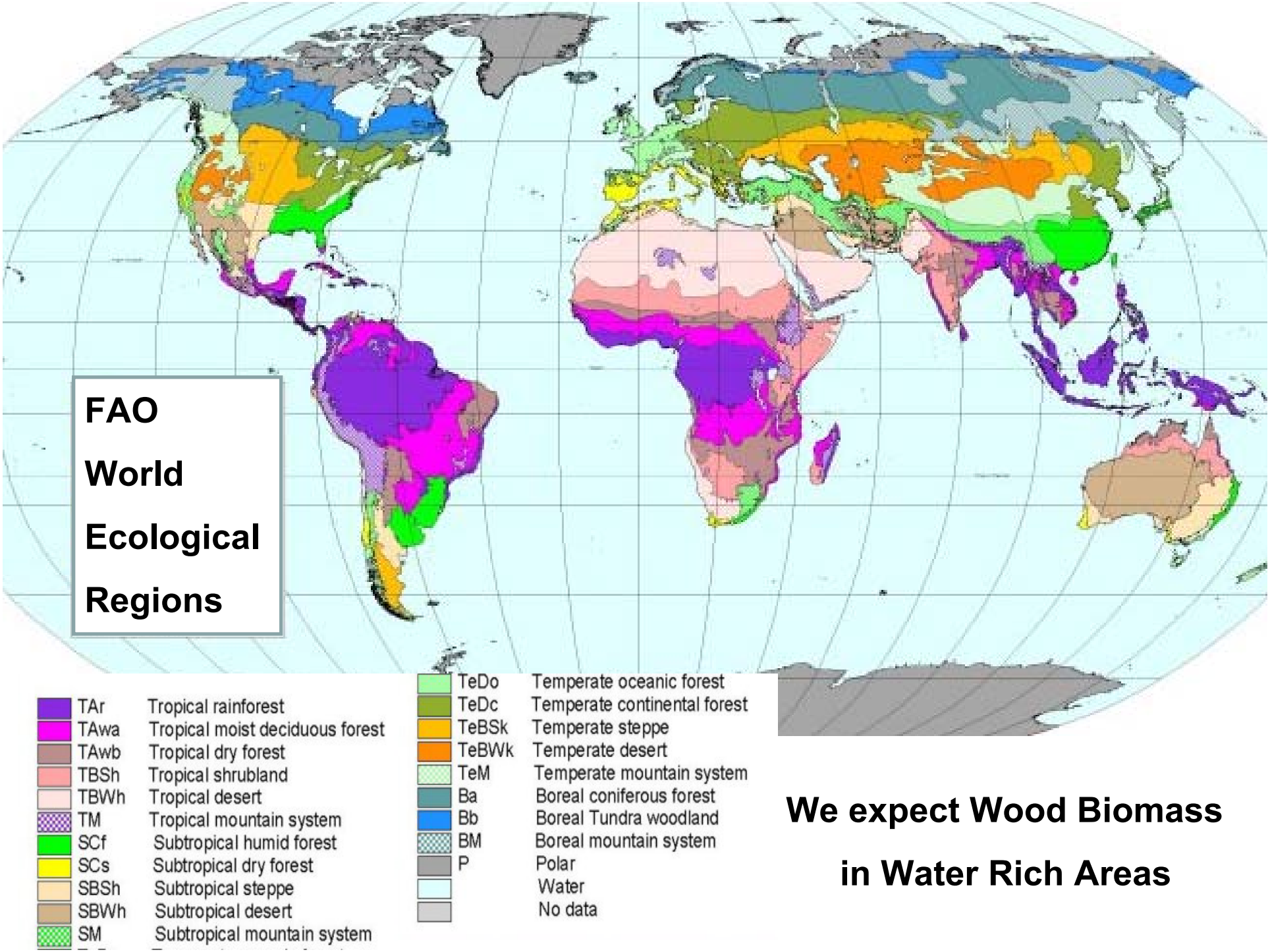
Taubaté - SP, Brasil - Dezembro de 2009



Dan Binkley
Mike Ryan
Robert Hubbard
Yann Nouvellon
Jean-Paul Laclau
Jose Leonardo Goncalves
....
....
....
BEPP and Eucflux Groups

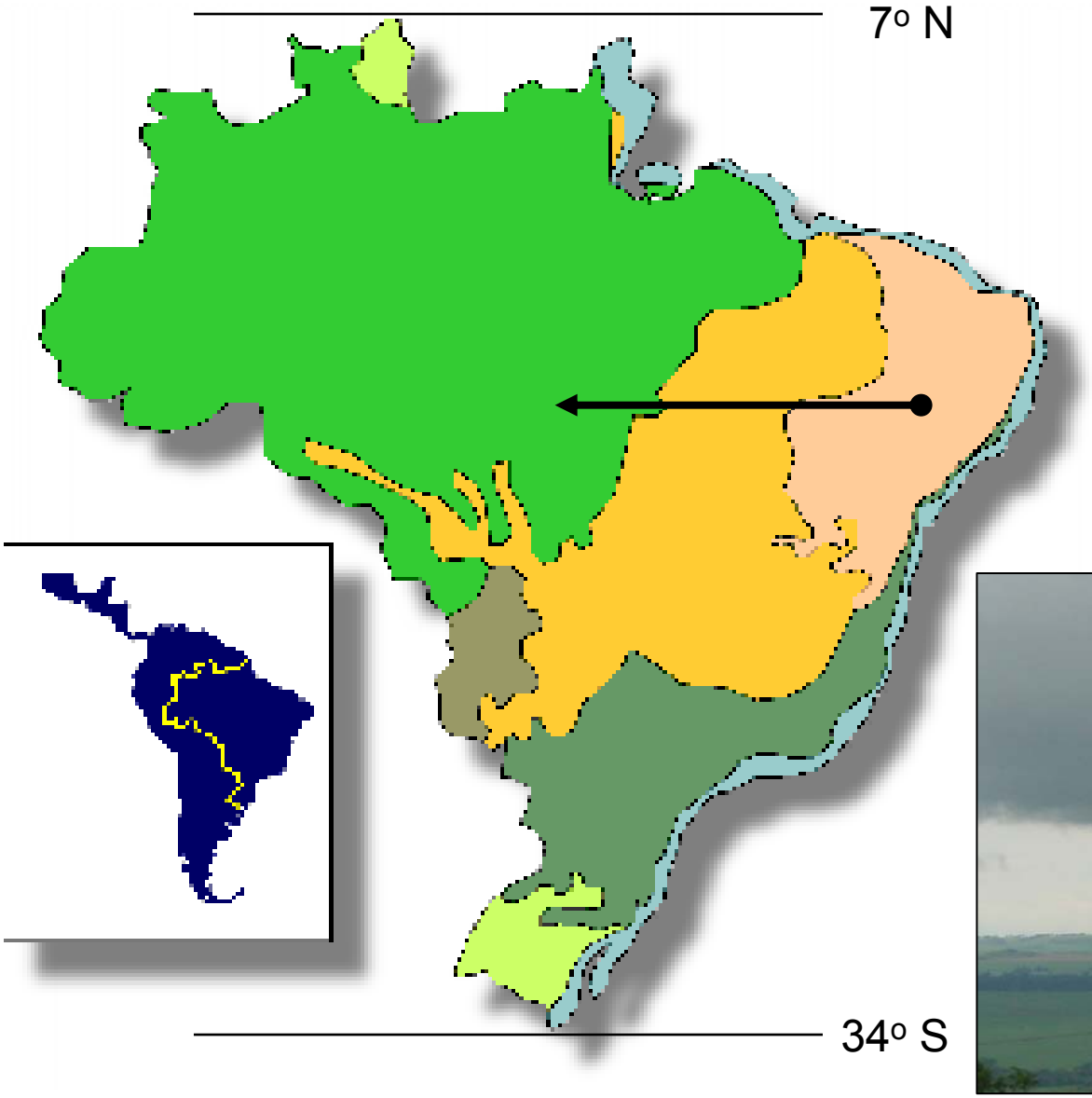
Topics

- Water Use and WUE in Natural Systems
- WU and WUE in *Eucalyptus* Plantations
  . BEPP Project: Leaf, Tree and Stand Level
  . Eucflux Projet: Landscape Level
- Management Implications
- Future Projects Needed



We expect Wood Biomass in Water Rich Areas

Hidrology and Natural Ecosystems in Brazil



Semi-Arid

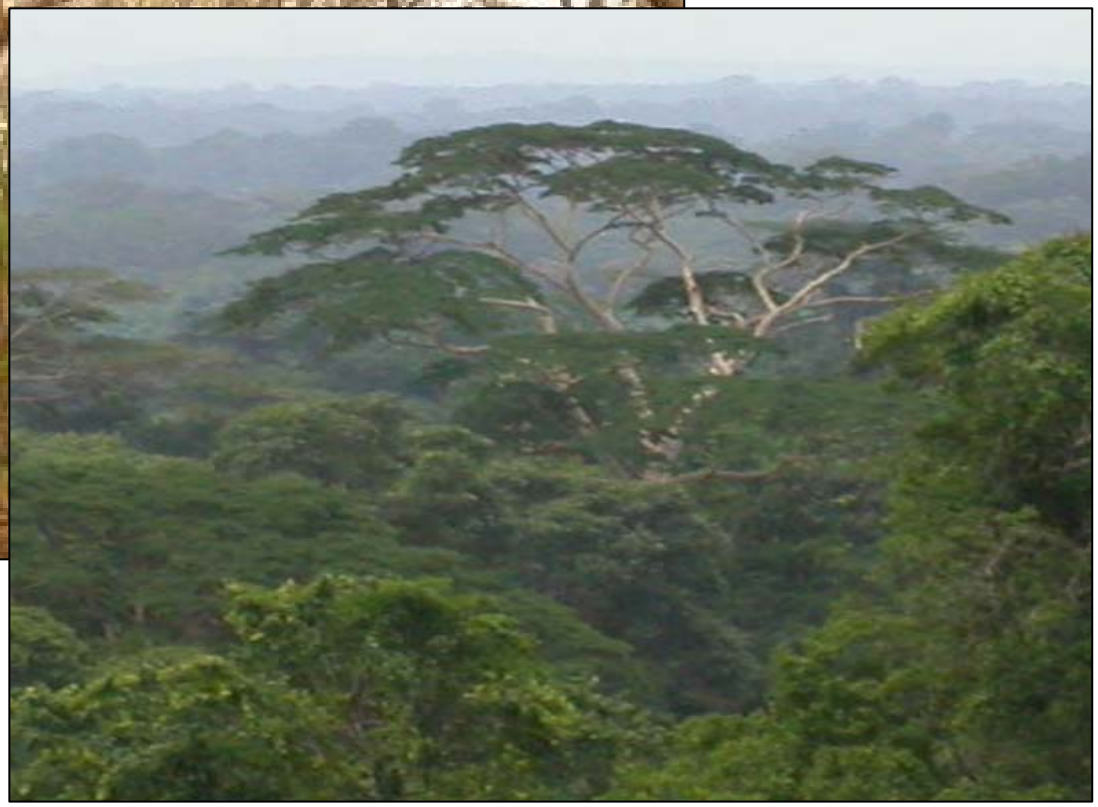
Savana

Amazon

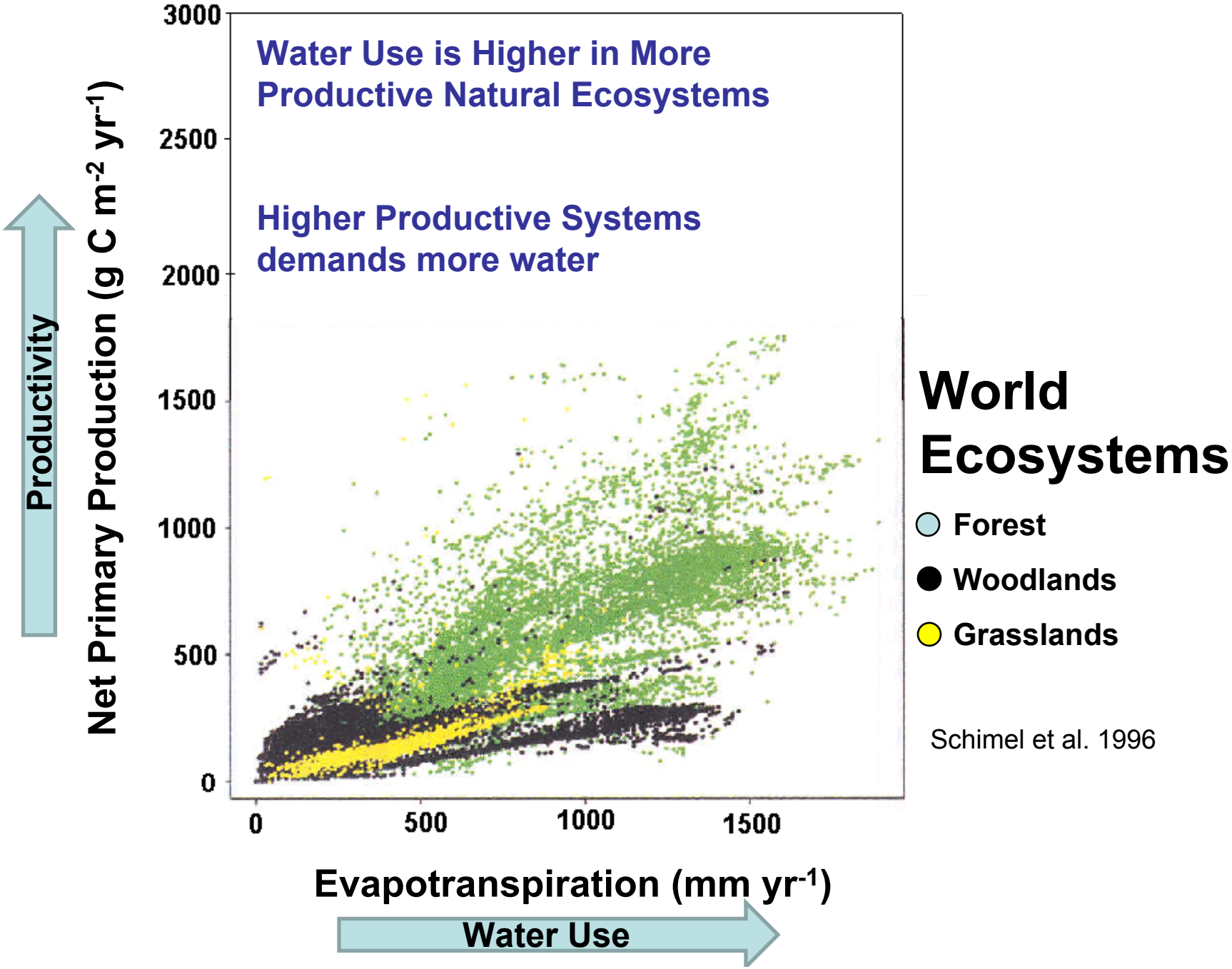
Hidrology and Natural Ecosystems in Brazil

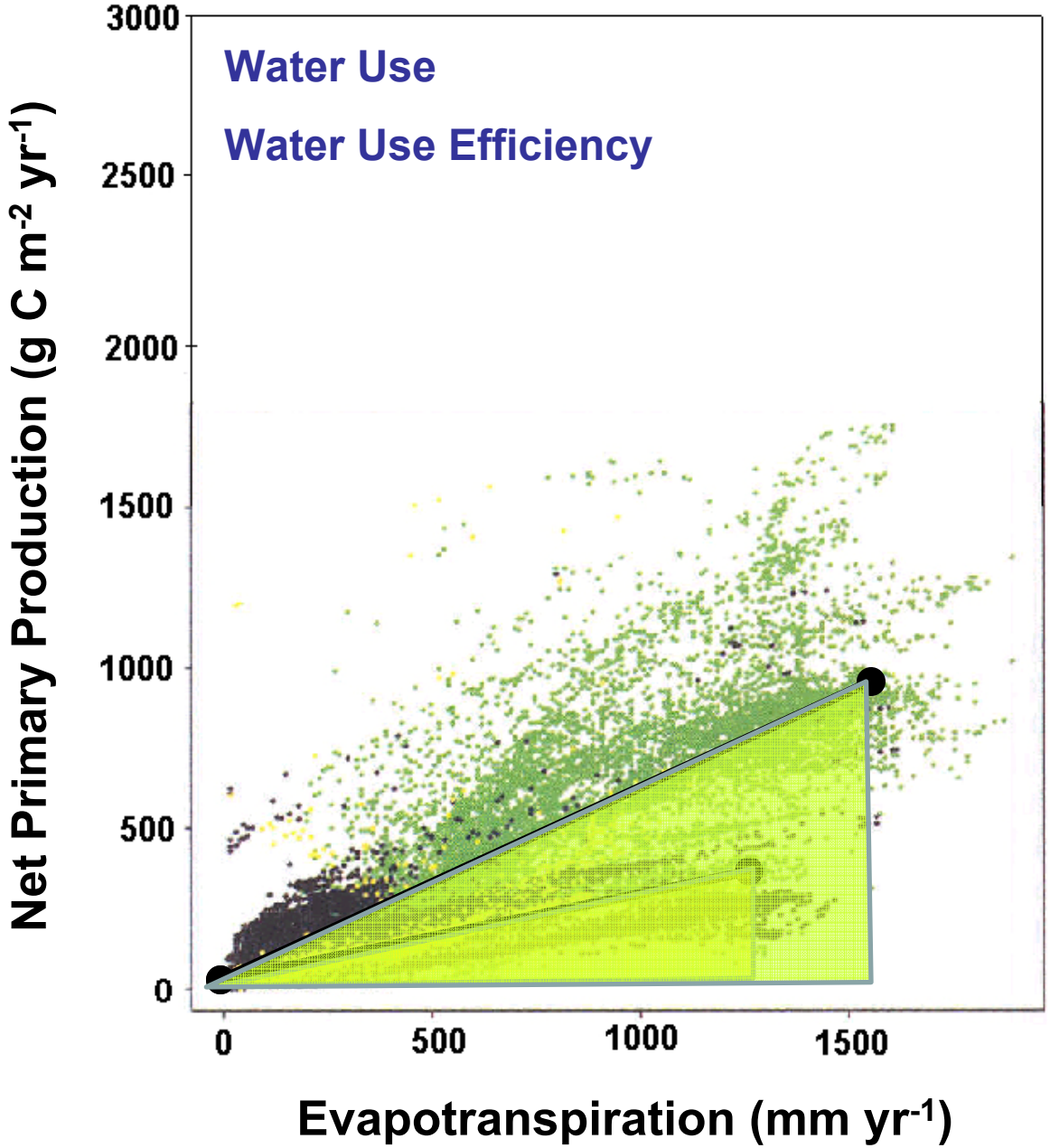
700 mm/yr

1100 mm/yr



1900 mm/yr


Water Use is Higher in More Productive Natural Ecosystems
Higher Productive Systems demands more water
Productivity
Net Primary Production (g C m-2 yr-1)
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
Evapotranspiration (mm yr-1)
Water Use
World Ecosystems
Forest
Woodlands
Grasslands
Schimel et al. 1996



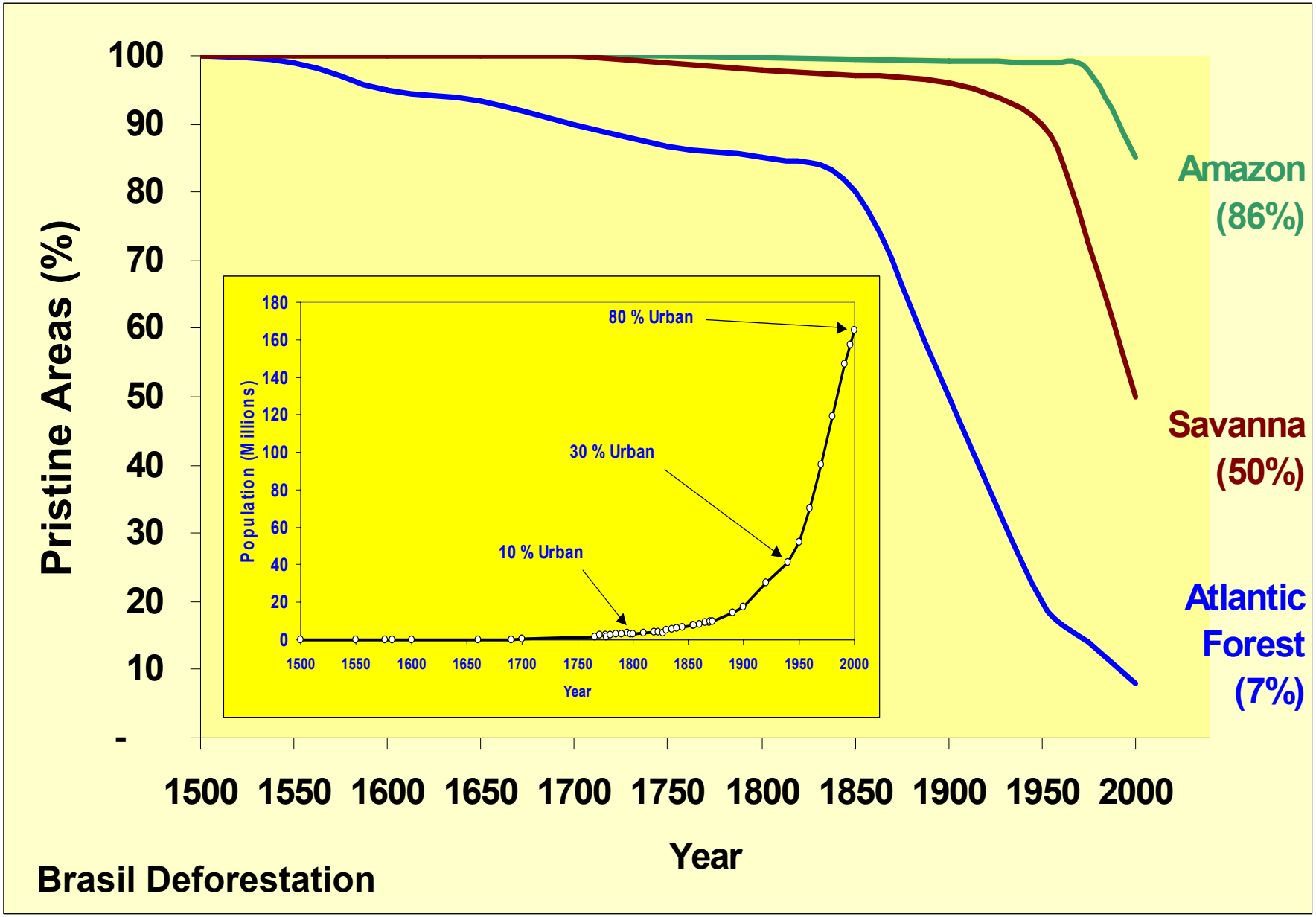
More productive systems use more water but…they are more efficient in using it (WUE)

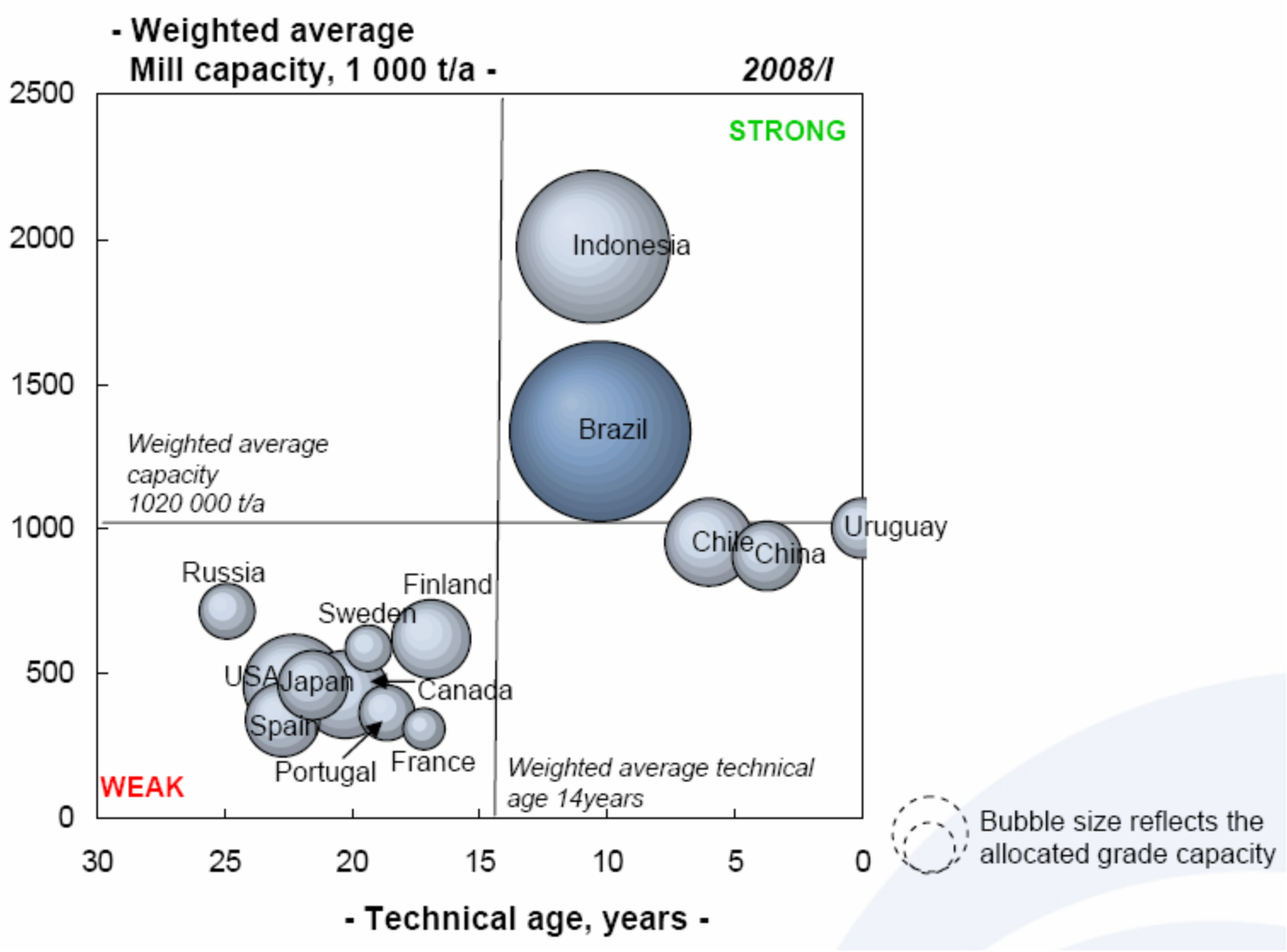
Forest = 0.8 kg/m^3

Savana = 0.2 kg/m^3

So, for a Fix amount of Wood, between the two, more land and water is needed for a Savana System

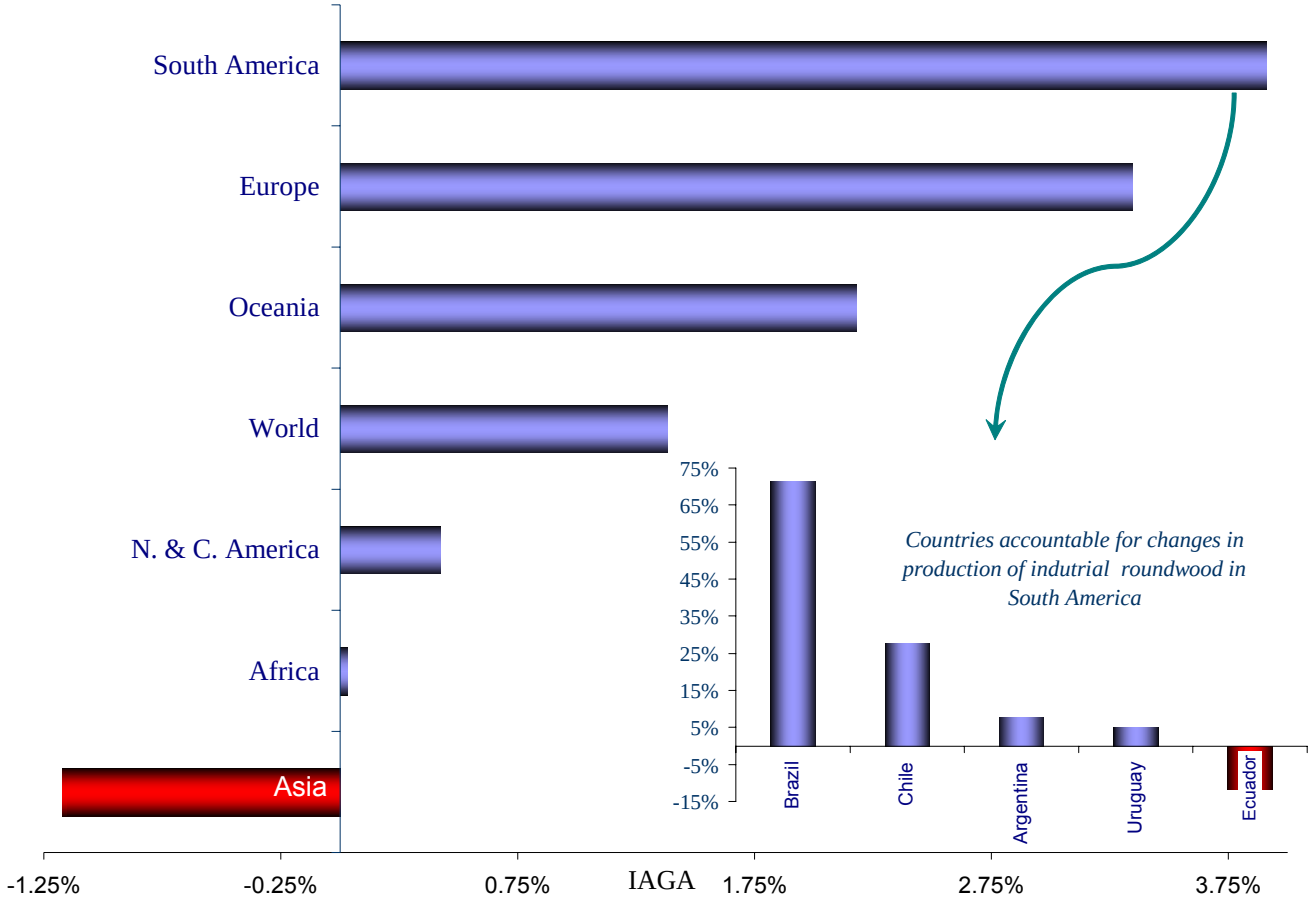
Reducing Wood Supply from Natural Ecosytems



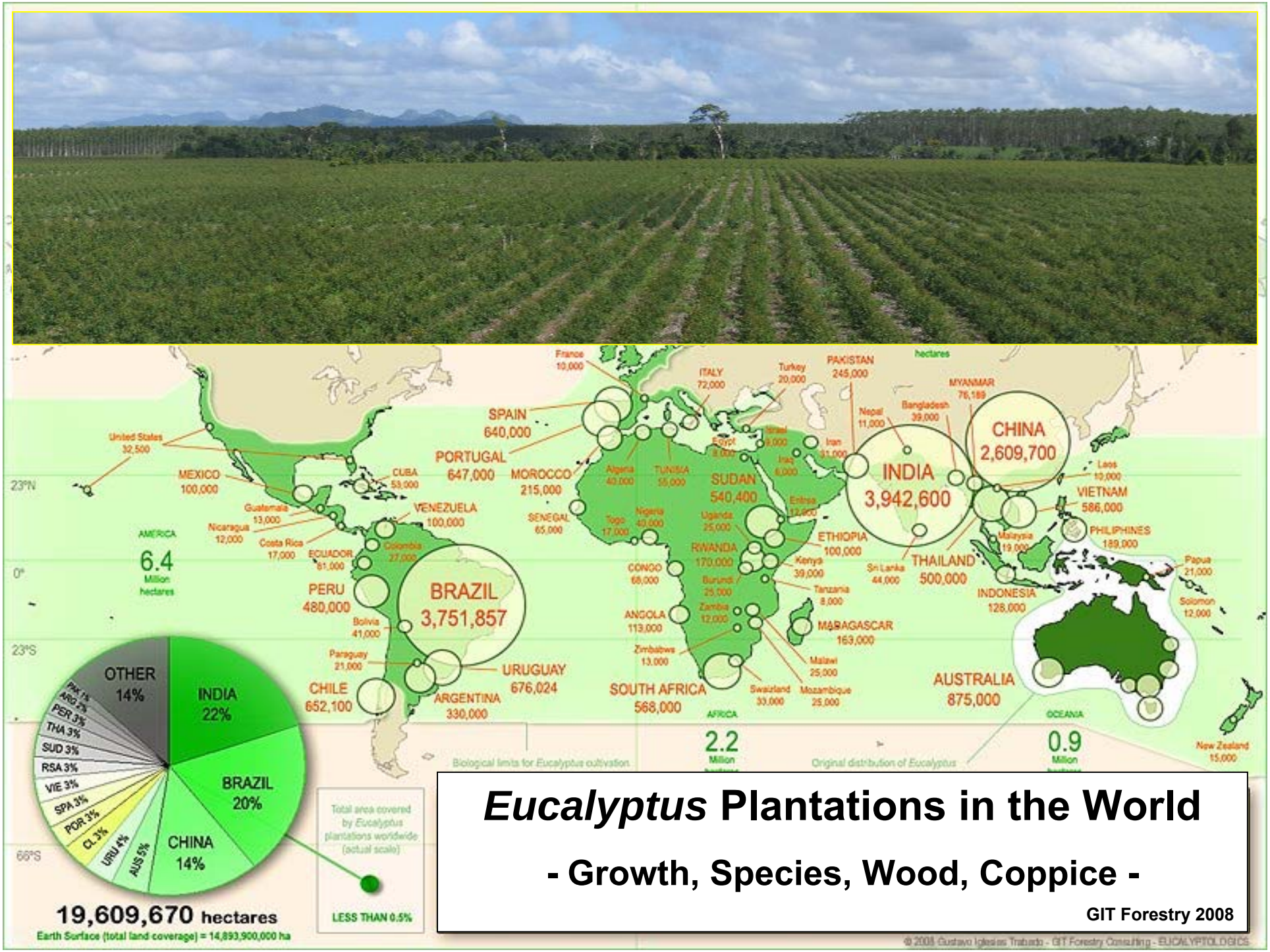

- Weighted average
Mill capacity, 1 000 t/a -
2008/I
STRONG
WEAK
Indonesia
Brazil
Chile
China
Uruguay
Russia
Finland
Sweden
USA
Japan
Canada
Spain
Portugal
France
Weighted average capacity 1020 000 t/a
Weighted average technical age 14years
2500
2000
1500
1000
500
0
30
25
20
15
10
5
0
- Technical age, years -
Bubble size reflects the allocated grade capacity

Poyry 2008

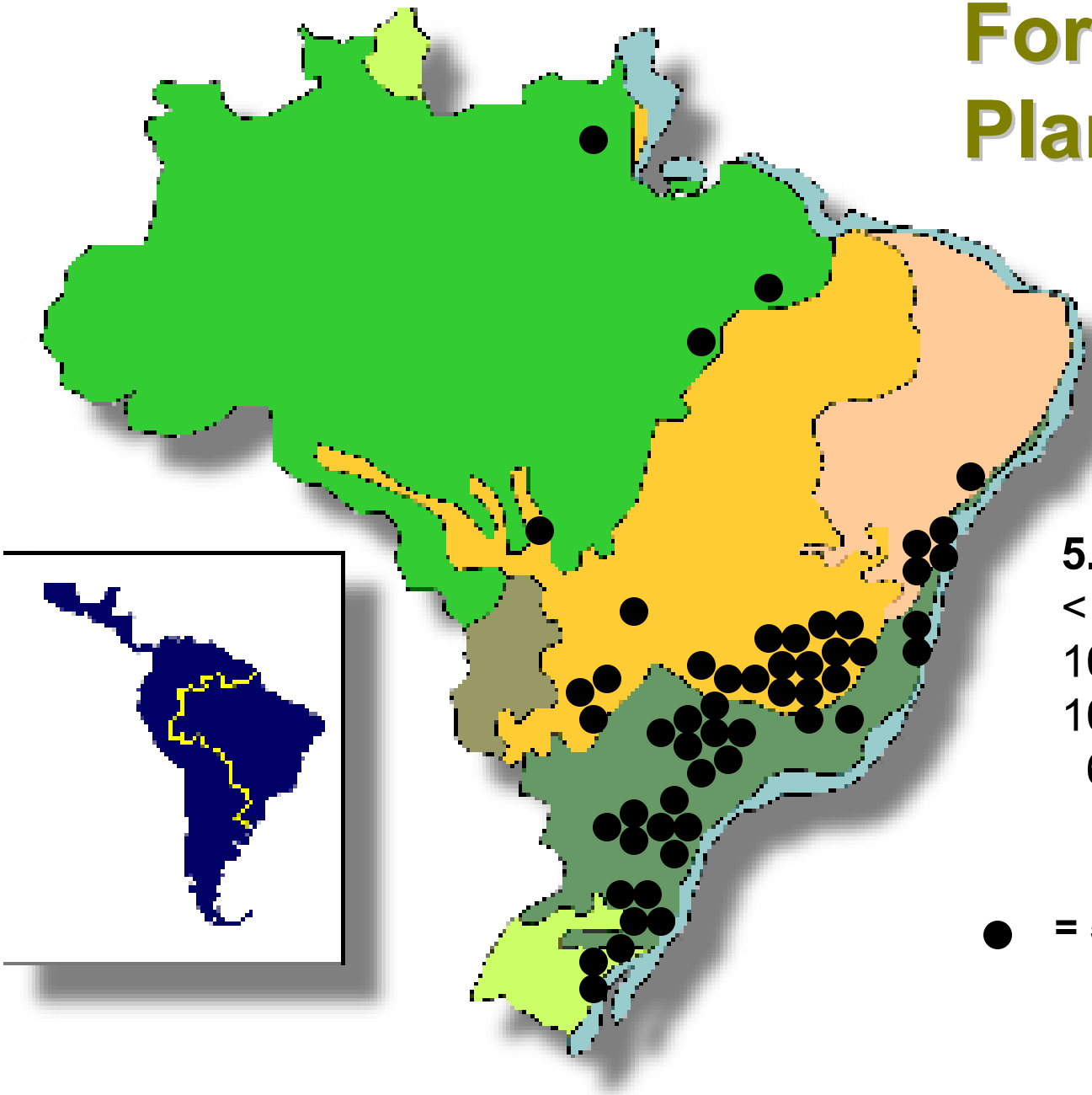
Annual Increase in Production by Region (%)



Source: Gonzalez et al. 2008, NCSU, from FAO 2007


Eucalyptus Plantations in the World
- Growth, Species, Wood, Coppice -
GIT Forestry 2008
19,609,670 hectares
Earth Surface (total land coverage) = 14,893,900,000 ha
OTHER 14%
INDIA 22%
BRAZIL 20%
CHINA 14%
AUS 5%
URU 4%
CL 3%
POR 3%
SPA 3%
VIE 3%
RSA 3%
SUD 3%
THA 3%
PER 3%
ARG 2%
PAK 1%
Total area covered by Eucalyptus plantations worldwide (actual scale)
LESS THAN 0.5%
AMERICA
6.4
Million hectares
AFRICA
2.2
Million
OCEANIA
0.9
Million
BRAZIL 3,751,857
CHINA 2,609,700
INDIA 3,942,600
AUSTRALIA 875,000
SPAIN 640,000
PORTUGAL 647,000
MOROCCO 215,000
SUDAN 540,400
PERU 480,000
CHILE 652,100
URUGUAY 676,024
ARGENTINA 330,000
SOUTH AFRICA 568,000
ANGOLA 113,000
RWANDA 170,000
ETHIOPIA 100,000
MADAGASCAR 163,000
THAILAND 500,000
VIETNAM 586,000
PHILIPHINES 189,000
INDONESIA 128,000
PAKISTAN 245,000
MEXICO 100,000
VENEZUELA 100,000
United States 32,500
Biological limits for Eucalyptus cultivation
Original distribution of Eucalyptus
© 2008 Gustavo Iglesias Trabado - GIT Forestry Consulting - EUCALYPTOLOGICS

Forest Plantations

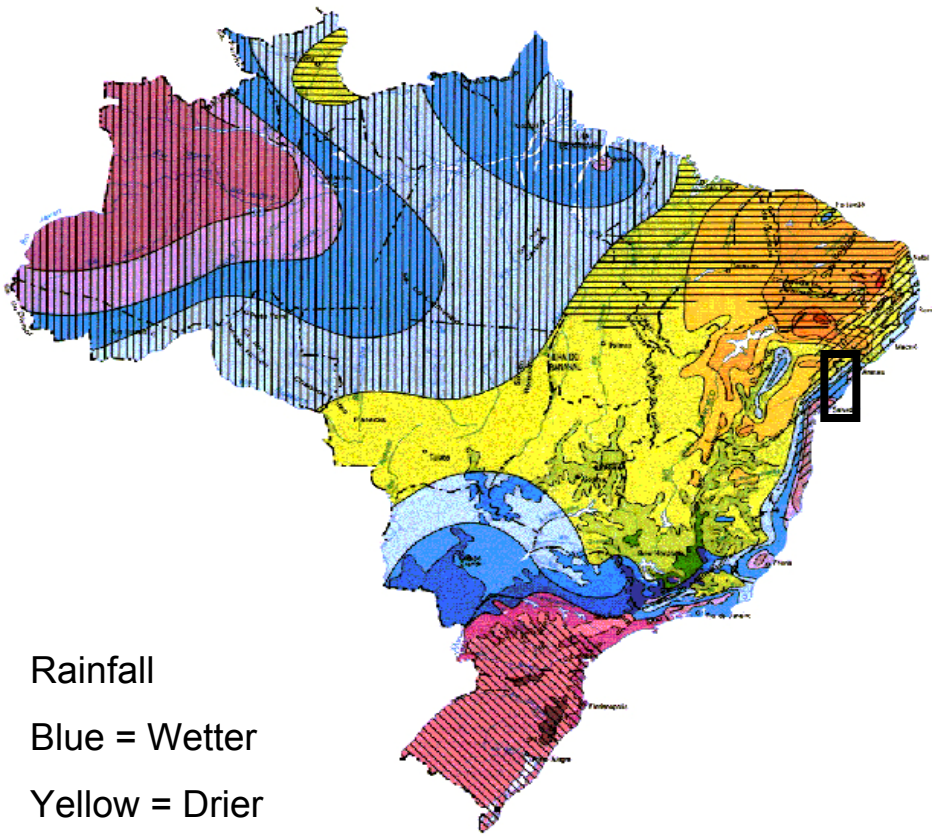


5.7 Millions ha
< 0.5% Land Use
100 % Pulp & Paper
100 % MDF
60 % Charcoal
35 % Sawlogs

● **= 50 a 100.000 ha**

Production Ecology of *Eucalyptus* Plantations

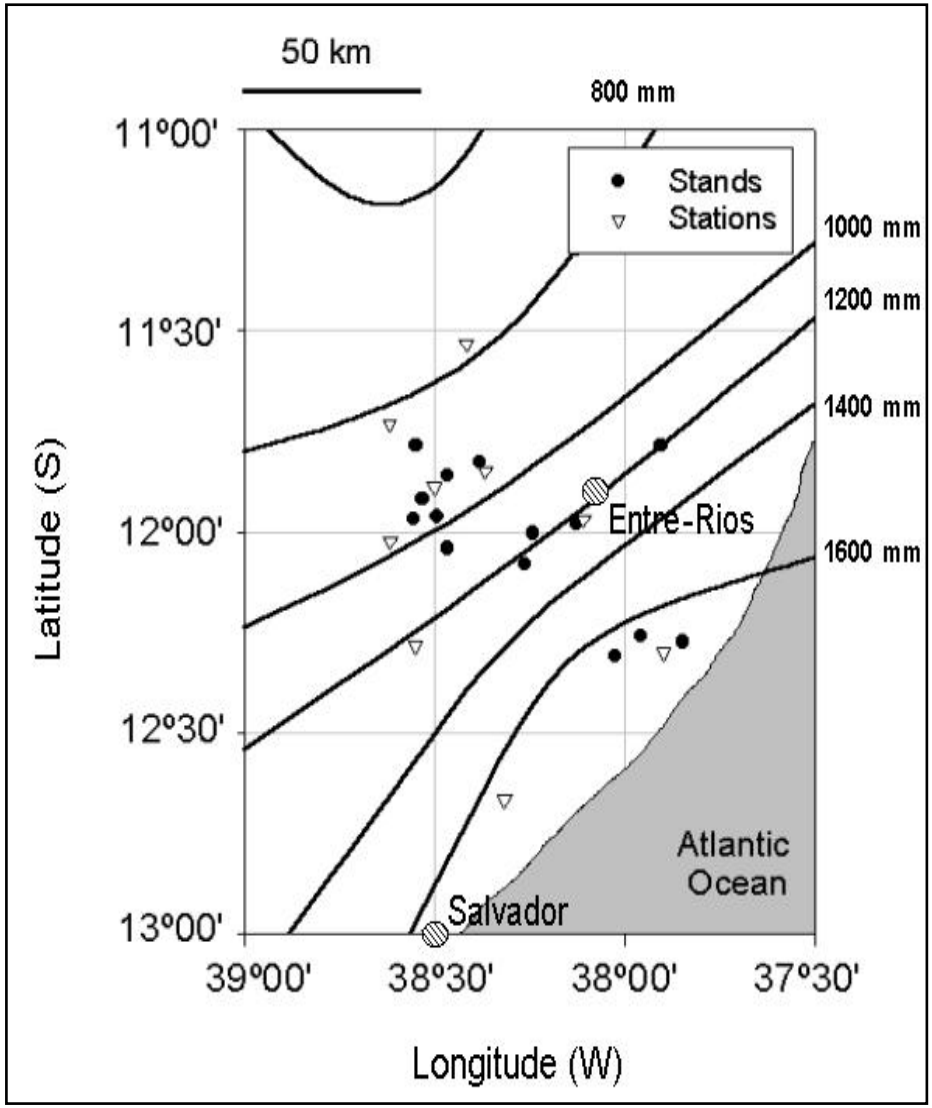
14 stands along a geographic gradient



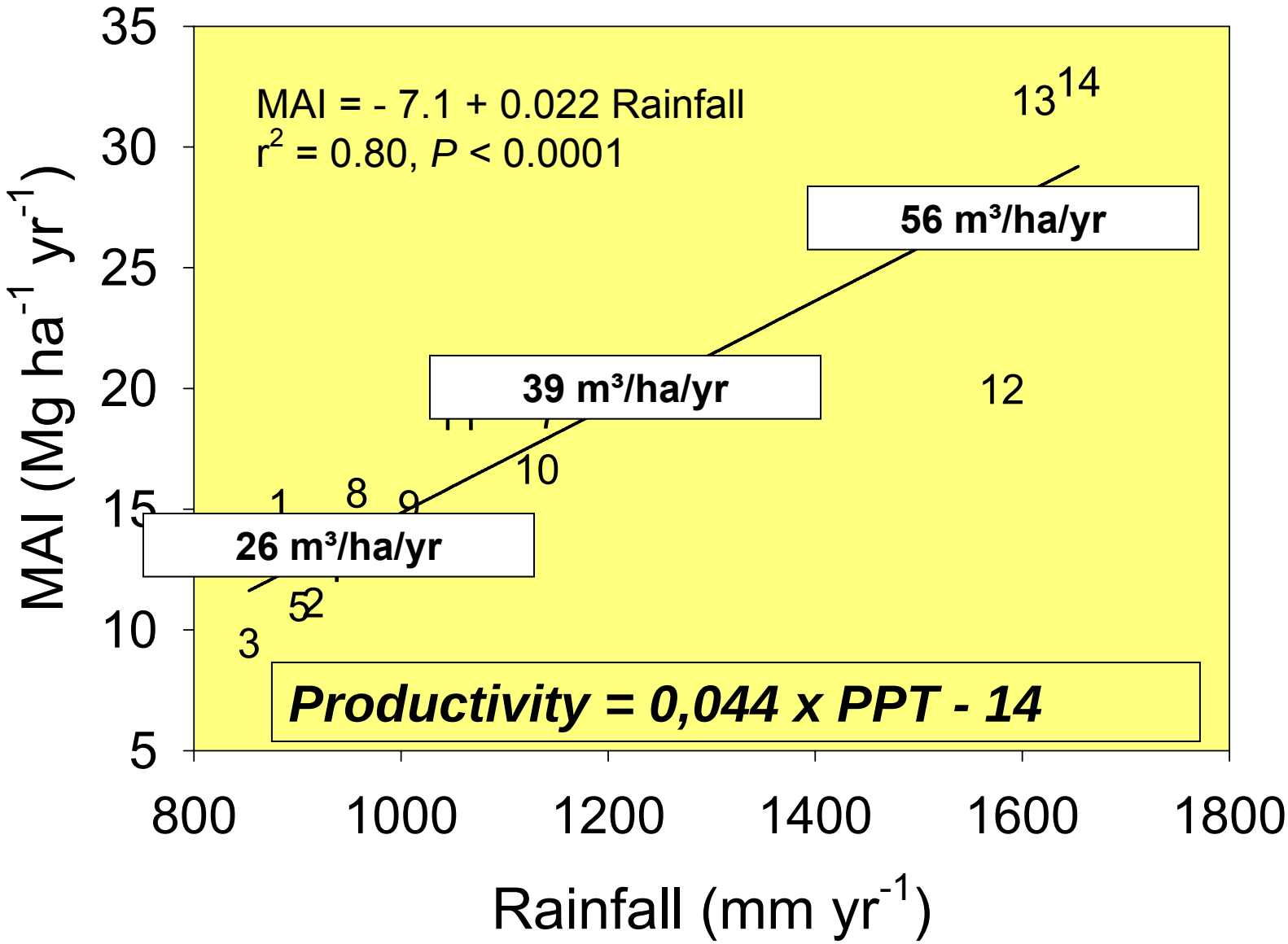
Rainfall

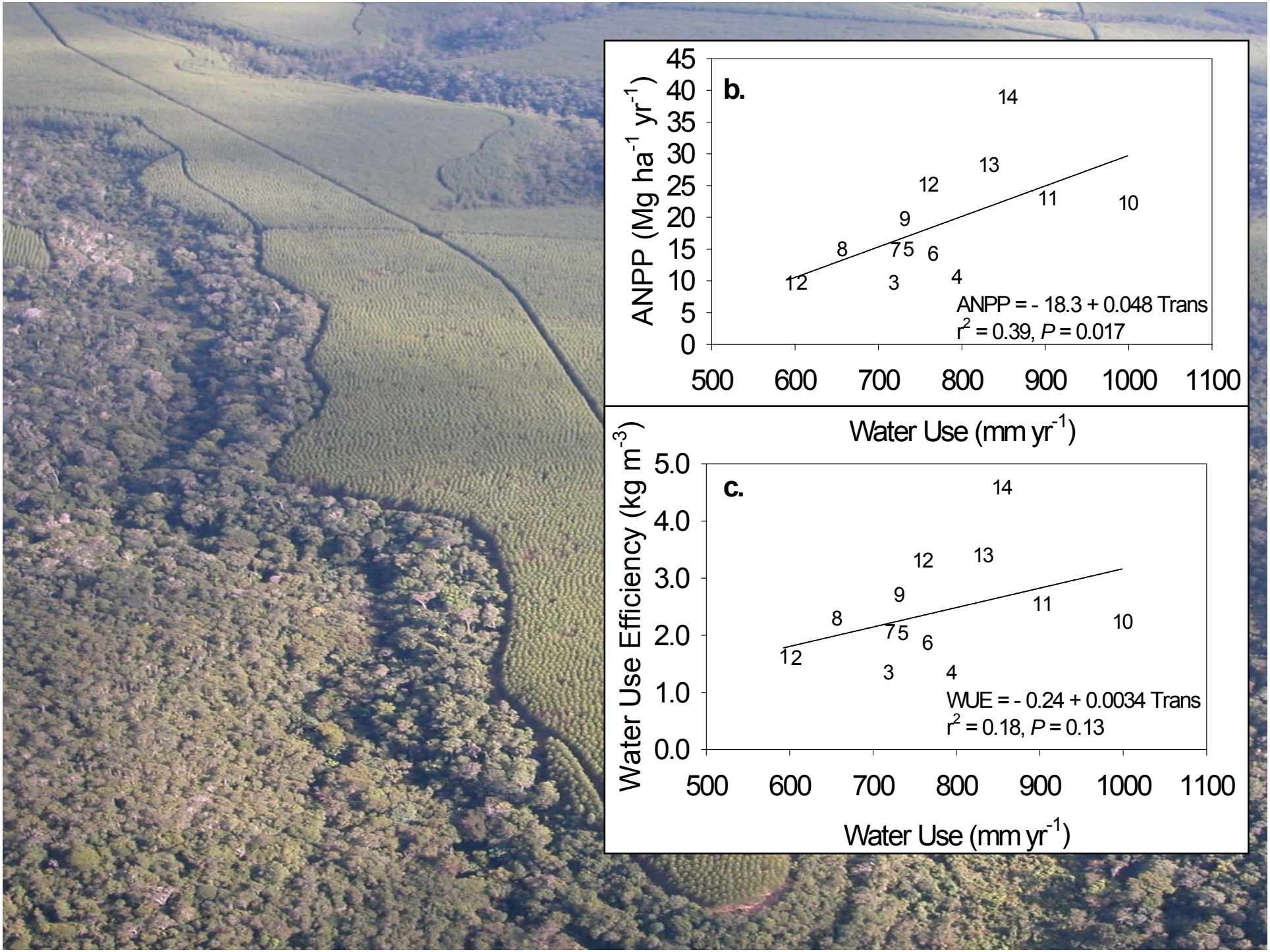
Blue = Wetter

Yellow = Drier

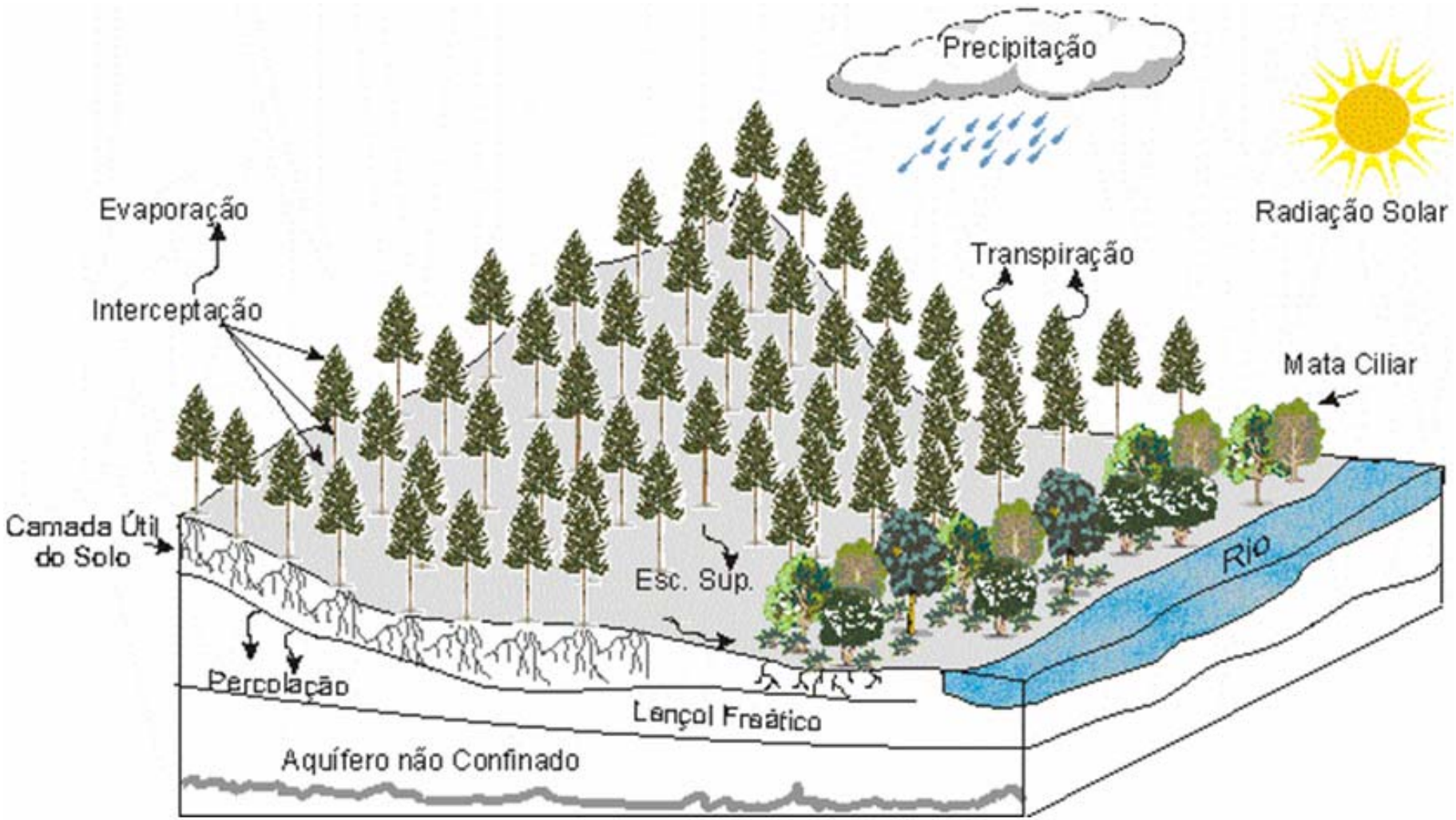


Productivity MAI: + 5 m³/ha/yr for each increase in + 100 mm/yr

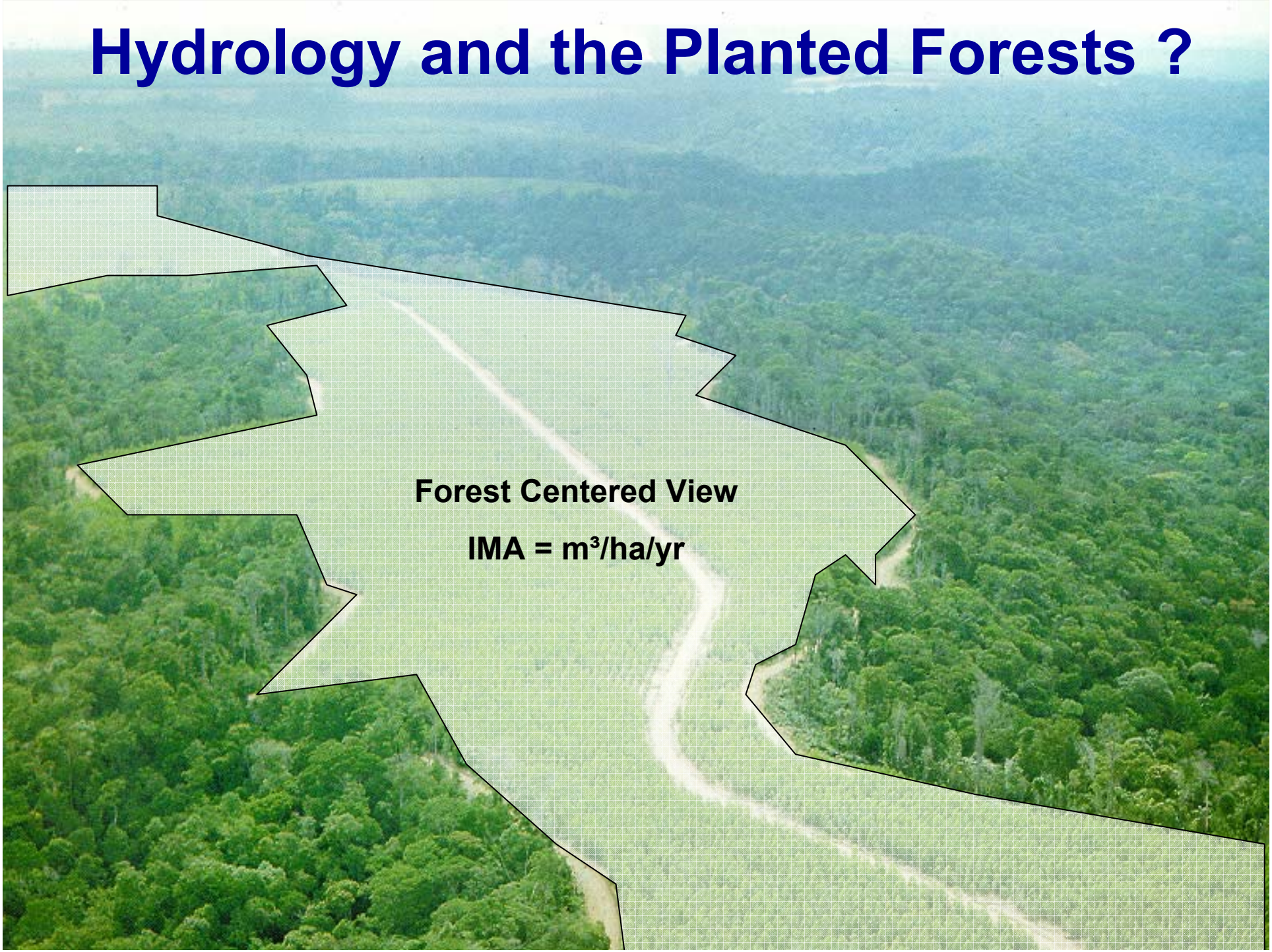



b.
ANPP (Mg ha-1 yr-1)
Water Use (mm yr-1)
ANPP = - 18.3 + 0.048 Trans
r2 = 0.39, P = 0.017
c.
Water Use Efficiency (kg m-3)
Water Use (mm yr-1)
WUE = - 0.24 + 0.0034 Trans
r2 = 0.18, P = 0.13

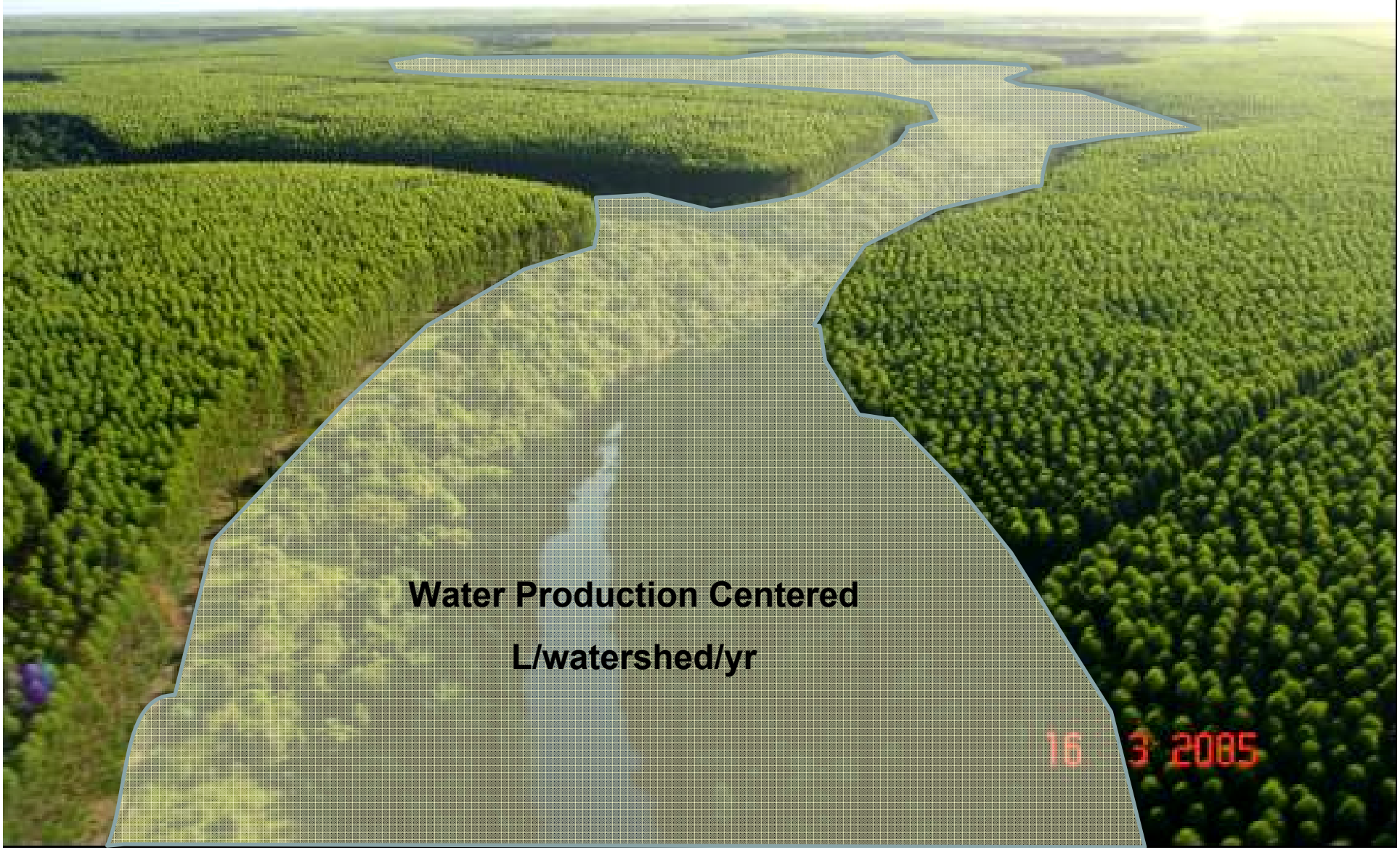
Hydrologic Balance – Links Among Water Flows



Water Drainage = PPT – I – R – E – T ± S

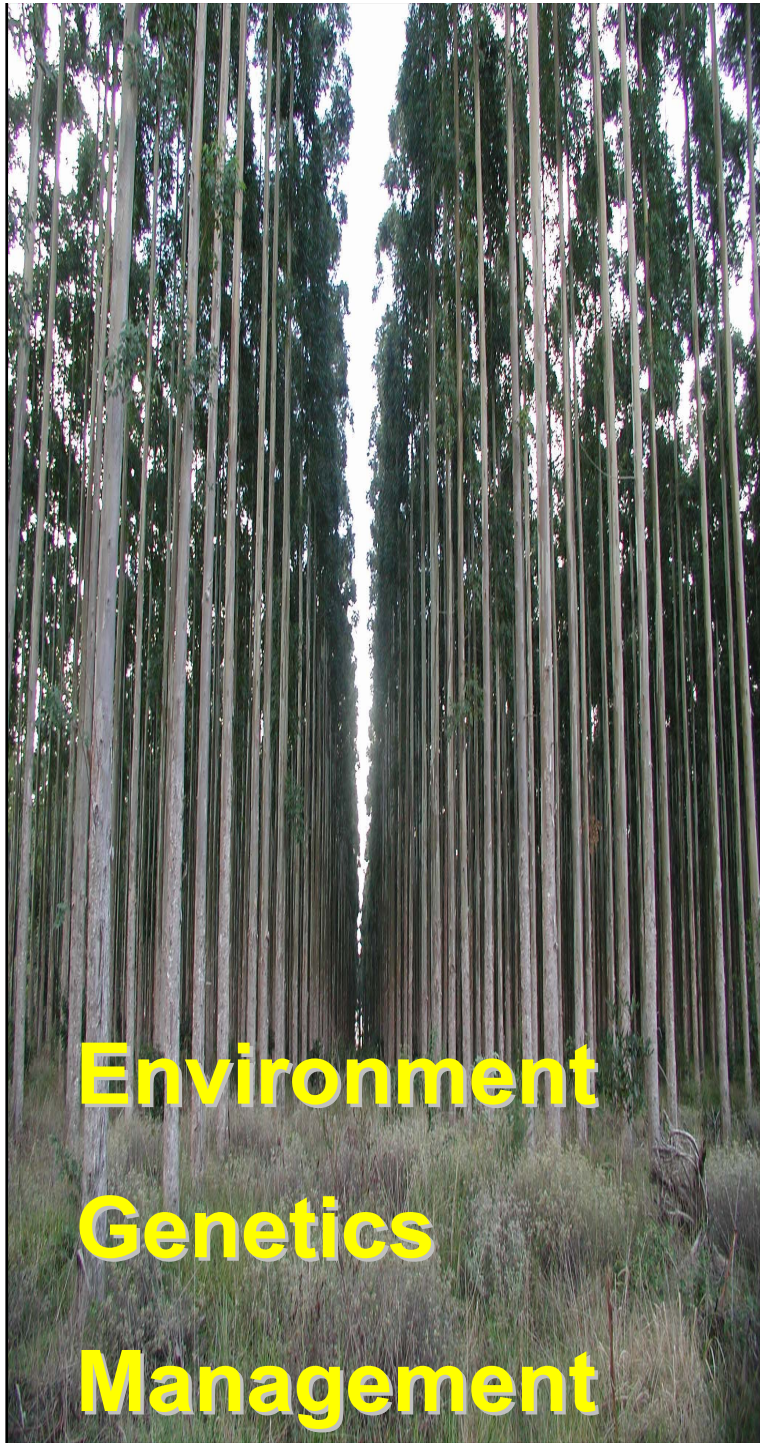

Hydrology and the Planted Forests ?
Forest Centered View
IMA = m³/ha/yr

Planted Forests and the Hydrology ?



+

=


Environment
Genetics
Management

Simplified Hydrologic Balance

Drainage = PPT – ETP

WUE = WNPP/ETP

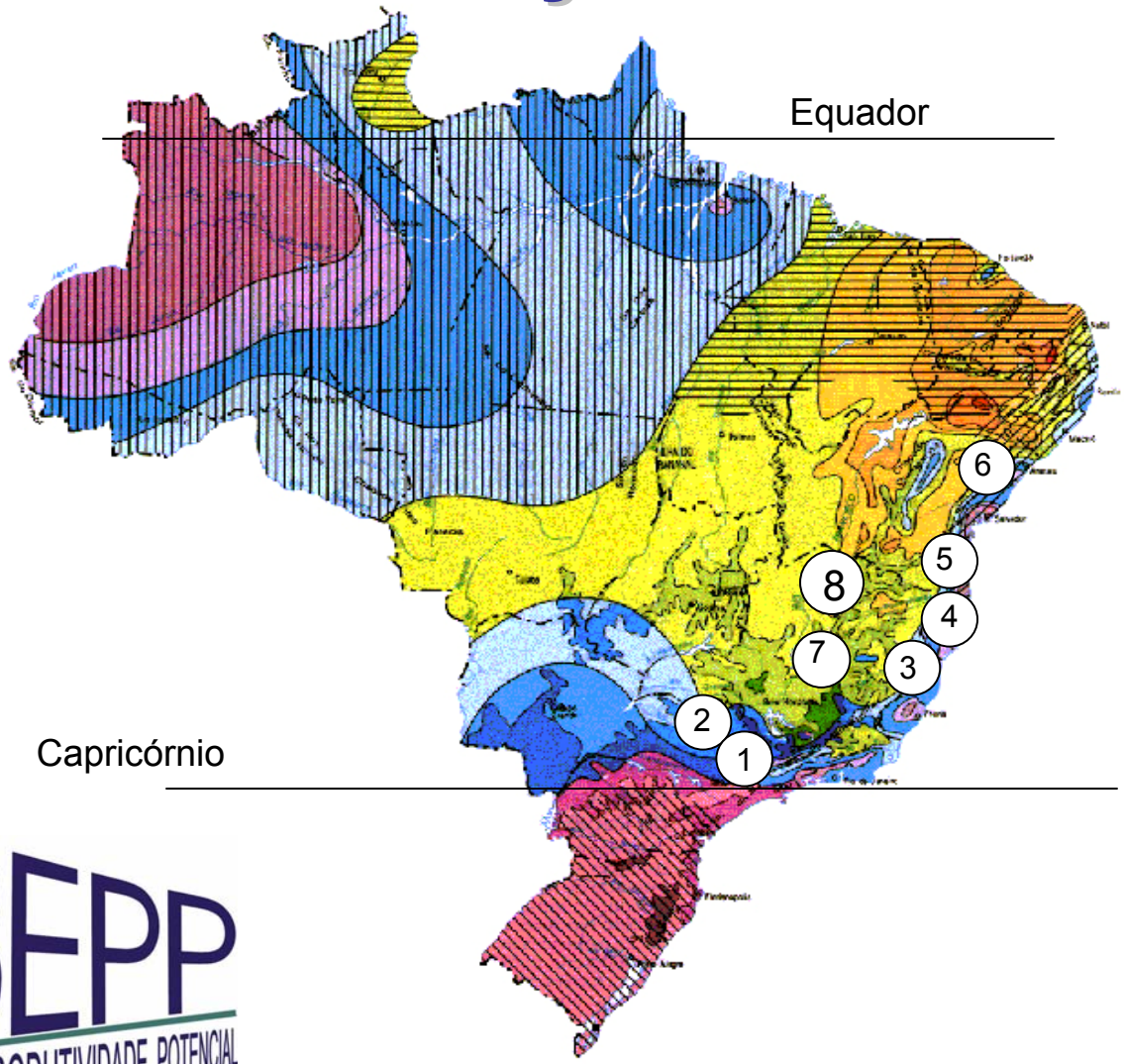
Drainage = PPT – WNPP / WUE

Drainage = PPT – WNPP / WUE

Important Questions

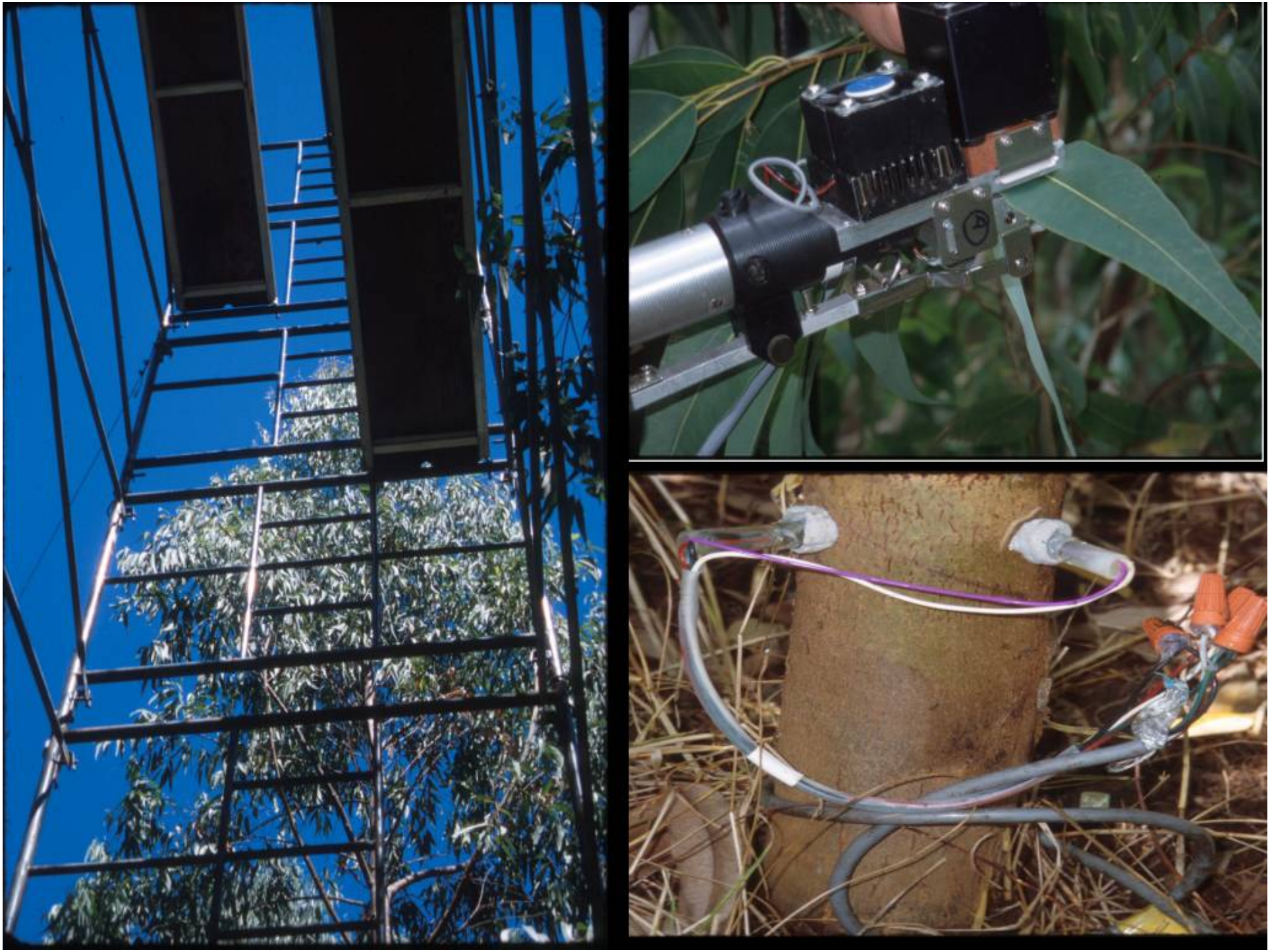
- **Are the Forest Plantations Water Limited ?**
- **How much (more) water they (can) use ?**
- **What is the WUE in these plantations ?**
- **Does *Eucalyptus* in tropical conditions control water use ?**
- **How significant is the WU in the hydrologic balance ?**

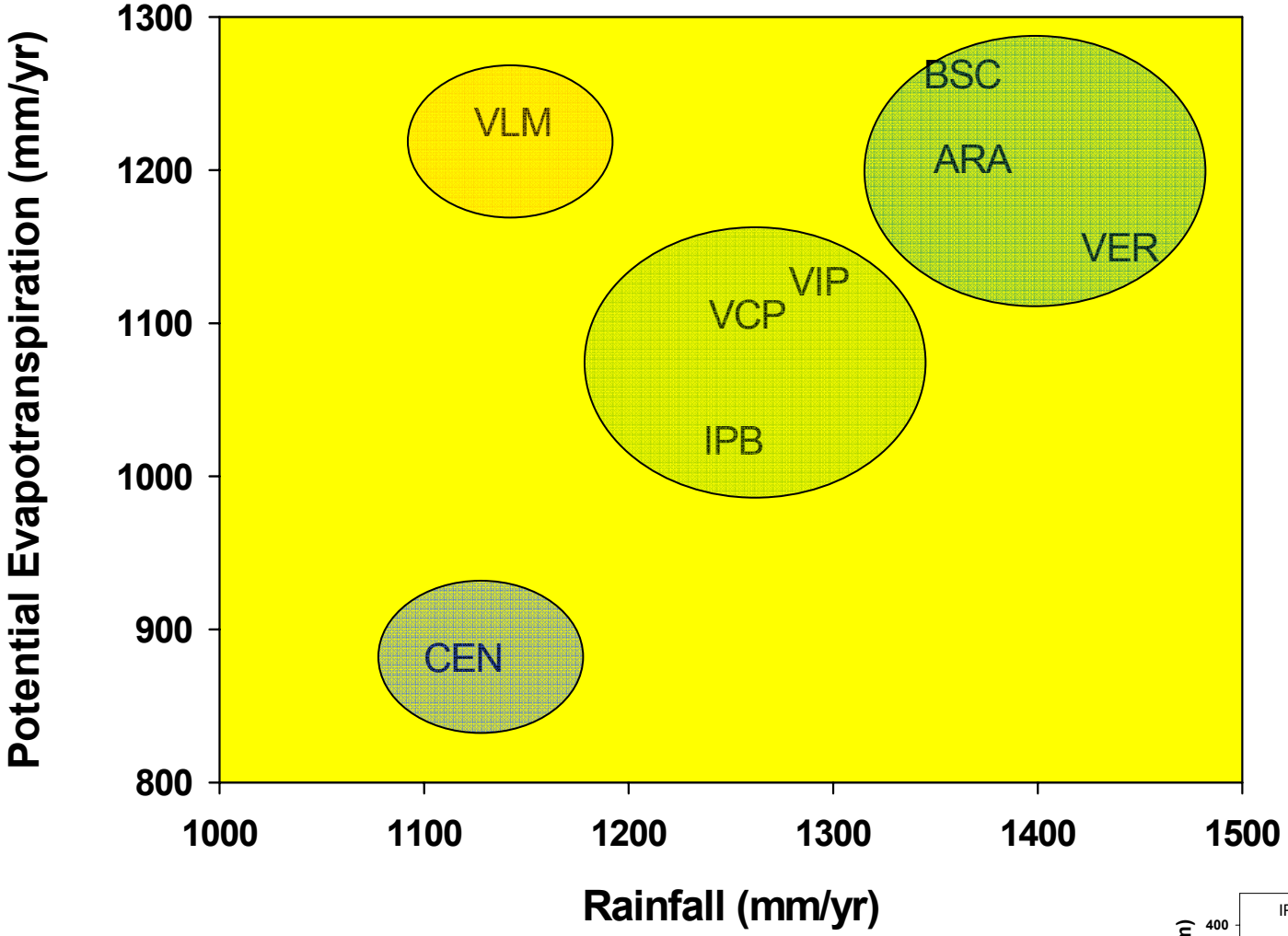
Brasil Eucalyptus Potential Productivity Network



IPEF

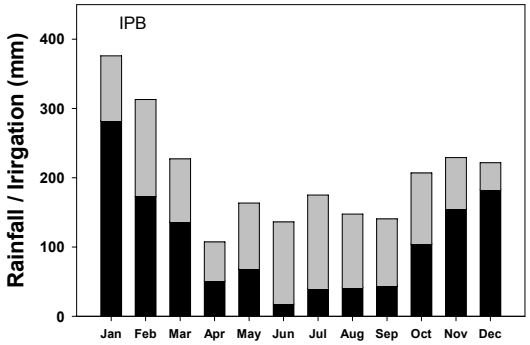
BEPP
BRASIL EUCALYPTUS PRODUTIVIDADE POTENCIAL





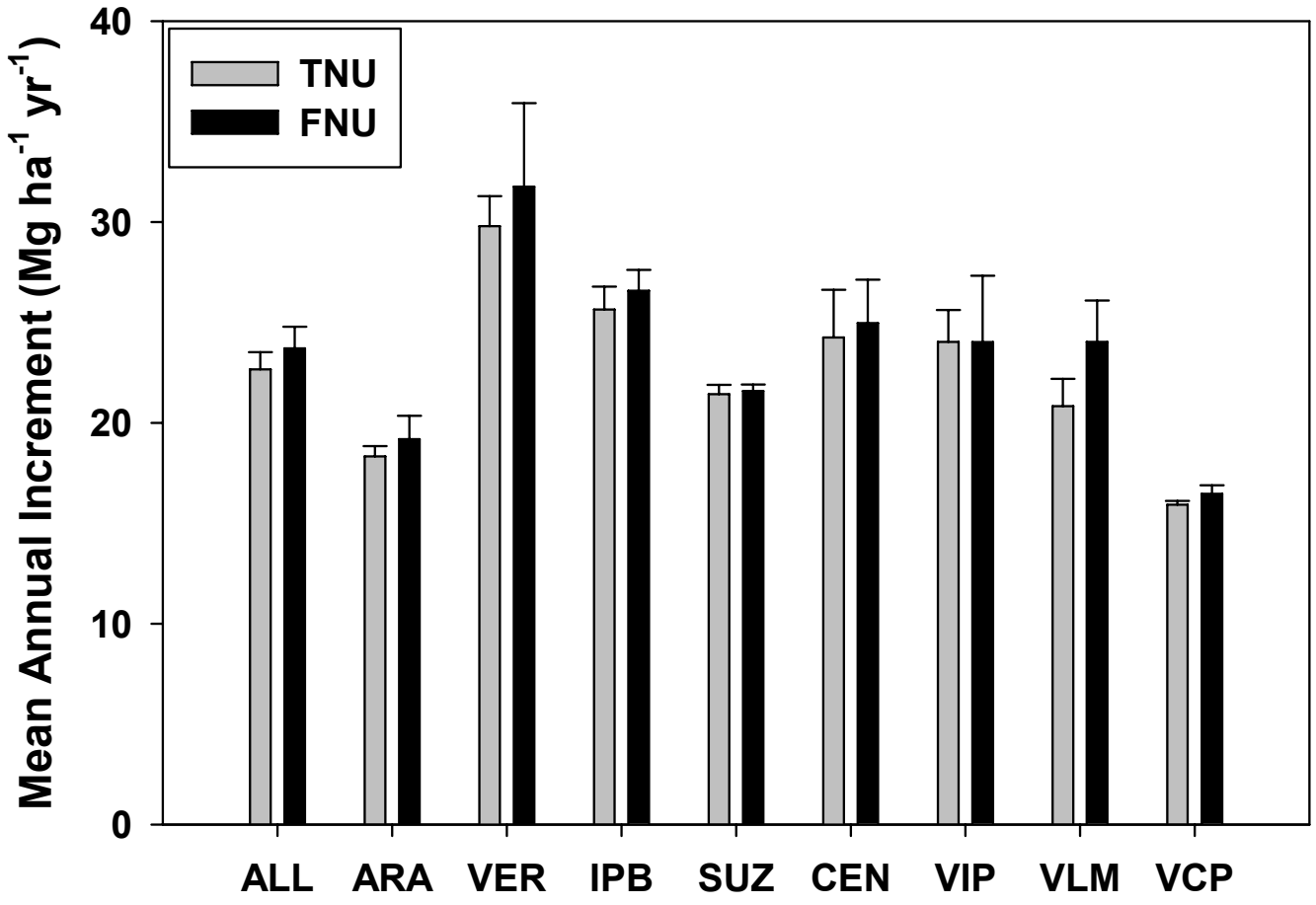
Seasonal Rainfall Regimes

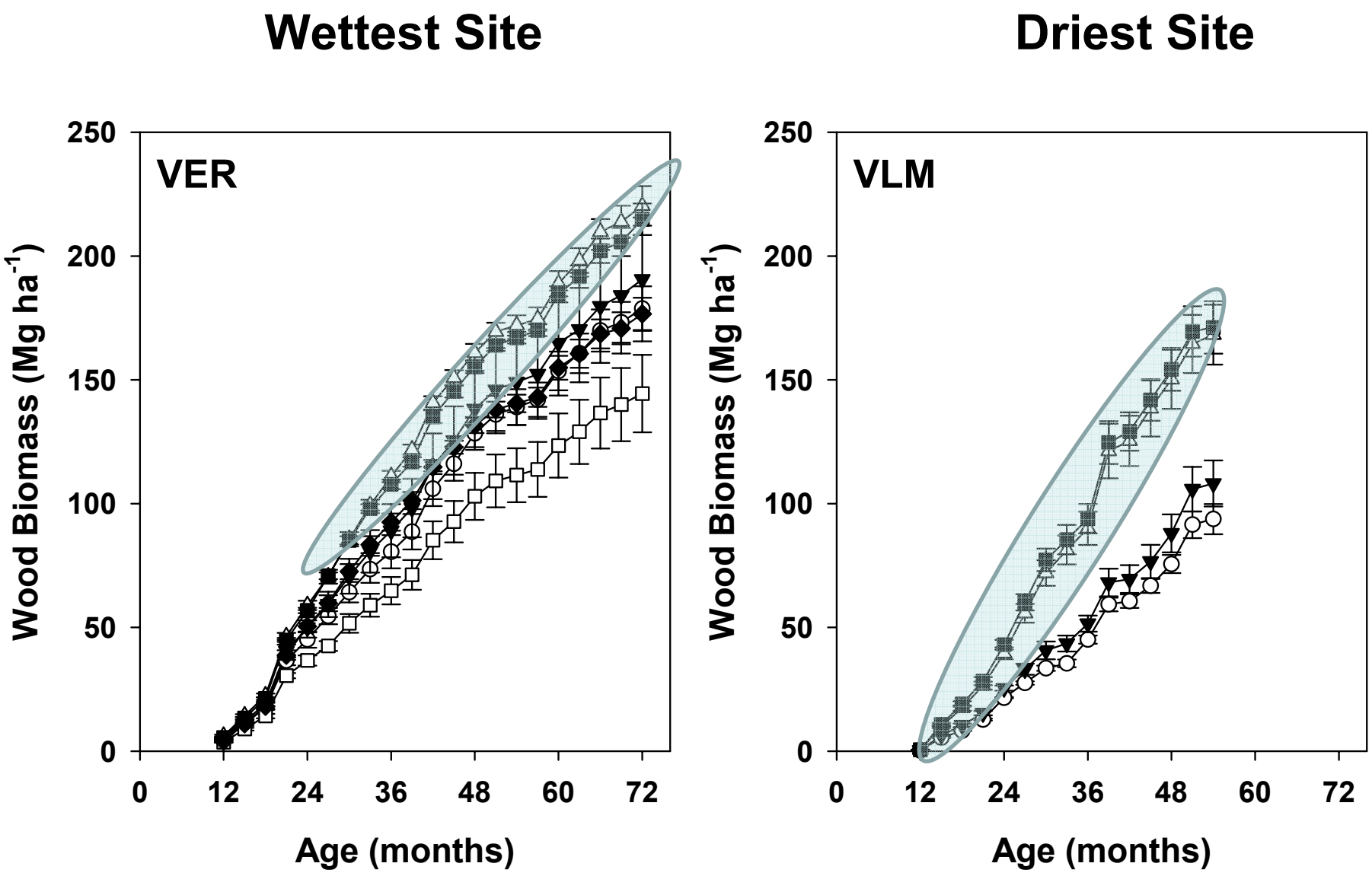
Wet-Summer



No Increase in Wood Biomass due to Extra-Fertilization

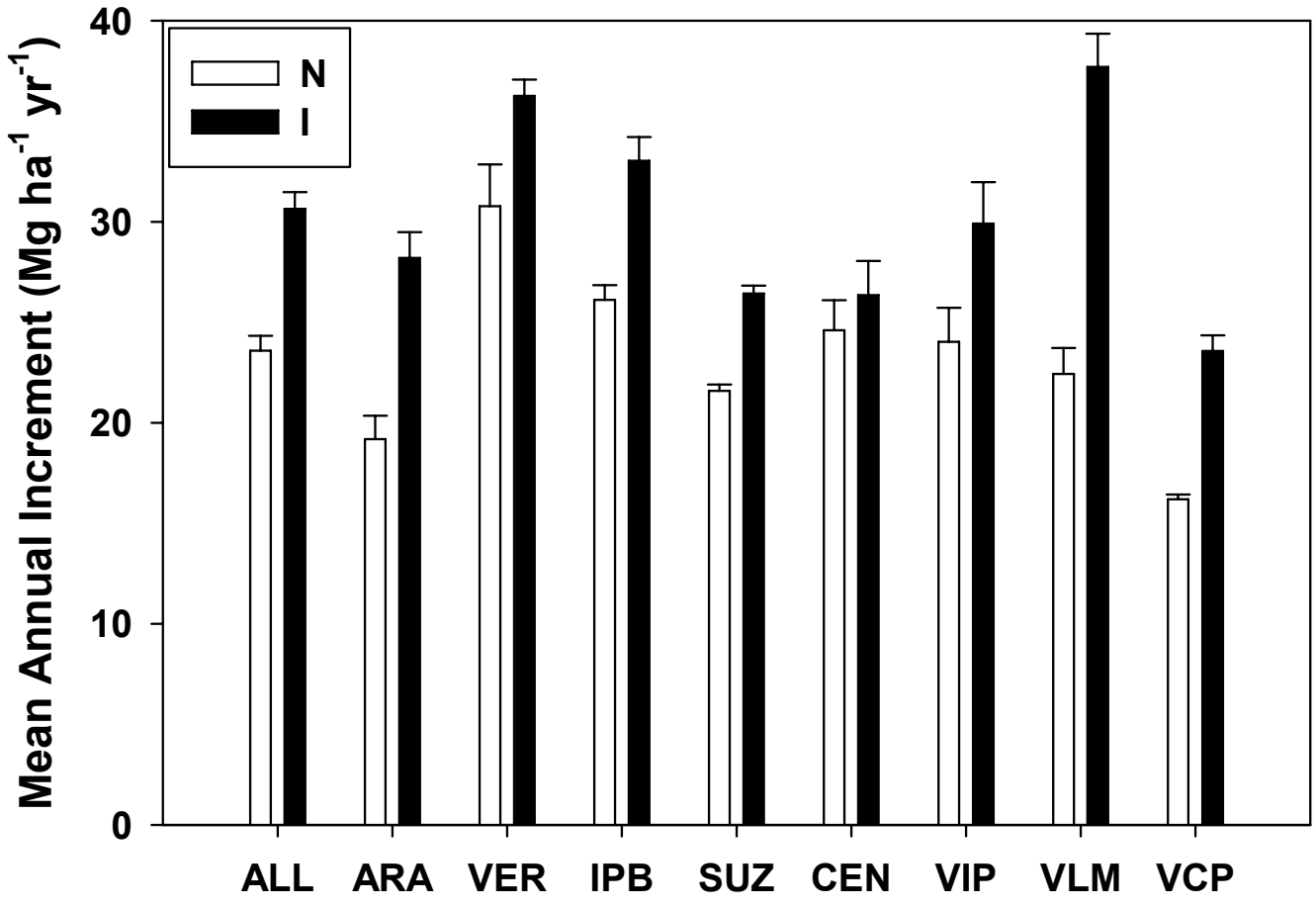
TNU = Traditional Fertilization
FNU = Extra Fertilization



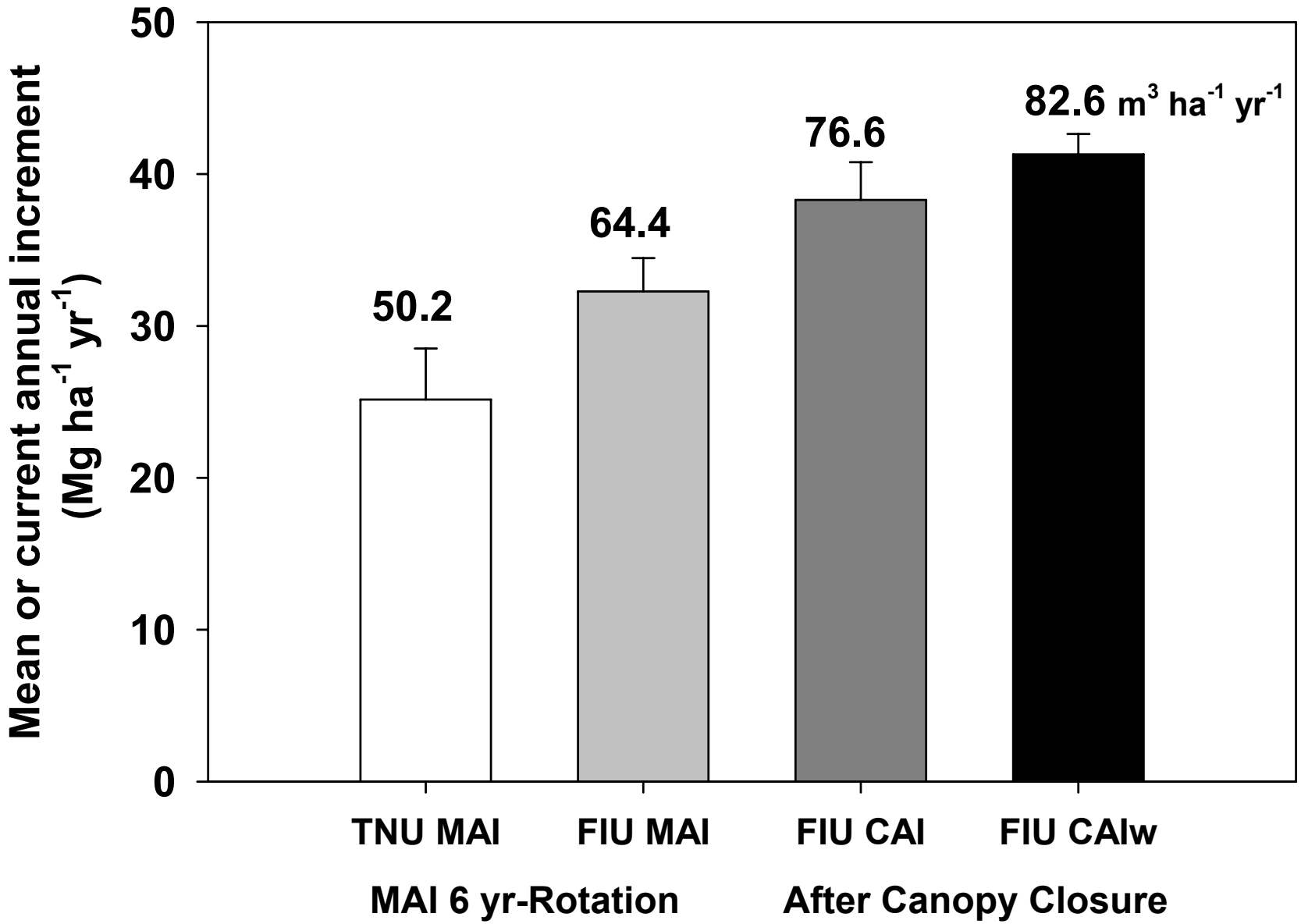

Wettest Site
Driest Site
VER
VLM
Wood Biomass (Mg ha-1)
Age (months)
0
50
100
150
200
250
0
12
24
36
48
60
72

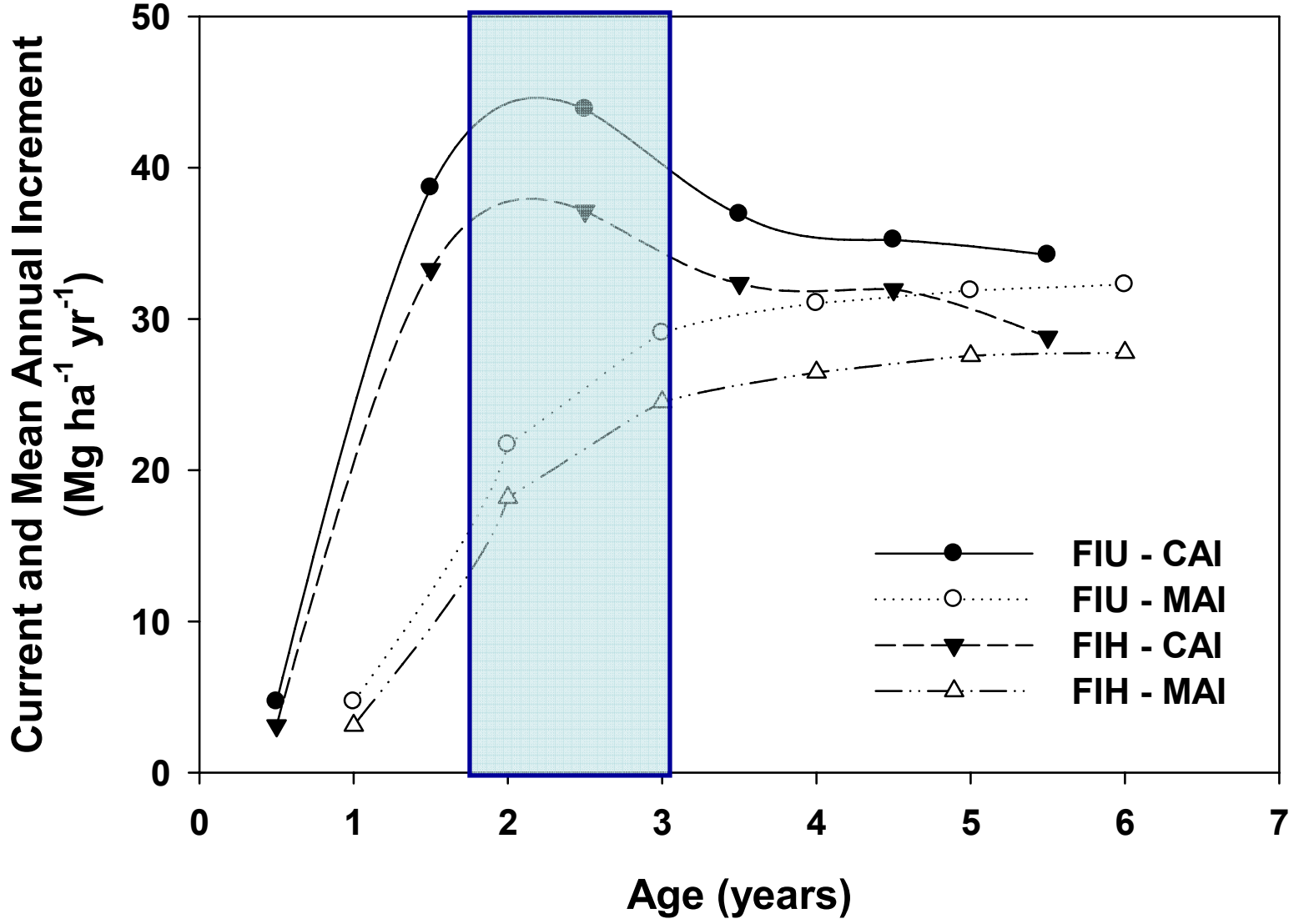
30% Increase in Wood Biomass due to Irrigation

N = Nom Irrigated
I = Irrigated

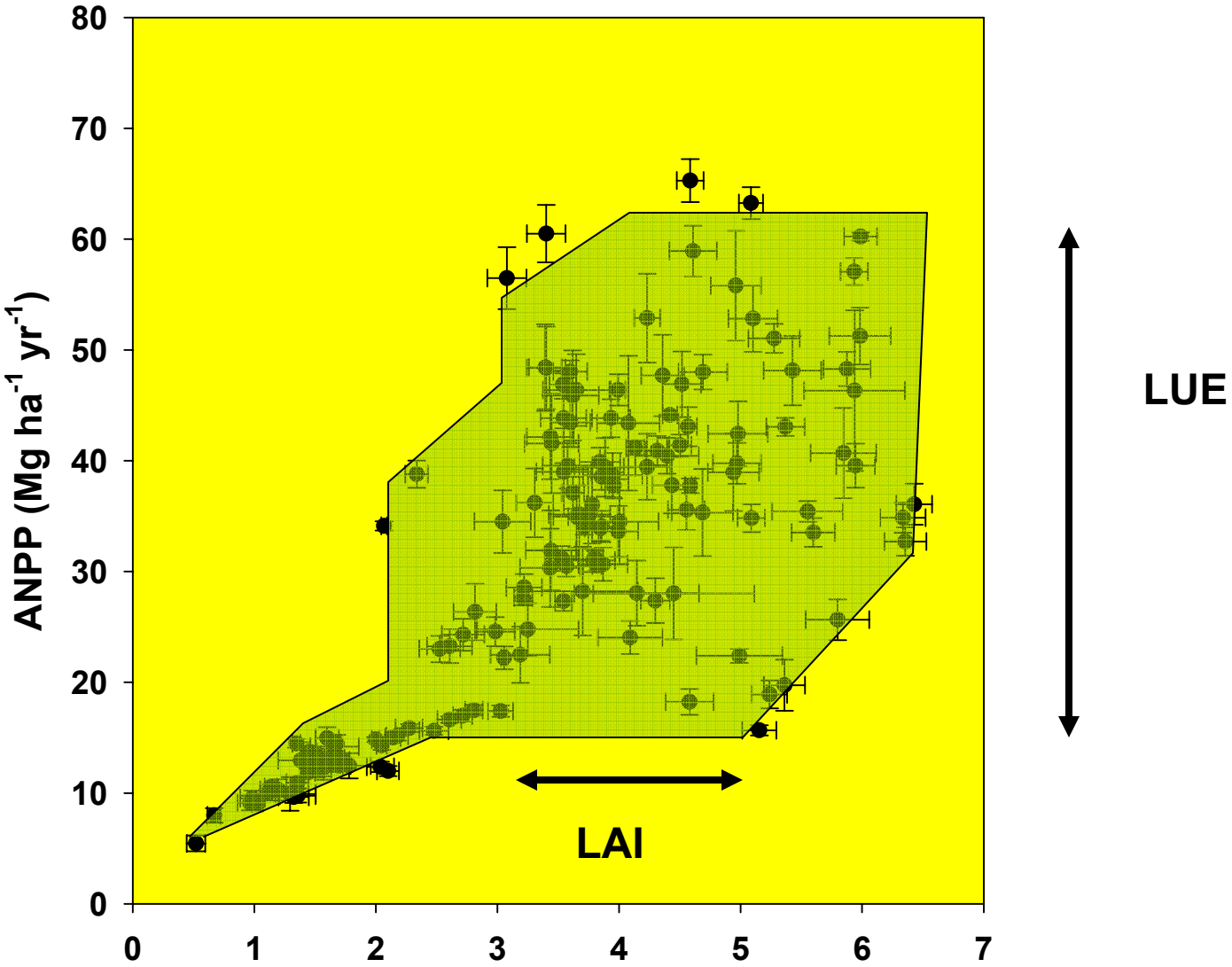


No Water x Nutrient Interaction

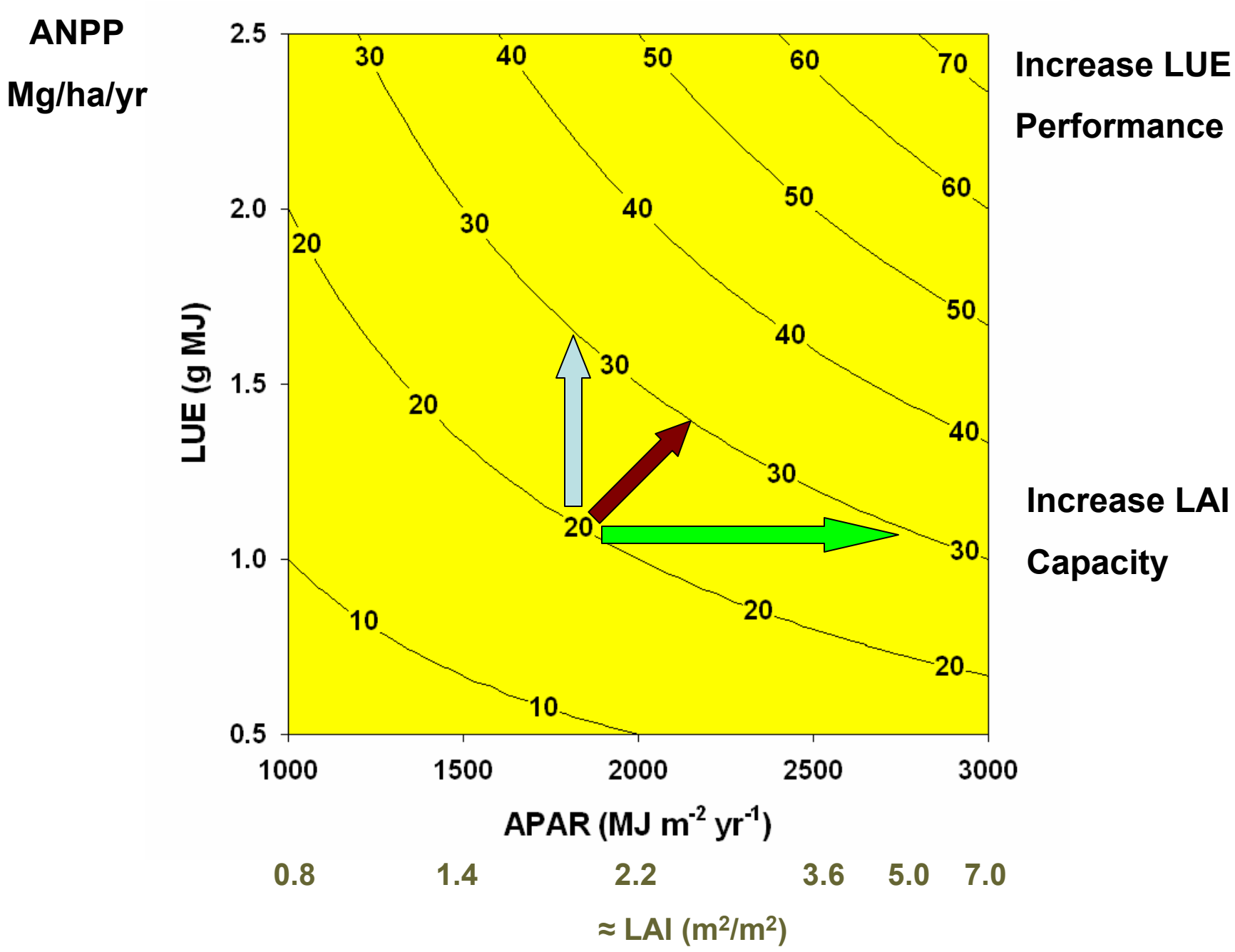

Mean or current annual increment
(Mg ha-1 yr-1)
50
40
30
20
10
0
50.2
64.4
76.6
82.6 m3 ha-1 yr-1
TNU MAI
FIU MAI
FIU CAI
FIU CAIw
MAI 6 yr-Rotation
After Canopy Closure


Current and Mean Annual Increment
(Mg ha-1 yr-1)
50
40
30
20
10
0
0
1
2
3
4
5
6
7
Age (years)
FIU - CAI
FIU - MAI
FIH - CAI
FIH - MAI

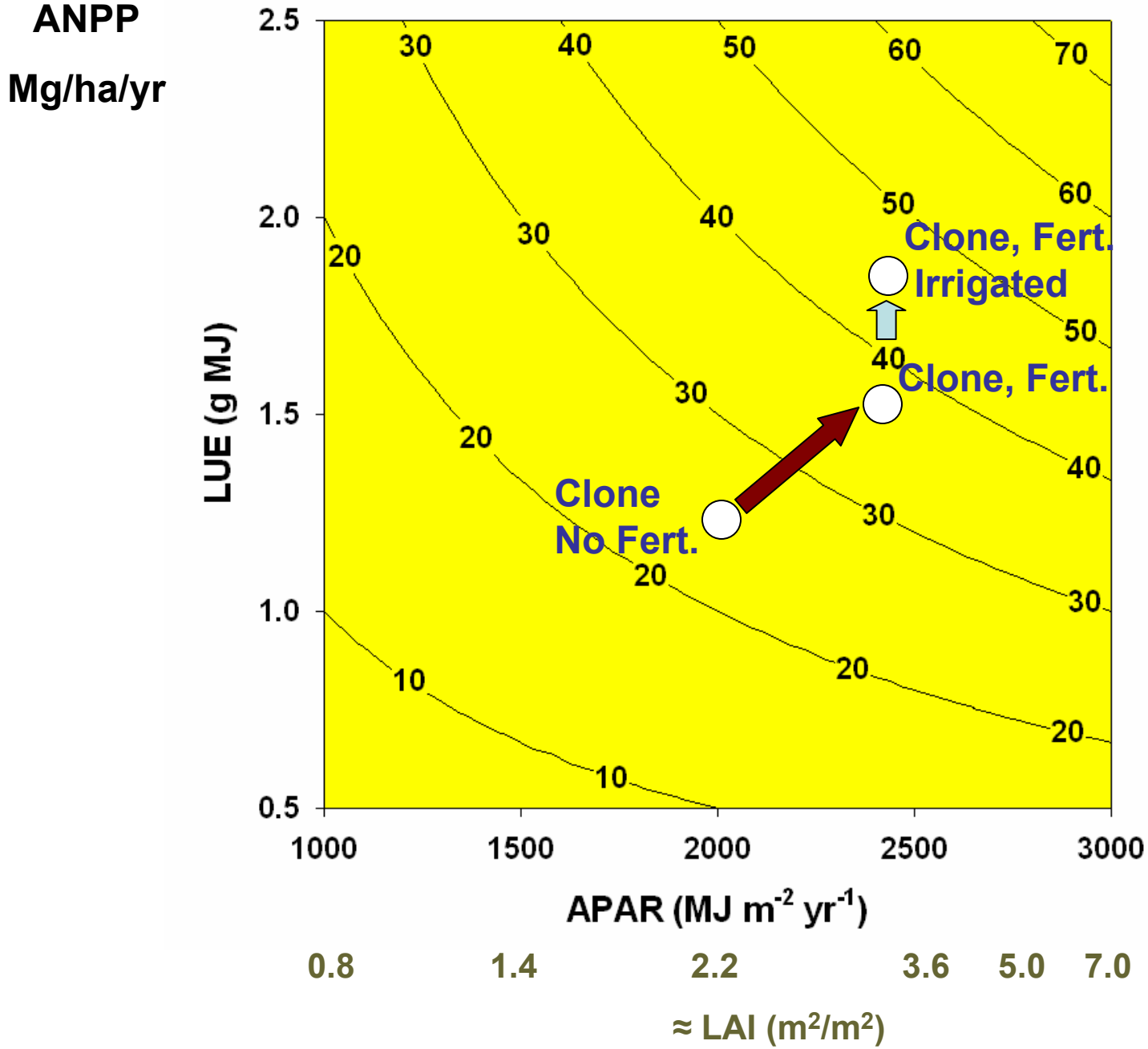
ANPP and LAI for all Plots from Years 1 to 3



"Leaves Grow Trees"


ANPP
Mg/ha/yr
Increase LUE
Performance
Increase LAI
Capacity
LUE (g MJ)
2.5
2.0
1.5
1.0
0.5
1000
1500
2000
2500
3000
APAR (MJ m-2 yr-1)
0.8
1.4
2.2
3.6
5.0
7.0
≈ LAI (m2/m2)
10
20
30
40
50
60
70

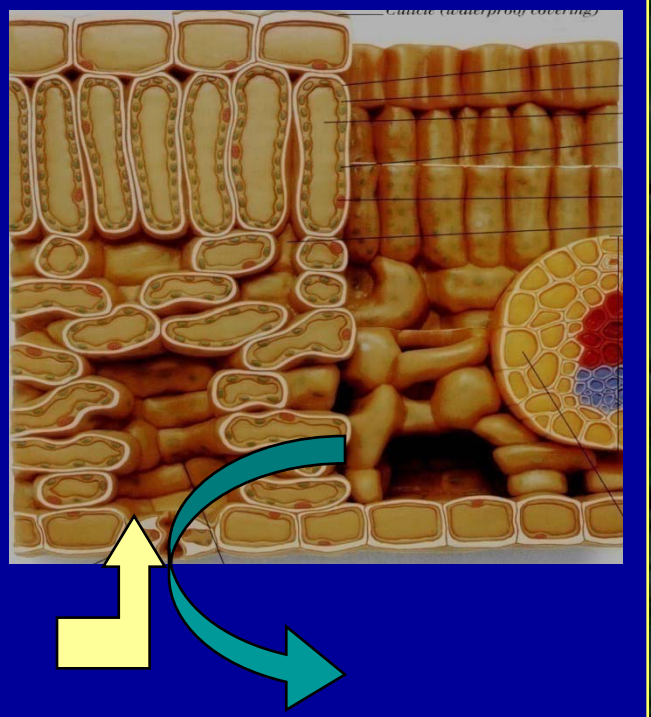
"Happy Leaves Grow Trees"

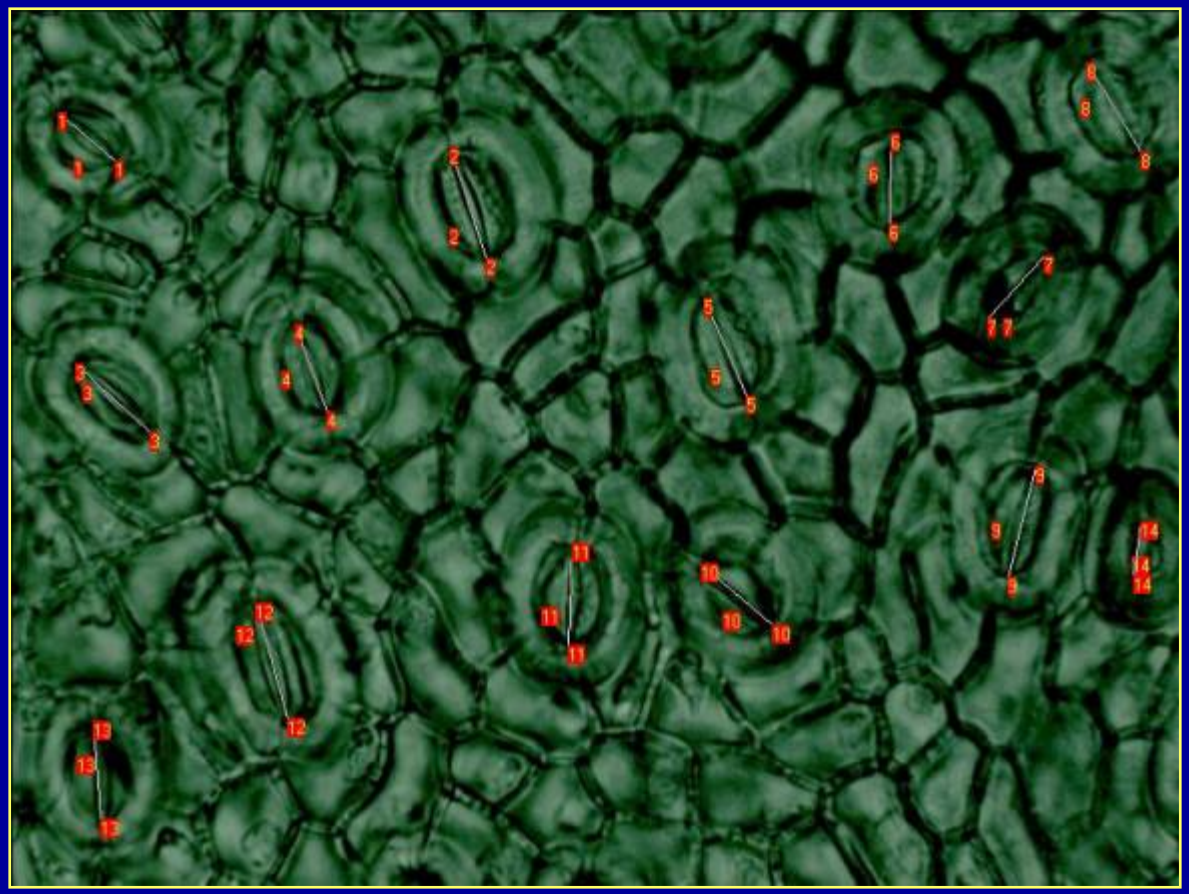


More Questions...

- How does the canopy (leaves) lose water ?
- Does it varies with canopy Age ? Clone ?
- And the WU and WUE questions...

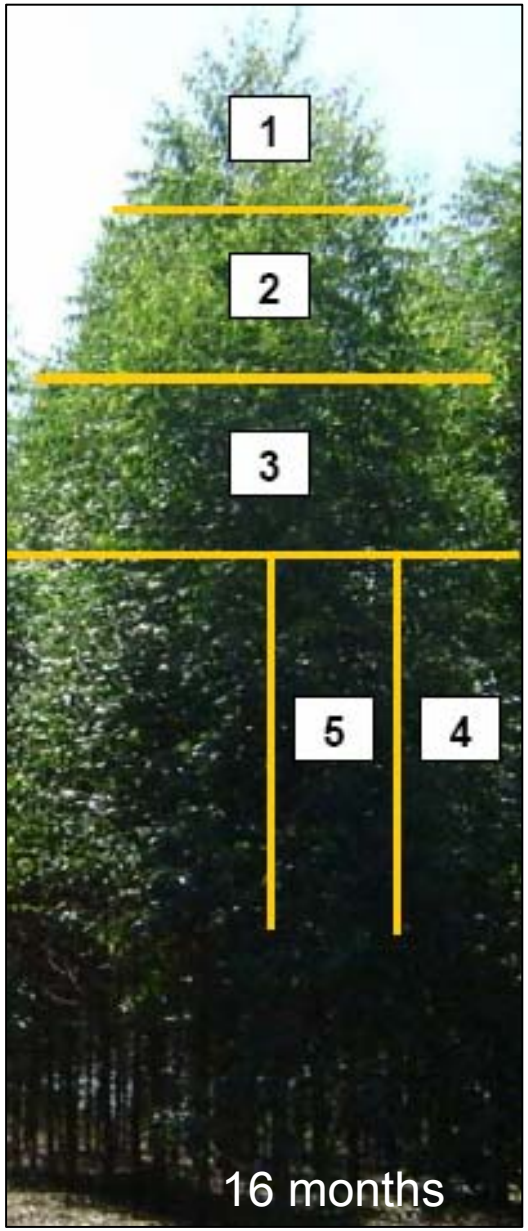
Assimilation - Transpiration



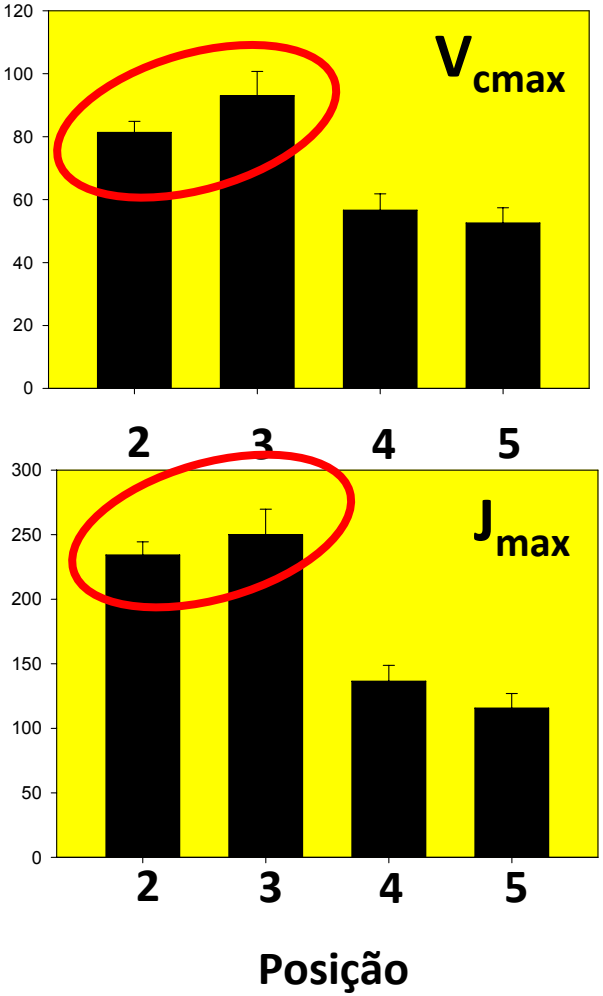


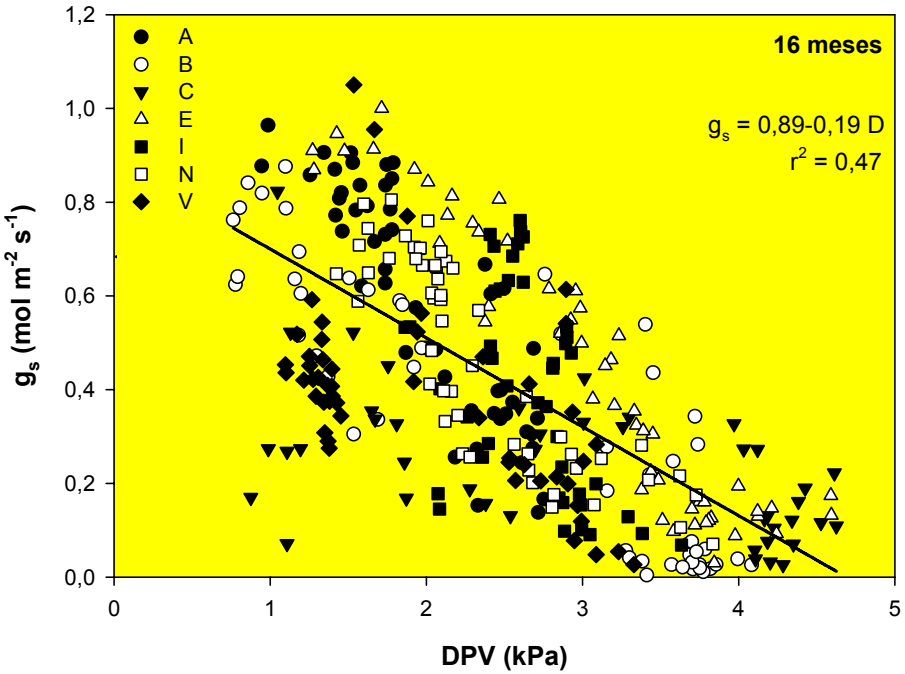
Stomata – *E.grandis x urophylla* – Clone COP0321

Curve A/C_i

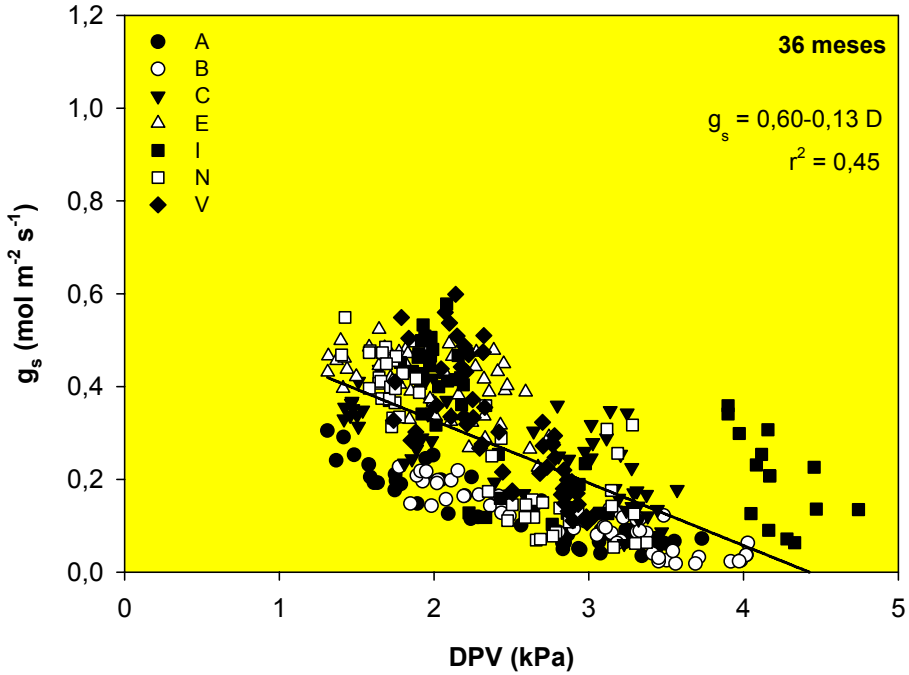

1
2
3
5
4
16 months

36 months


V_{cmax}
120
100
80
60
40
20
0
2
3
4
5
J_{max}
300
250
200
150
100
50
0
2
3
4
5
Posição



16 Months



36 Months

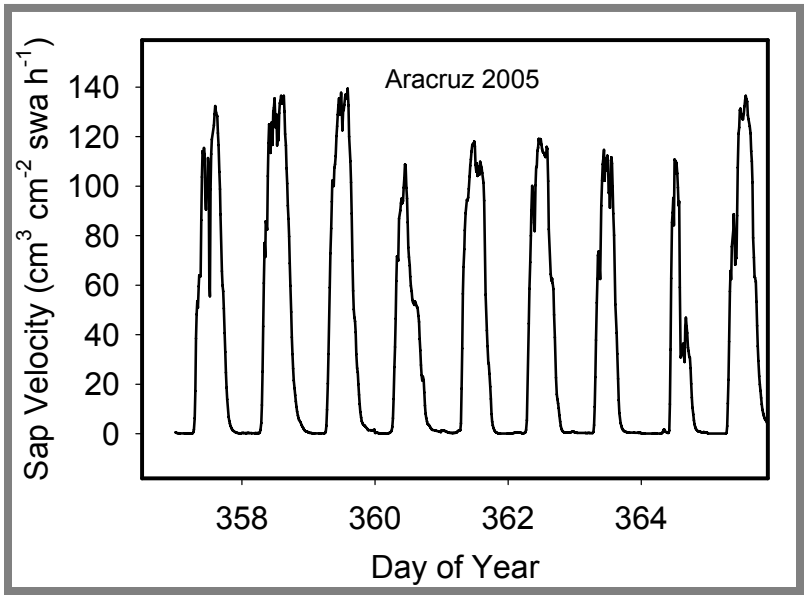
16 months: Higher gs and - 0,2 mol m^{-2} s^{-1} / kPa DPV

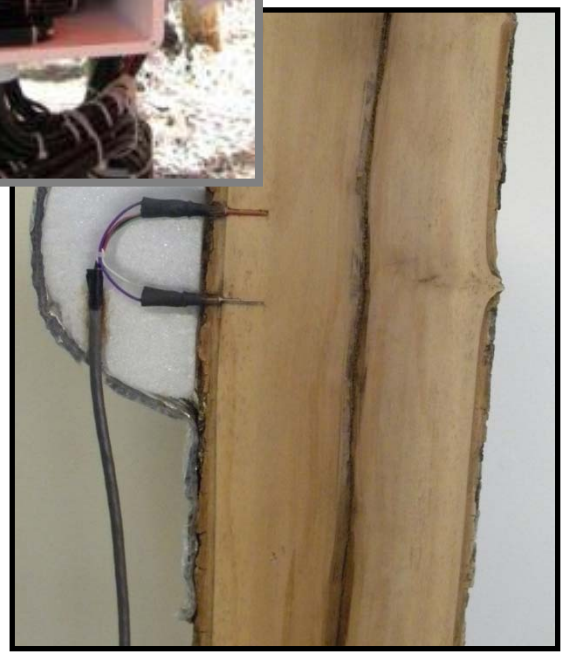
36 months: Lower gs and - 0,1 mol m^{-2} s^{-1} / kPa de DPV

Different Clonal Sensitivity to VPD

Measuring Tree Water Use

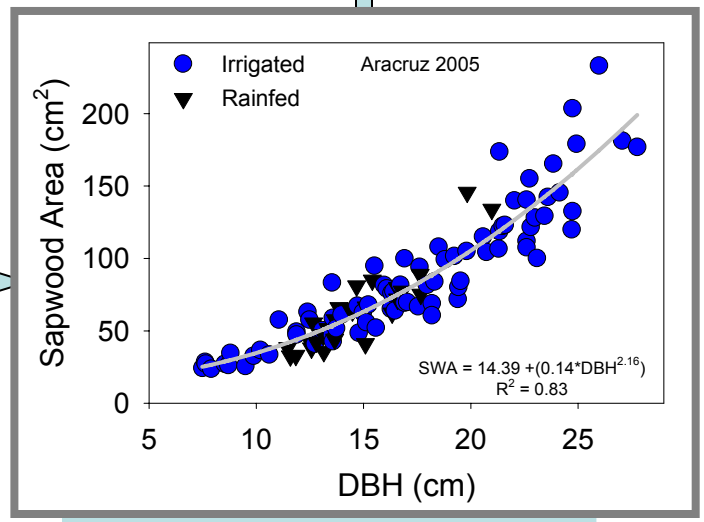
- **Thermal dissipation probes**
- **Sap velocity logged 15 minutes**
- **Calibration curve**
- **Aracruz and Veracel Sites**
- **40 and 80 m^3/ha/yr**



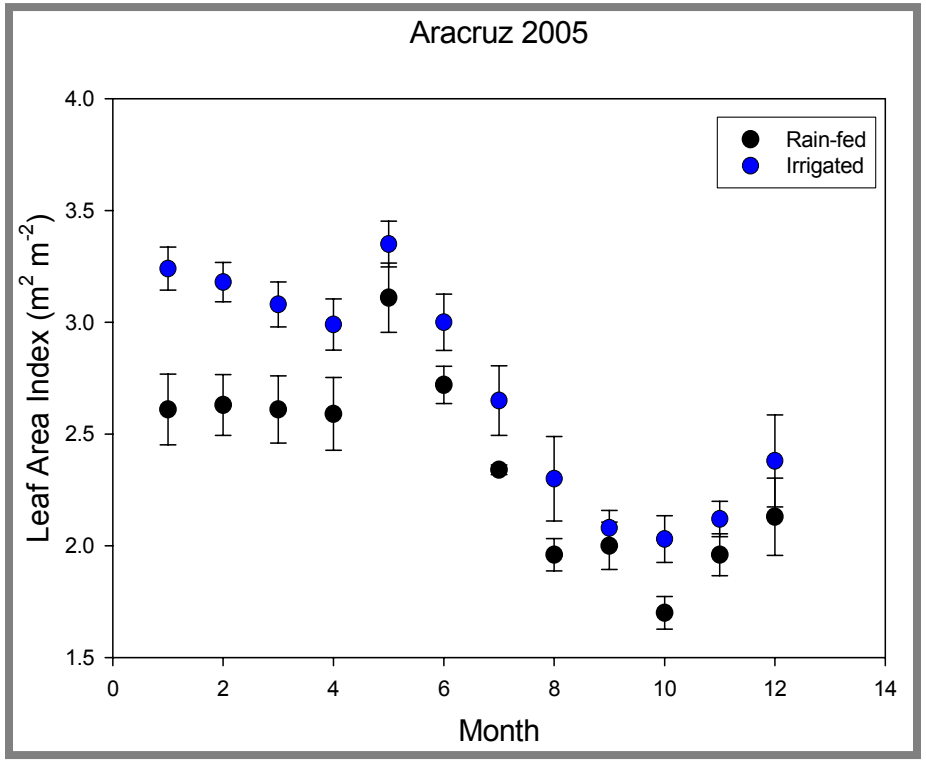


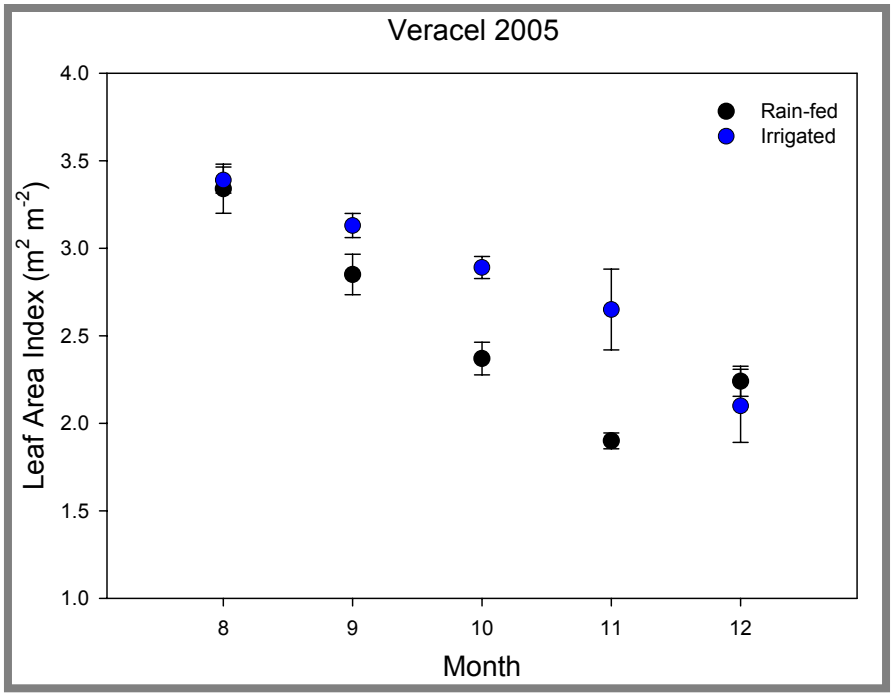
Scaling Up

- Sap Flow per unit sapwood area measured on one plot per treatment
- Assumed this did not differ between plots
- Scaled to replicate plots using quarterly inventory data

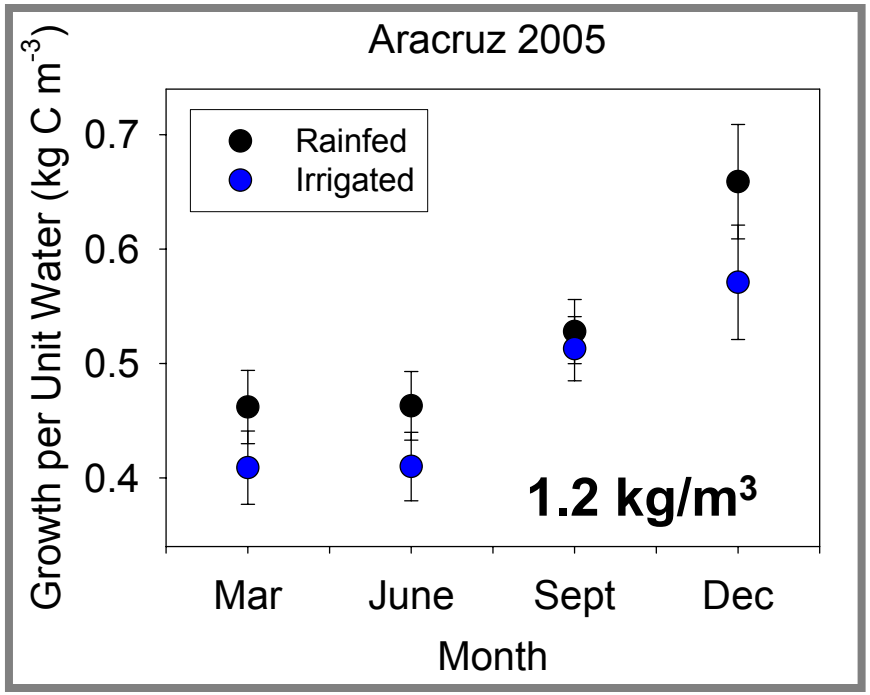


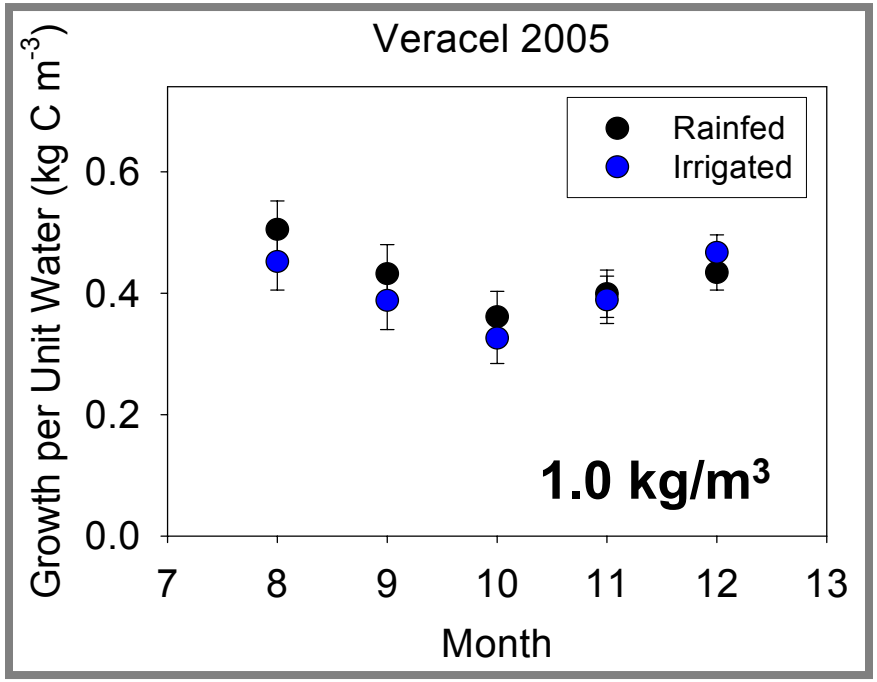
Leaf Area at Aracruz and Veracel



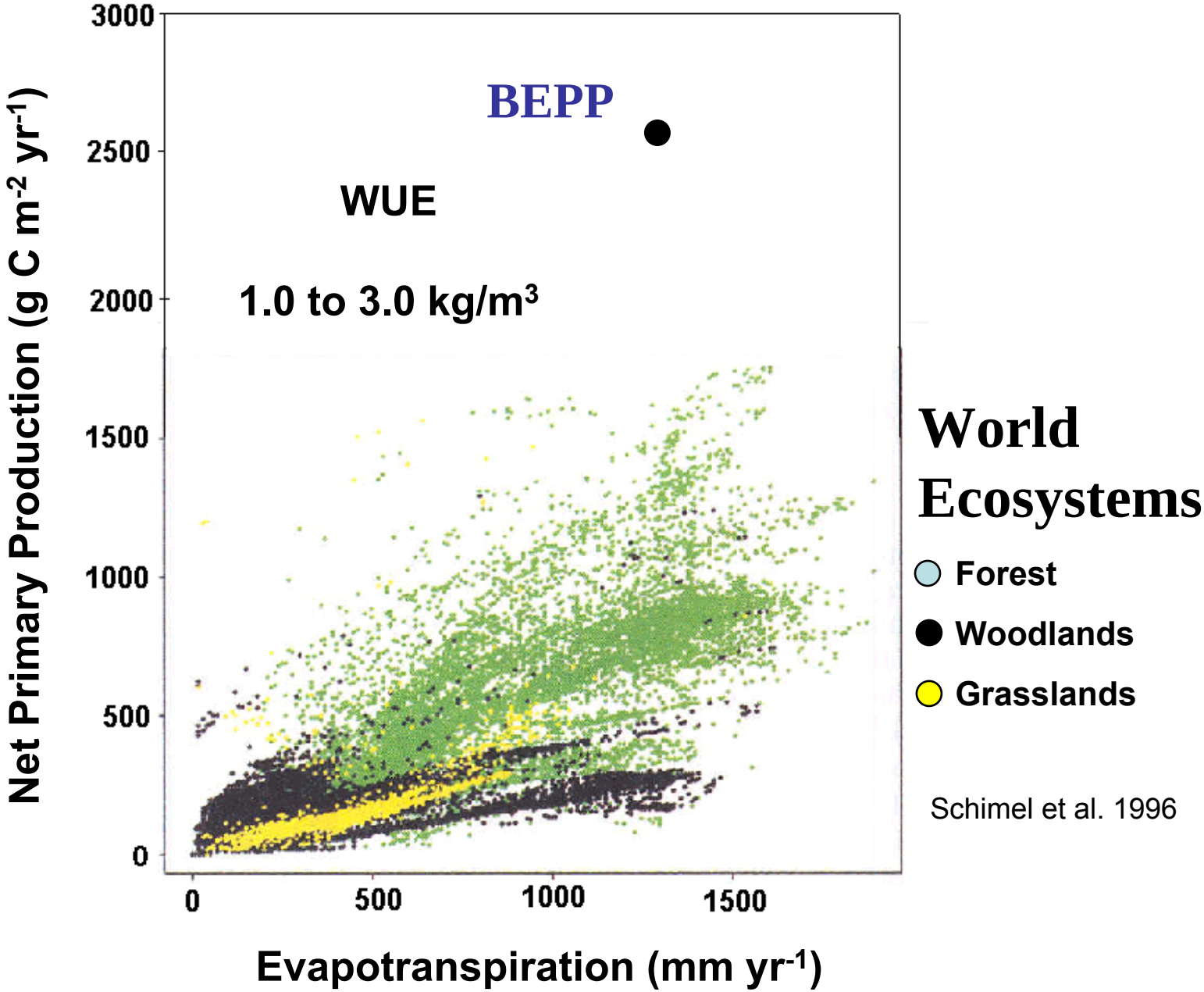


Does Irrigation Influence WUE ?





- No significant change in WUE at Aracruz
- No significant change in WUE at Veracel



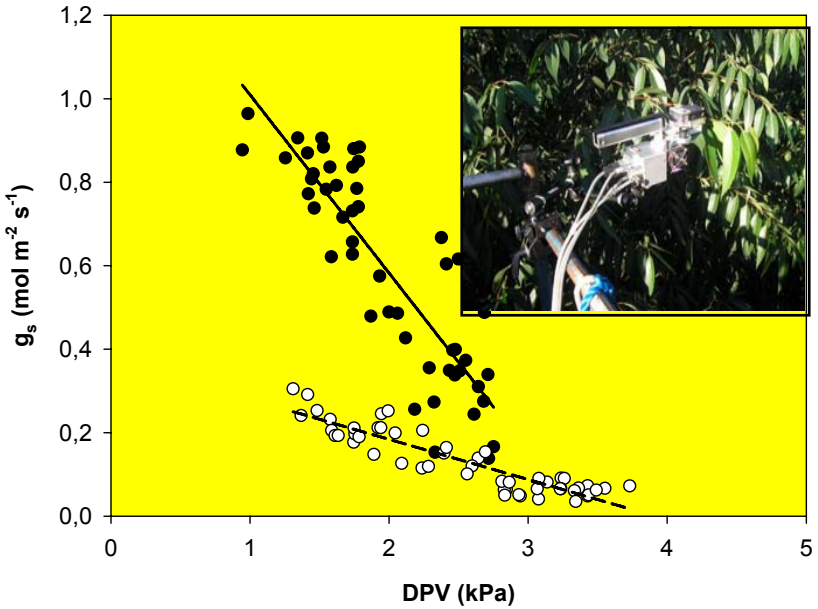
Schimel et al. 1996

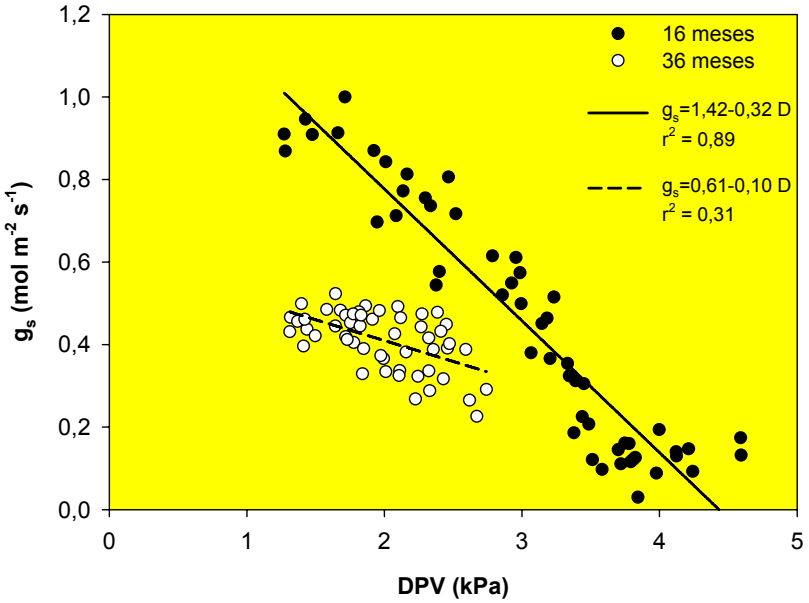
Drainage = PPT – WNPP / WUE

Important Questions

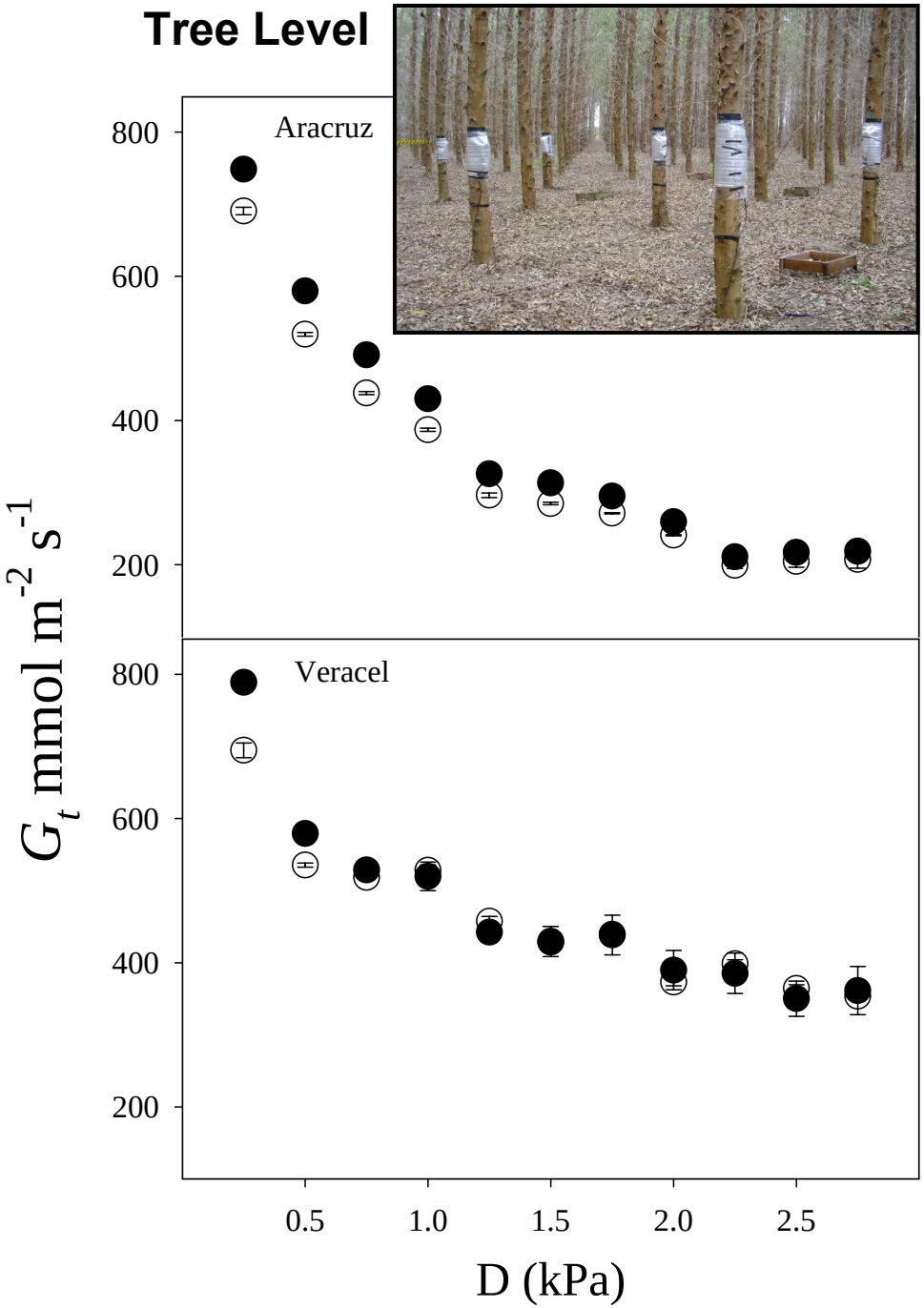
- **Are the Forest Plantations Water Limited ?**
- **How much (more) water they (can) use ?**
- **What is the WUE in these plantations ?**
- **Does *Eucalyptus* in tropical conditions control water use ?**
- **How significant is the WU in the hydrologic balance ?**

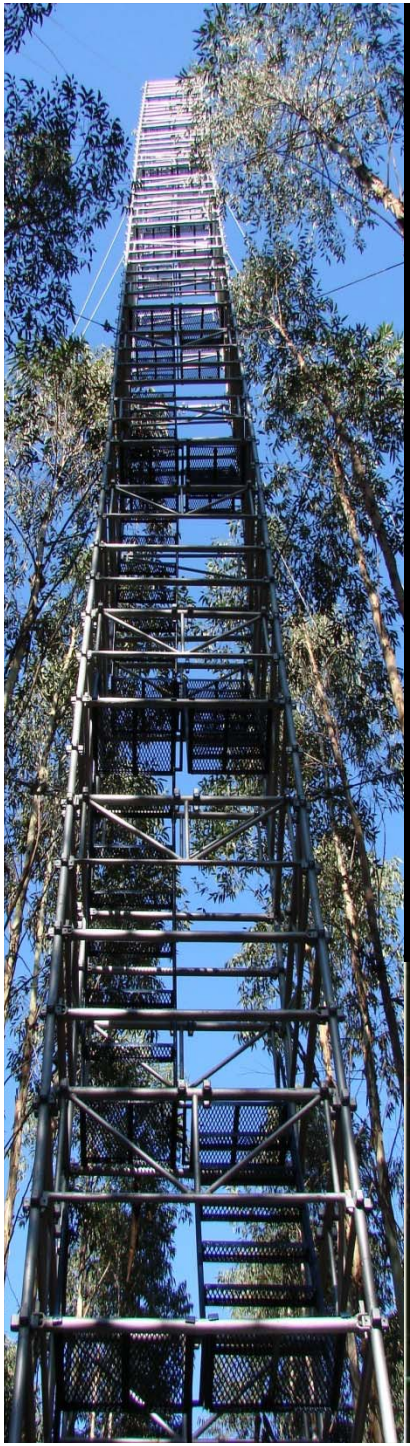
Leaf Level

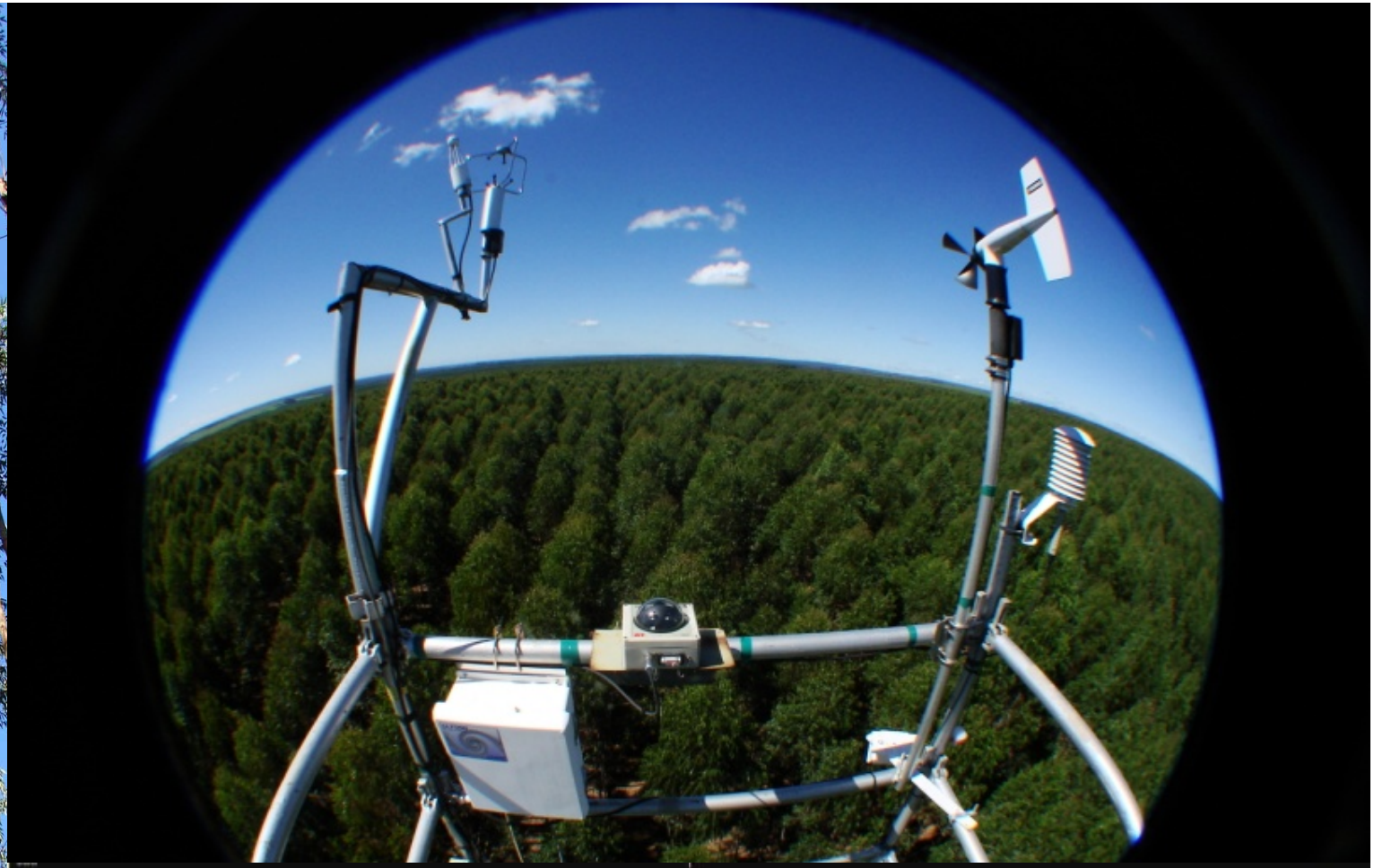


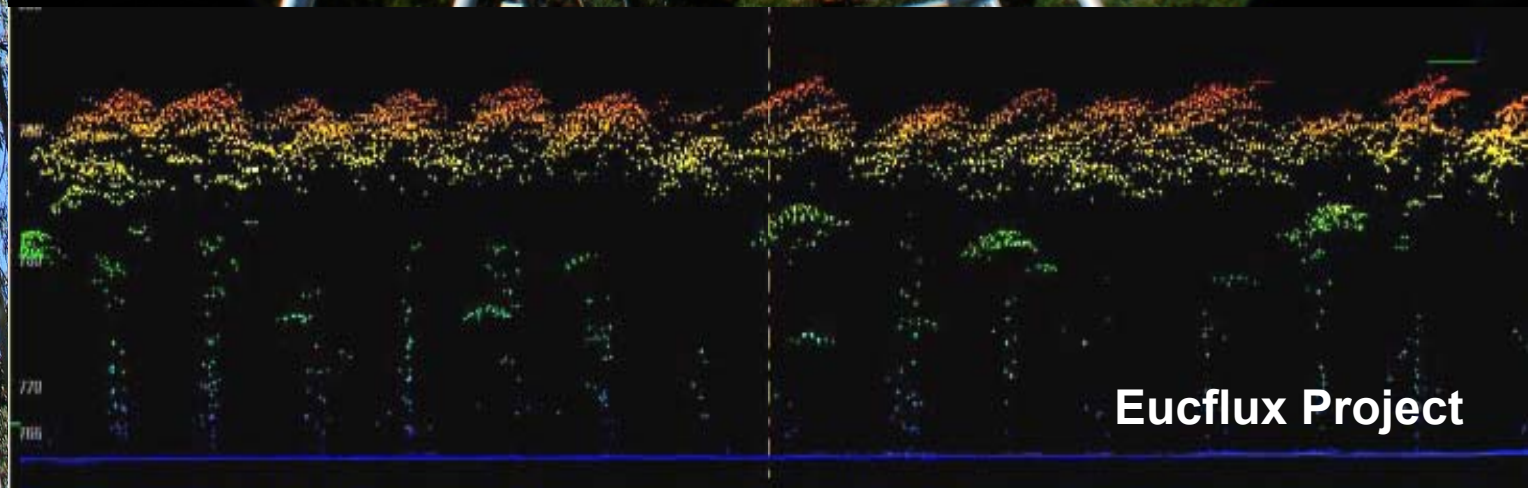


Tree Level

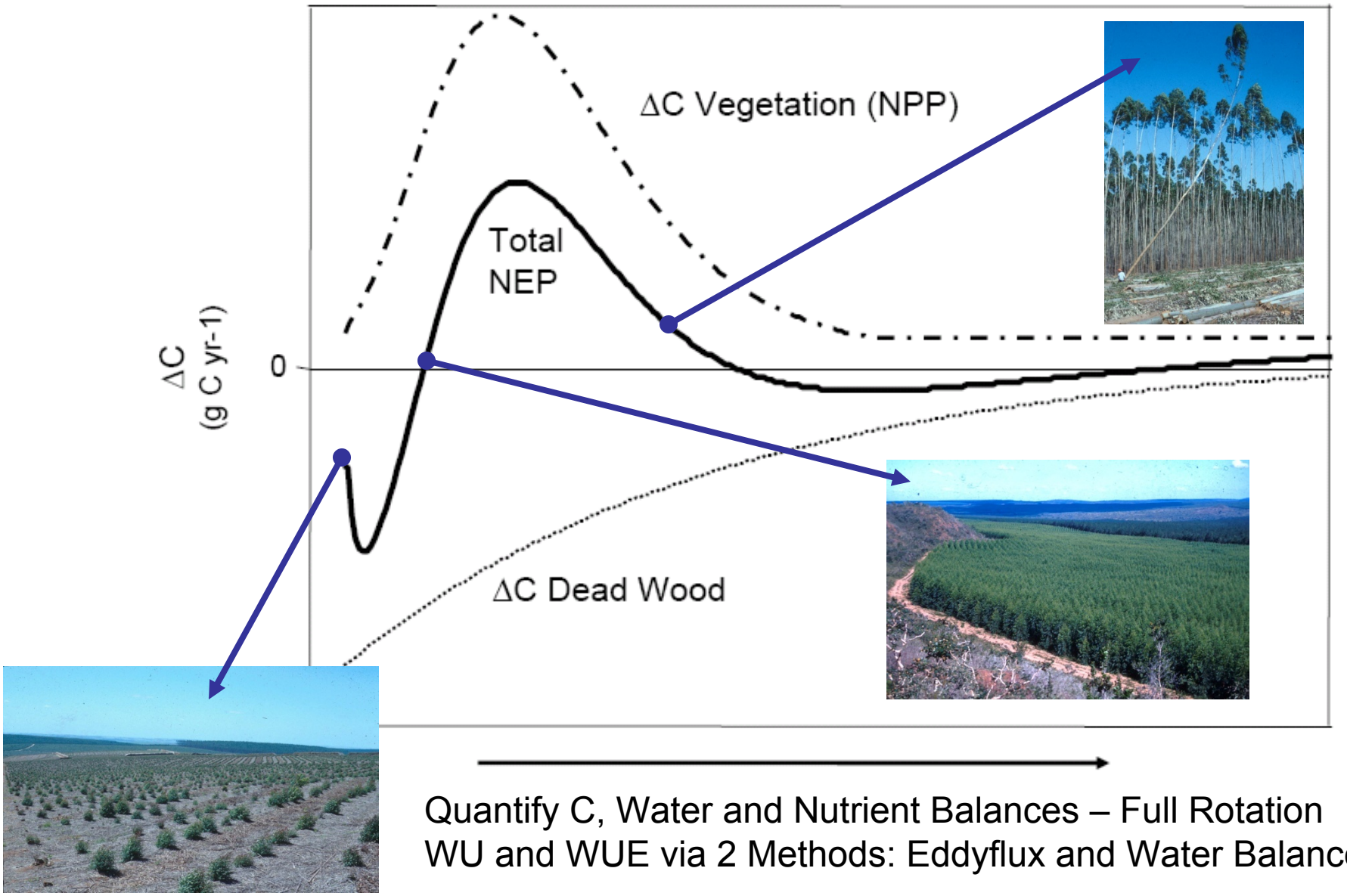




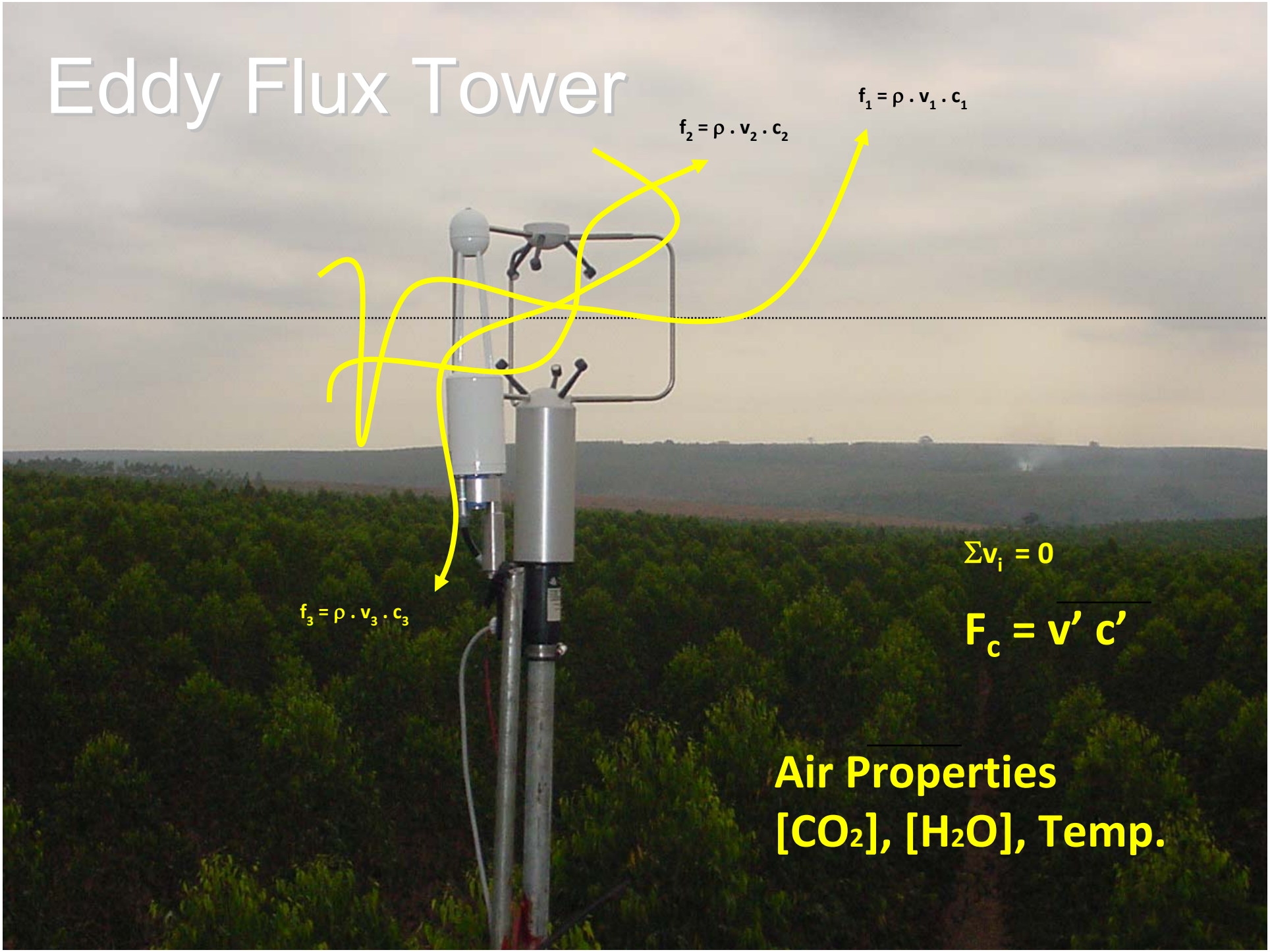


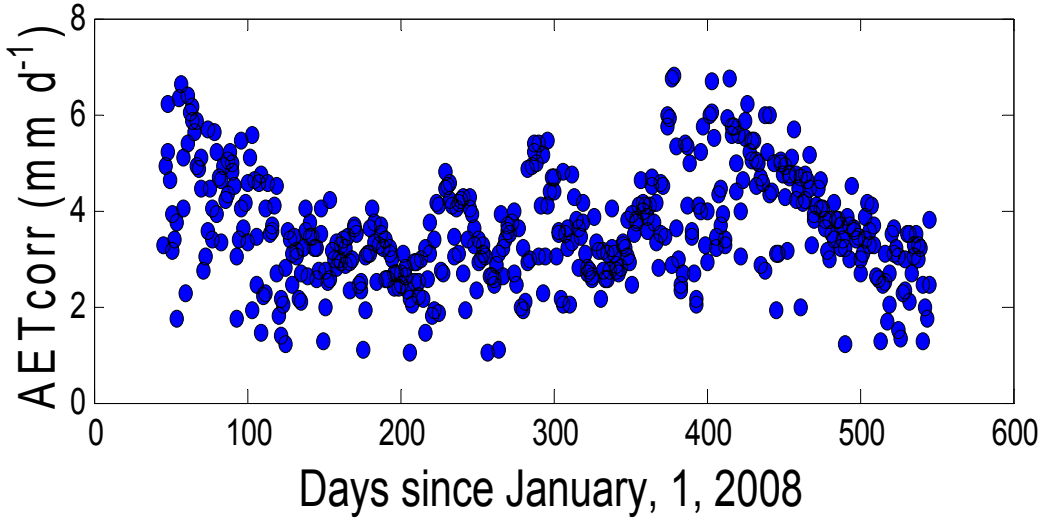

Eucflux Project

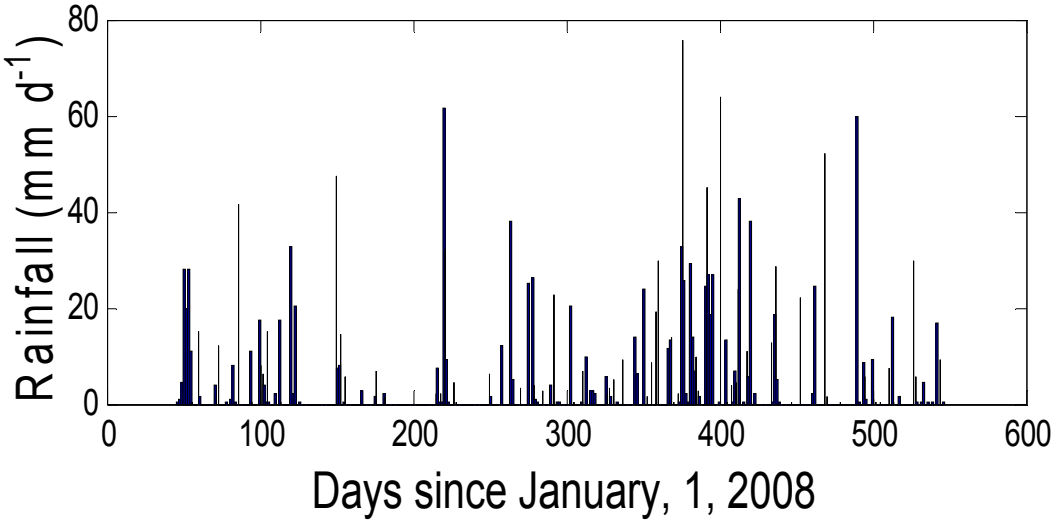
- **Landscape *Eucalyptus* Production Approach**

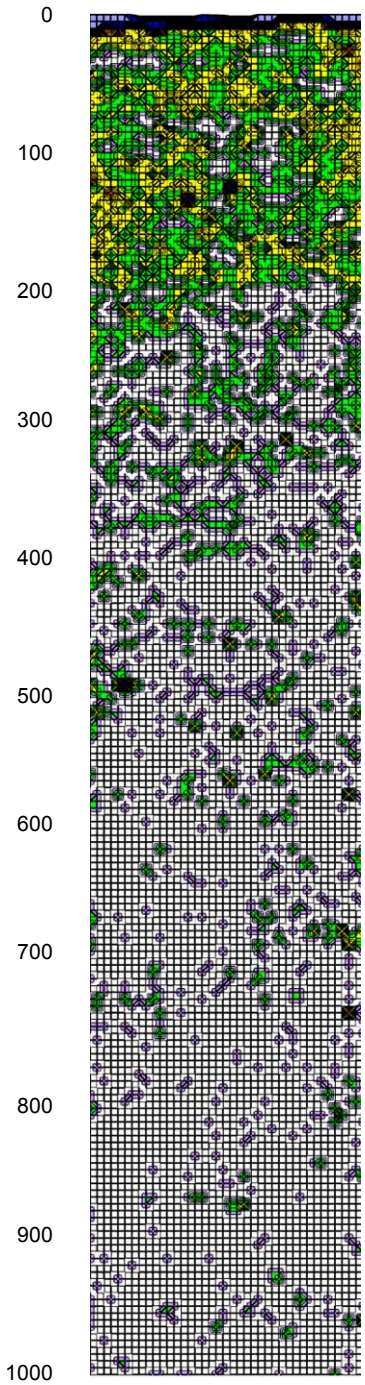


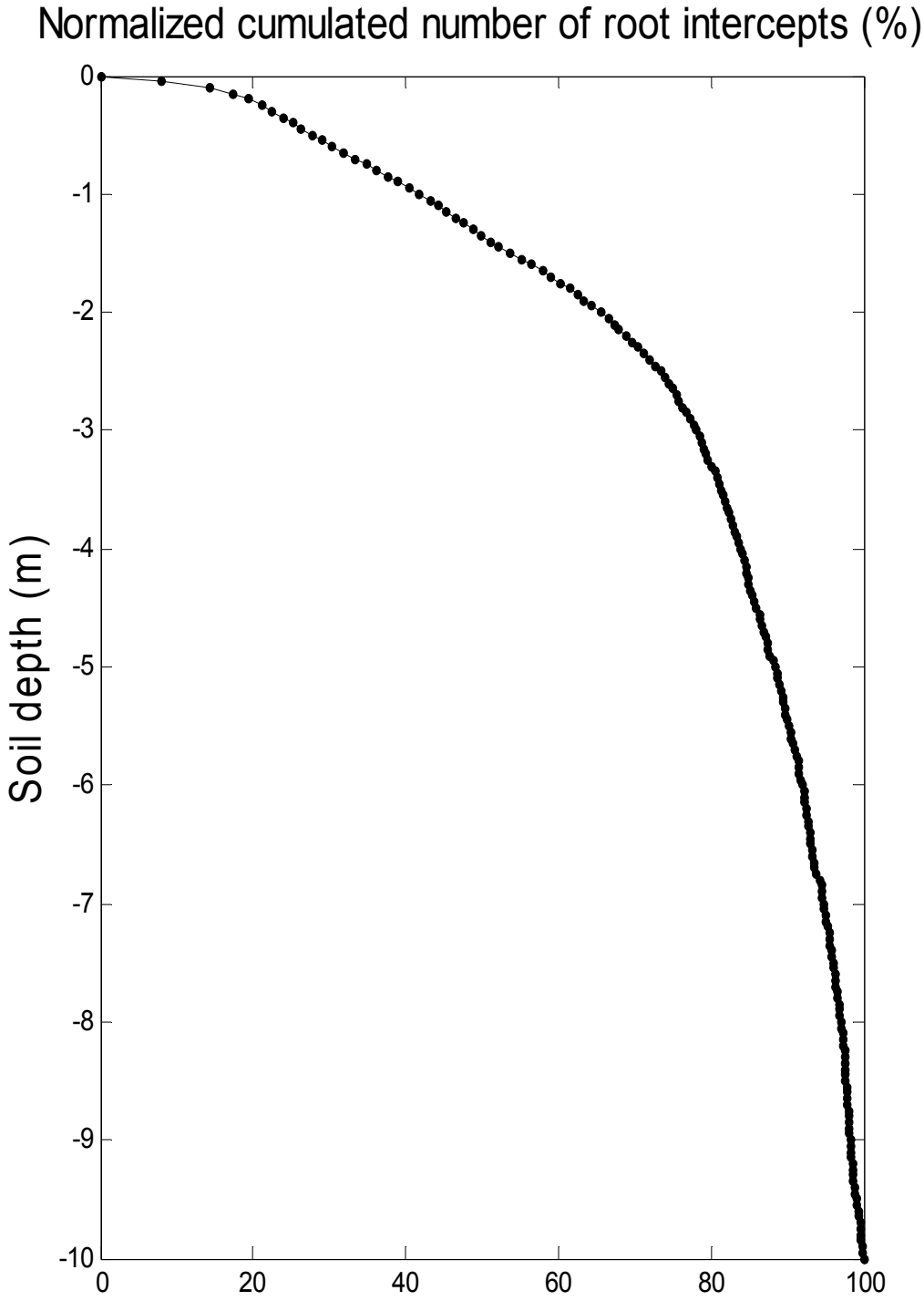
Quantify C, Water and Nutrient Balances – Full Rotation
WU and WUE via 2 Methods: Eddyflux and Water Balance


Eddy Flux Tower
$f_1 = \rho \cdot v_1 \cdot c_1$
$f_2 = \rho \cdot v_2 \cdot c_2$
$f_3 = \rho \cdot v_3 \cdot c_3$
$\Sigma v_i = 0$
$F_c = \overline{v' c'}$
Air Properties
[CO_2], [H_2O], Temp.


AETcorr (mm d-1)
0
2
4
6
8
0
100
200
300
400
500
600
Days since January, 1, 2008

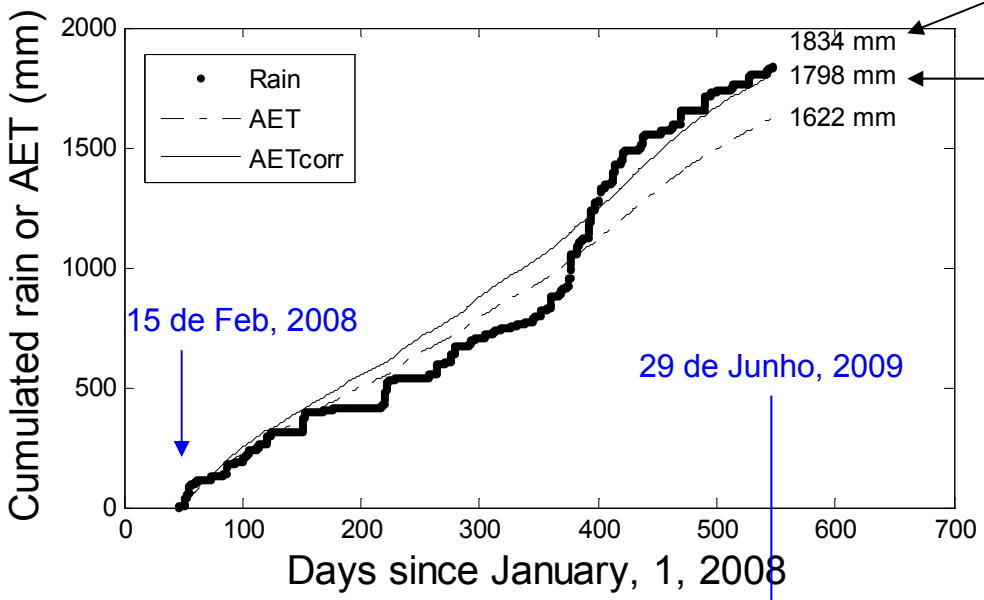

Rainfall (mm d-1)
0
20
40
60
80
0
100
200
300
400
500
600
Days since January, 1, 2008


0
100
200
300
400
500
600
700
800
900
1000

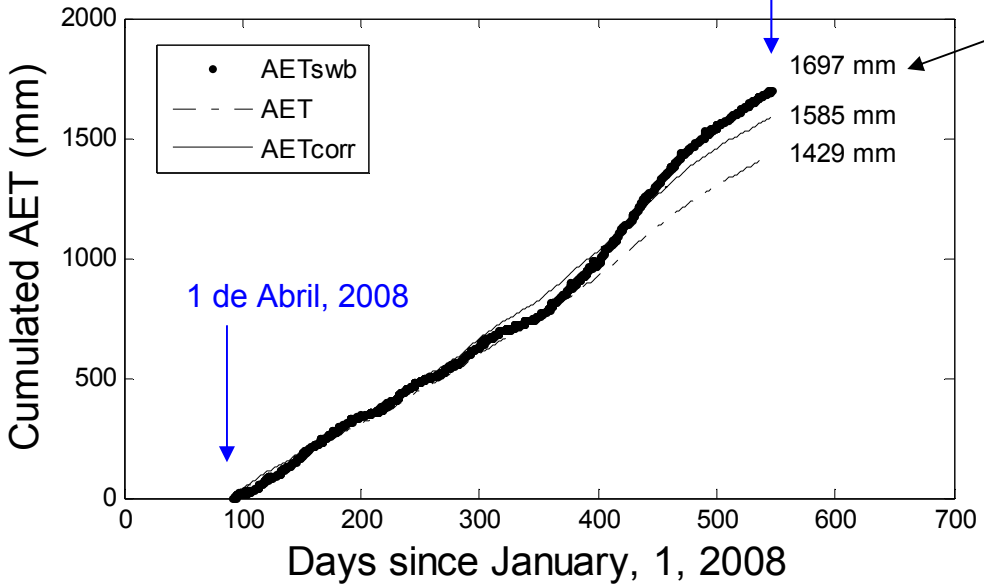

Normalized cumulated number of root intercepts (%)
Soil depth (m)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
20
40
60
80
100

Rainfall 1834 mm – 16 months

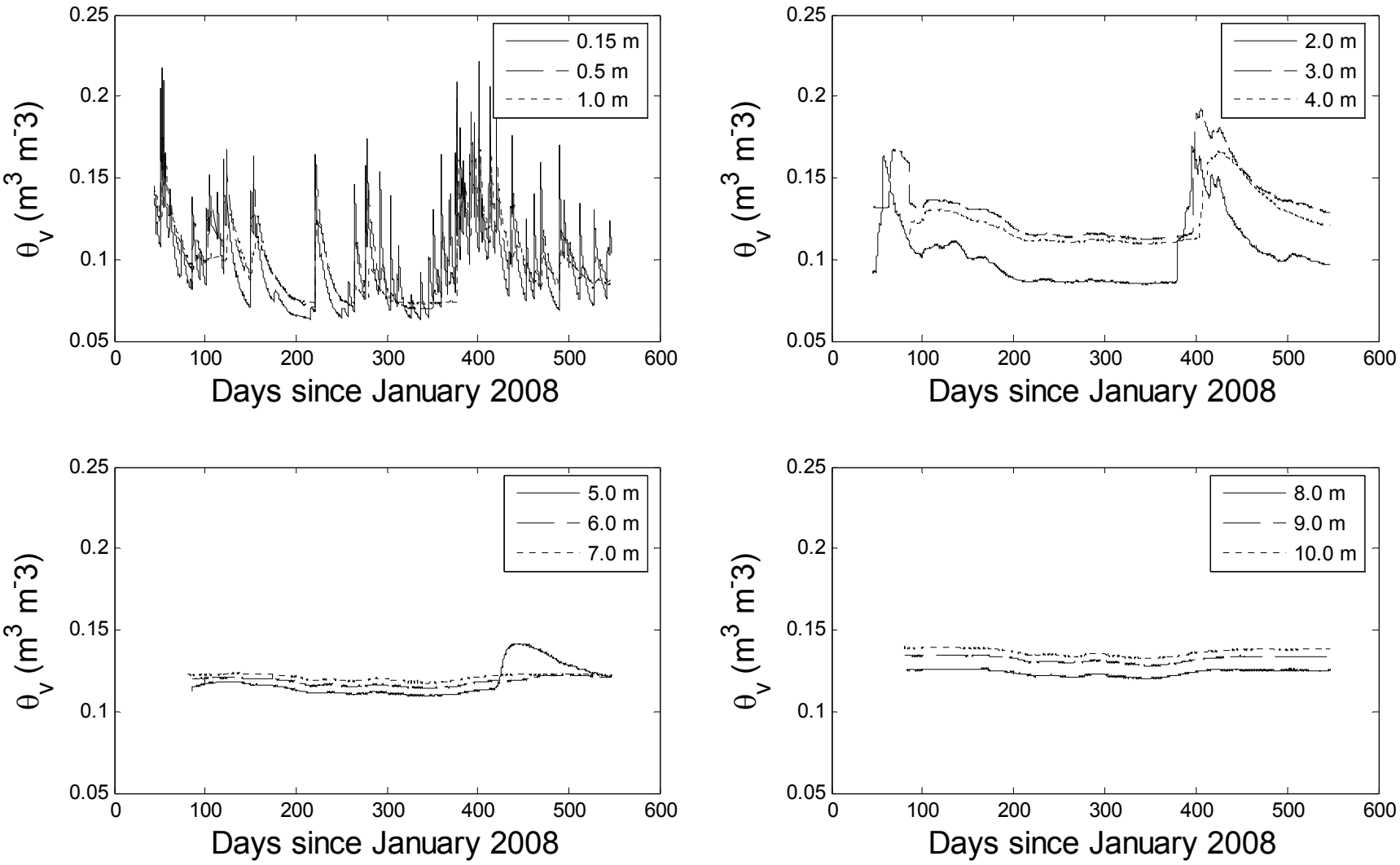
AET Eddy = 1798 mm



AET SWB = 1697 mm – 14 months



Excelent Agreement Between AET via Eddy and Soil Balance


0.15 m
0.5 m
1.0 m
2.0 m
3.0 m
4.0 m
5.0 m
6.0 m
7.0 m
8.0 m
9.0 m
10.0 m
θv (m3 m-3)
Days since January 2008
0.05
0.1
0.15
0.2
0.25
0
100
200
300
400
500
600

Stomatal Conductance Modelling

Psychrometric constant

g_a estimated from eddy-cov (friction velocity) and wind speed)

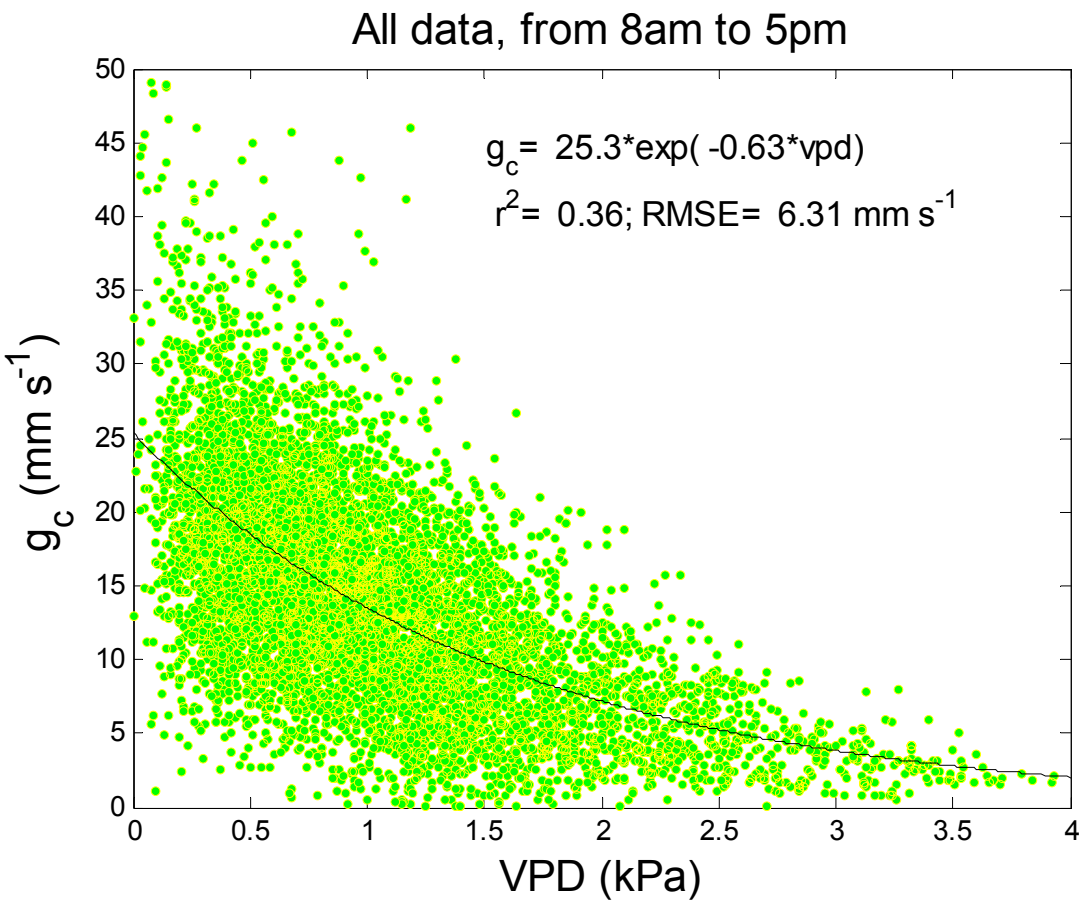
$$g_c = \frac{\gamma\ LE\ g_a}{s\,A + \rho_a\ c_p\ vpd - LE\,(s+\gamma)}$$

Available Energy=Rn-G-S

Slope of saturated water pressure curve

Variation: g_c depends not only on vpd, but also on LAI, plant water status, soil water status, PAR (e.g. Jarvis model), photosynthesis (e.g. Ball and Berry model), etc.

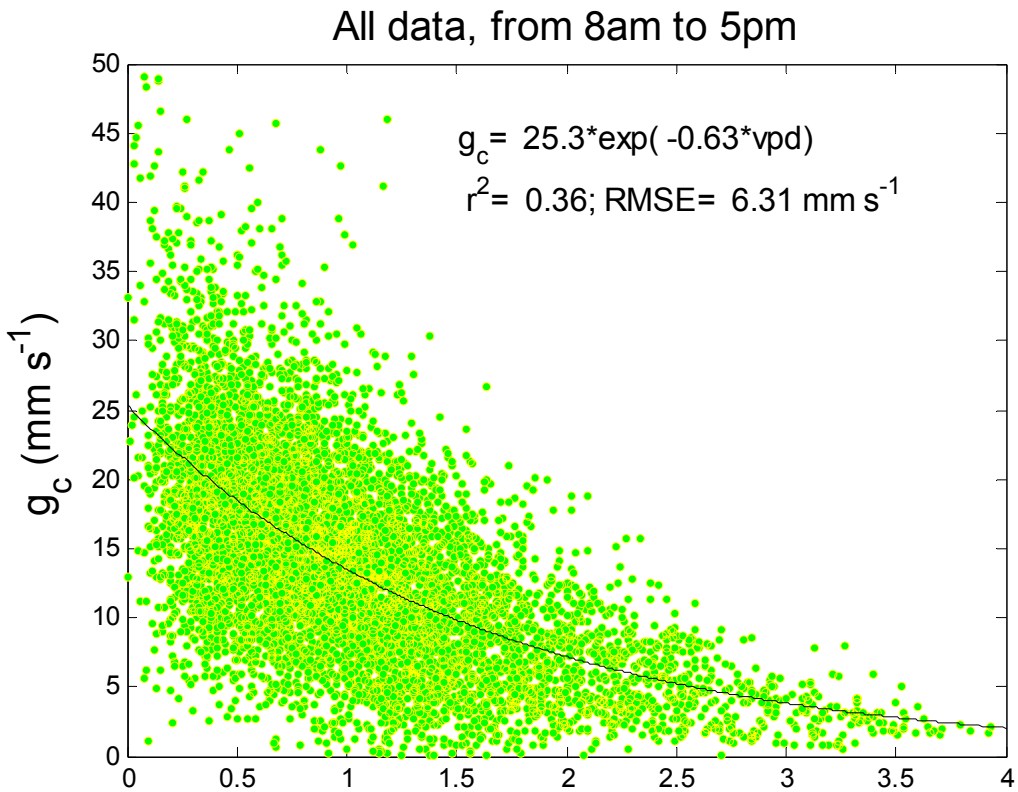
+ computed values of g_c can be affected by soil and litter evaporation



gc (vpd=0) =25 mm/m2/s
= 1 mmol/m2/s

LAI approximamente
= 2.5

gsmax=0.4 mol/m2/s



Ana Eloisa Marrichi, 2009
: gsmax=0.6 mol/m2/s for a 36 month-old BEPP clones

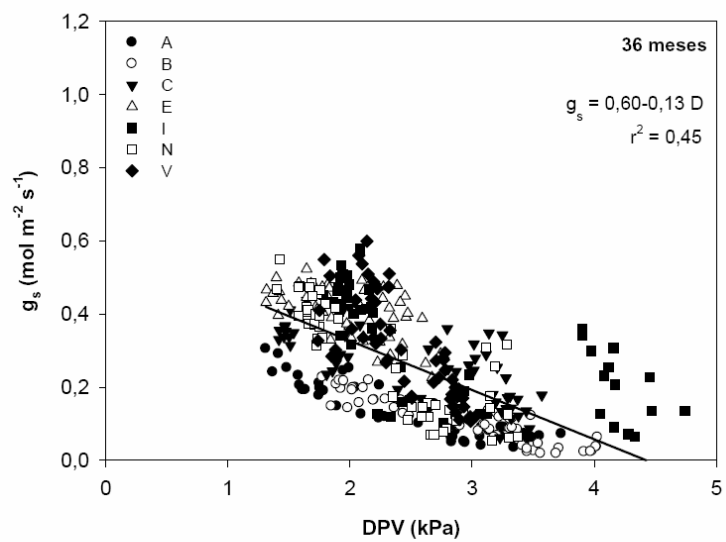


Figura 19 – Representação gráfica da relação entre condutância estomática (g_s) e Déficit de Pressão de Vapor (DPV), para os 7 clones, aos 36 meses

gsmax decreases with stand age:
≈ 1.0 mol/m2/s at 16 months, 0.6 at 36 months, and 0.4 mol/m2/s at the end of the rotation?

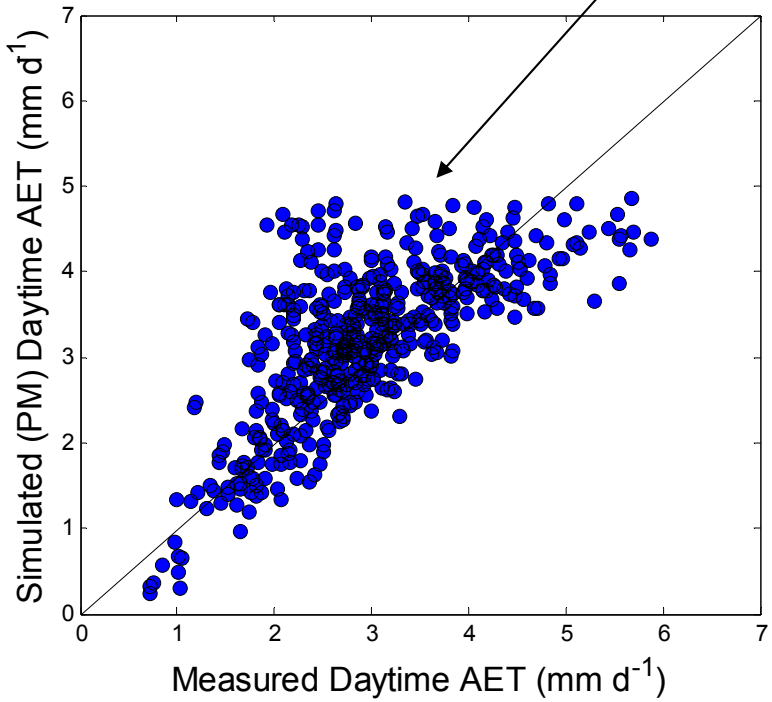
AET by Penman-Monteith with gc=f(vpd)

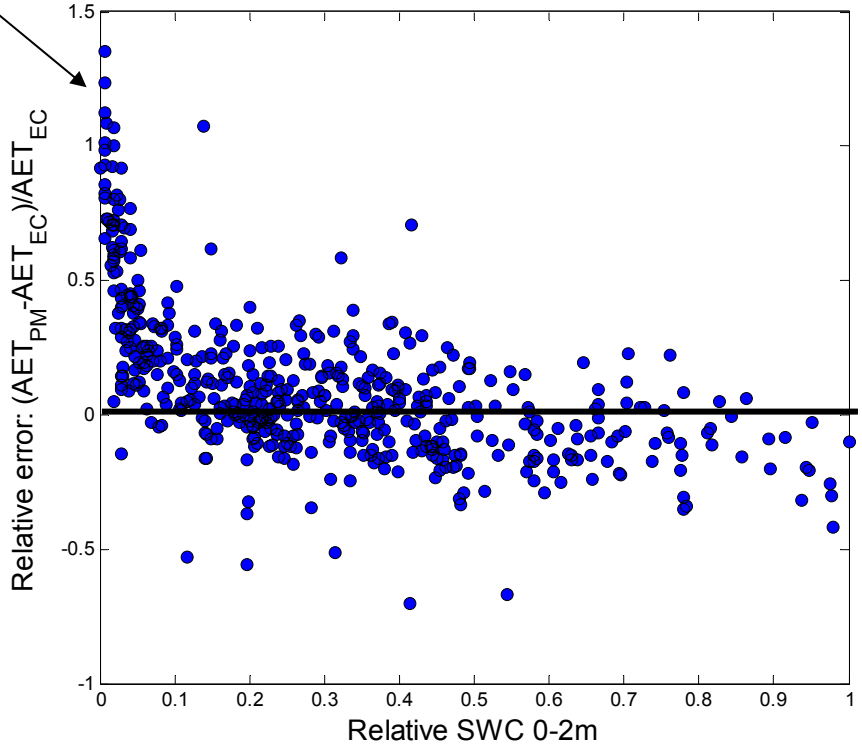
$$LE = \frac{s\,A + \rho_a\, c_p\, vpd\, g_a}{s + \gamma\left(1 + \frac{g_a}{g_c}\right)}$$

g_a=f(wind speed)

g_s=f(vpd)=25.3*exp(-0.63*vpd)

Sobre-estimaçao da AET quando o solo esta seco…

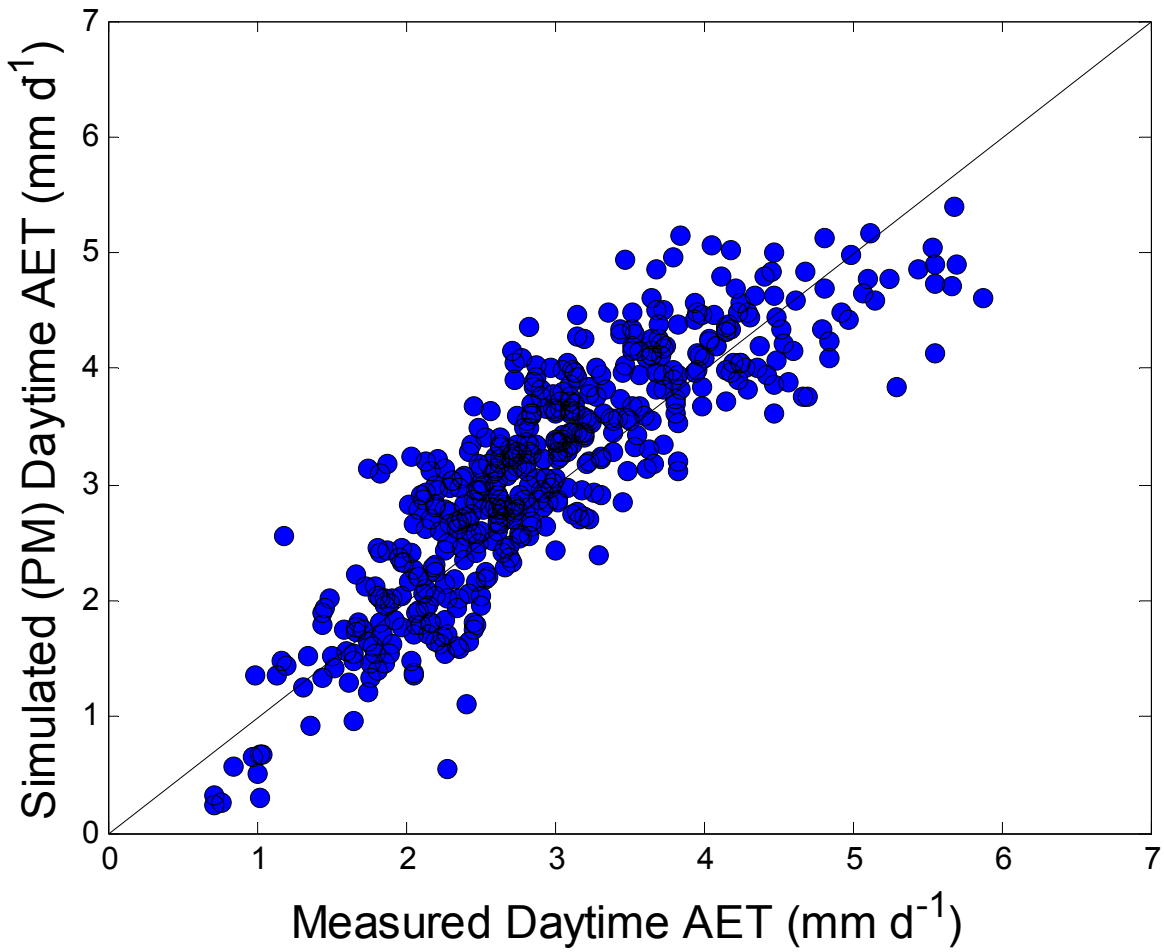




AET by Penman-Monteith with gc=f(vpd, soil moisture)

$$LE = \frac{s\,A + \rho_a\, c_p\, vpd\, g_a}{s + \gamma\left(1 + \frac{g_a}{g_c}\right)}$$

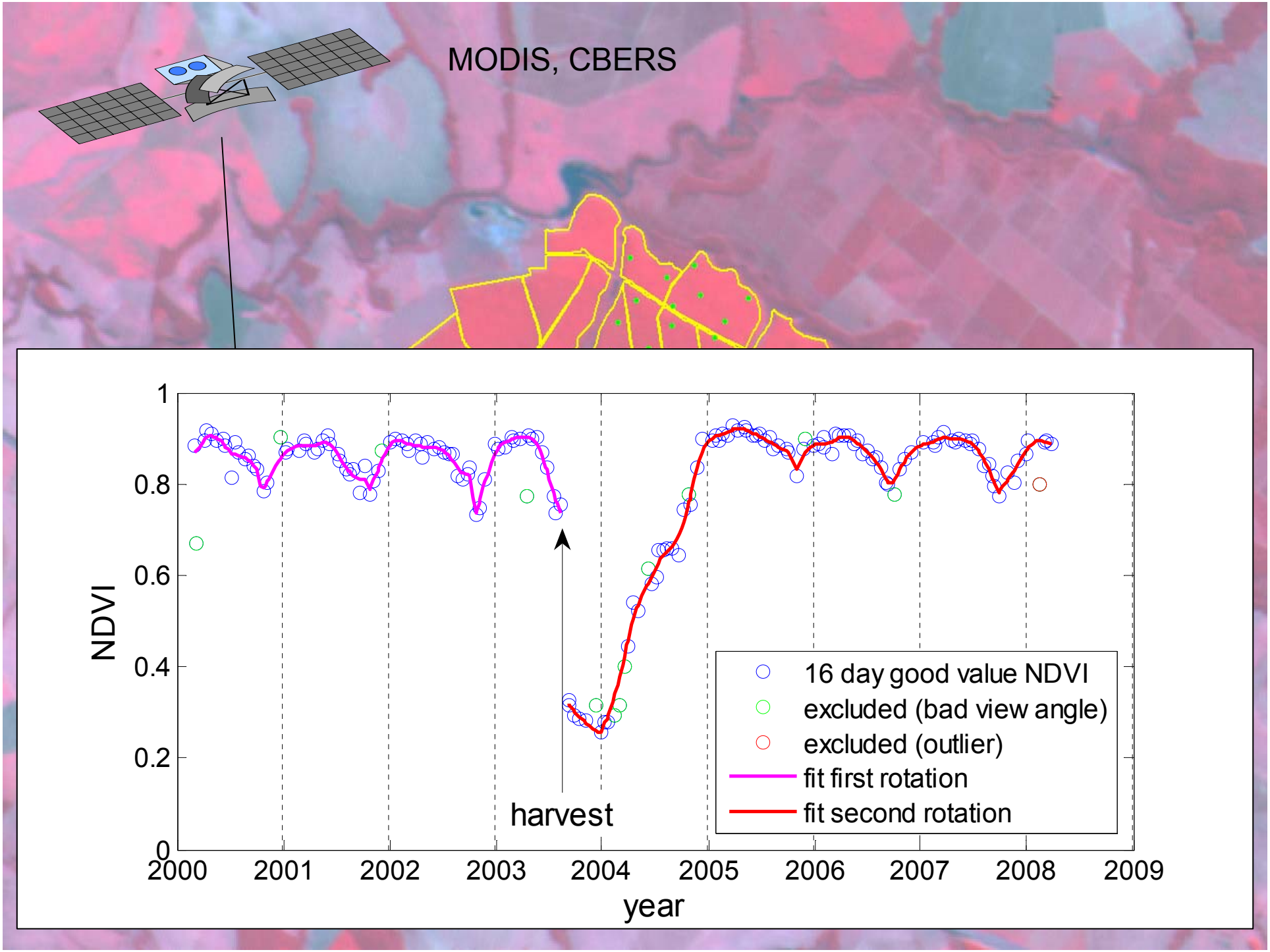
g_s=f(vpd)=25.6*exp(-0.57*vpd)*(1-exp(-33.52*RSWC))



RSWC between 0-2 m => Should be improved with RSWC between 0-10 m…

Simulations should be improved if we account for the effect of LAI on gc, and LAI can be obtained from remote sensing…

Muitas possibilidades para melhorar: so começamos a analisar/utilisar os dados…


MODIS, CBERS
NDVI
year
harvest
16 day good value NDVI
excluded (bad view angle)
excluded (outlier)
fit first rotation
fit second rotation
0
0.2
0.4
0.6
0.8
1
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

C Balance – 1 year (from year 6 to 7)

Ecosystem respiration during the night ~ 5 µmol m^{-2} s^{-1}

Soil respiration being ~ 2.8 µmol m^{-2} s^{-1} => nocturnal aboveground plant respiration ~ 2.2 µmol m^{-2} s^{-1}

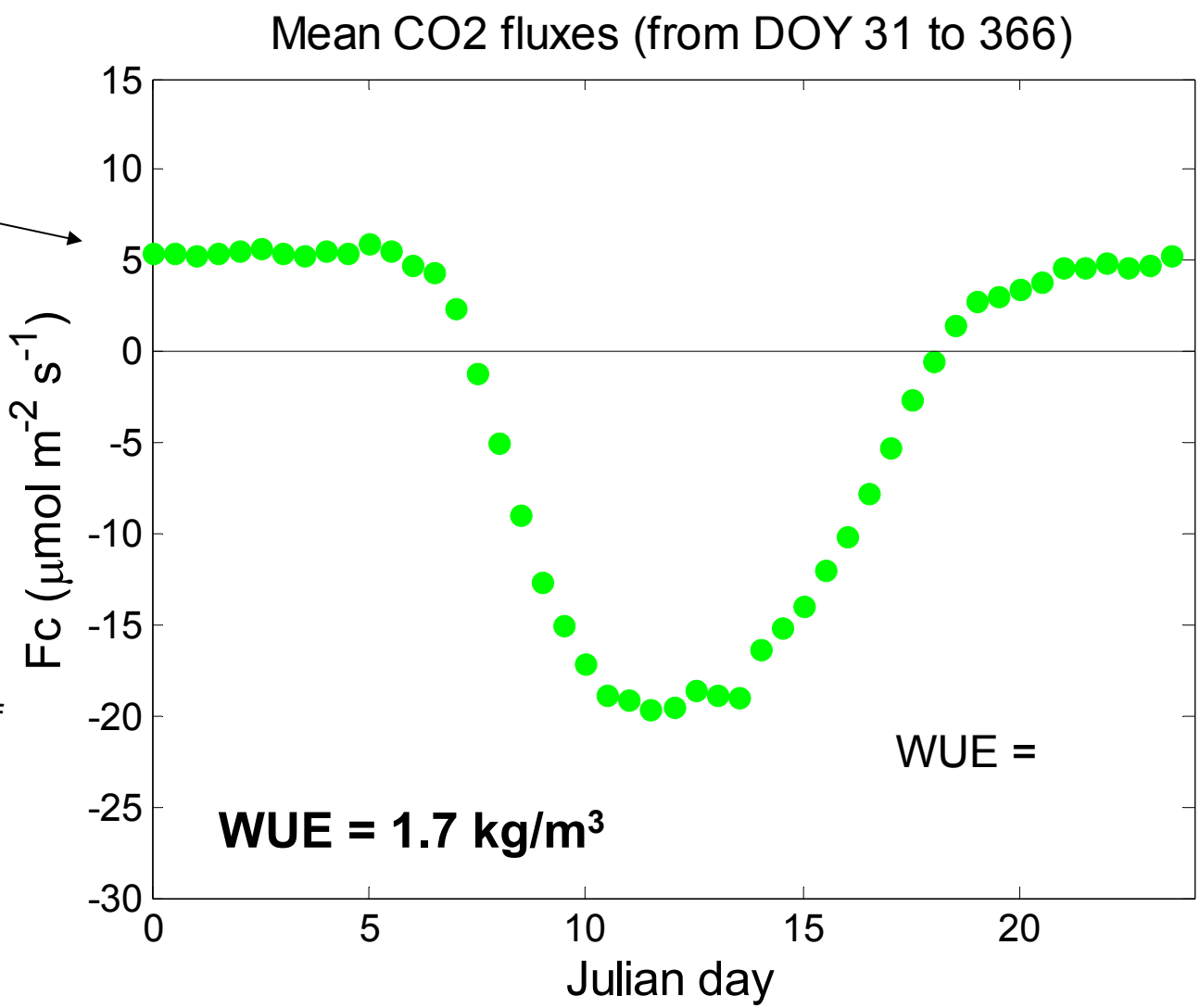
NEE ~ -3.25 µmol m^{-2} s^{-1}

This would represent an annual C sequestration of about 12.3 t C ha^{-1} yr^{-1}

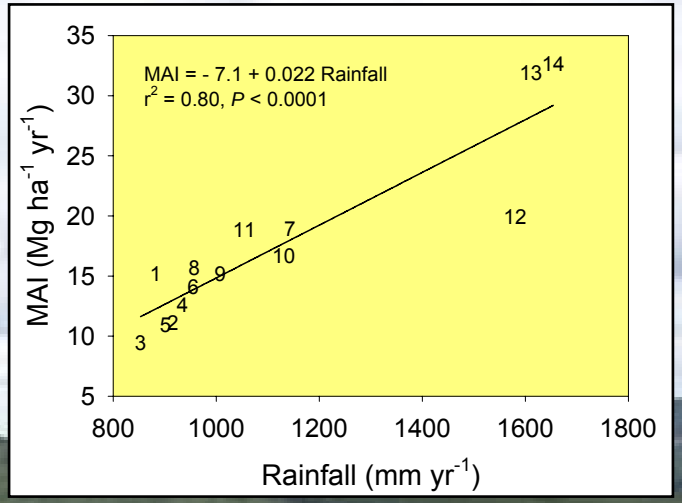
This is close to the biomass increment

32 tDM/ha/yr

48 m3/ha/yr



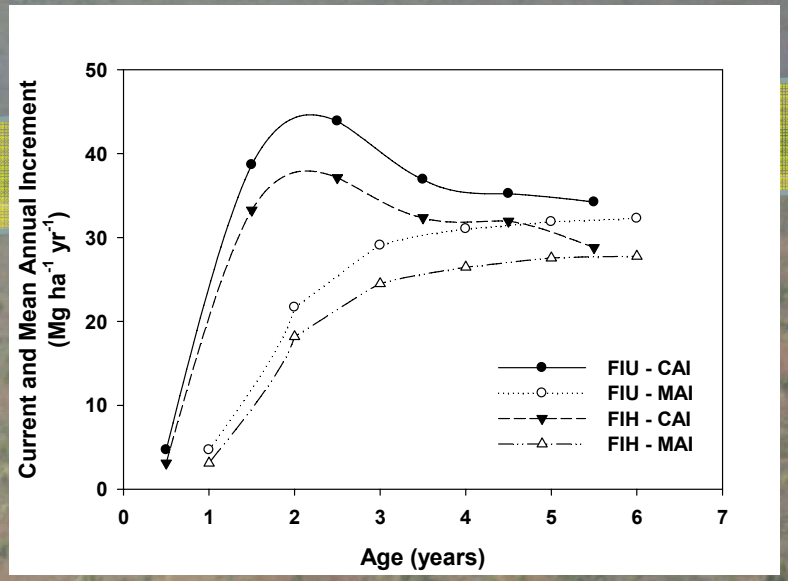
So, is the stomatal conductance control enough ?

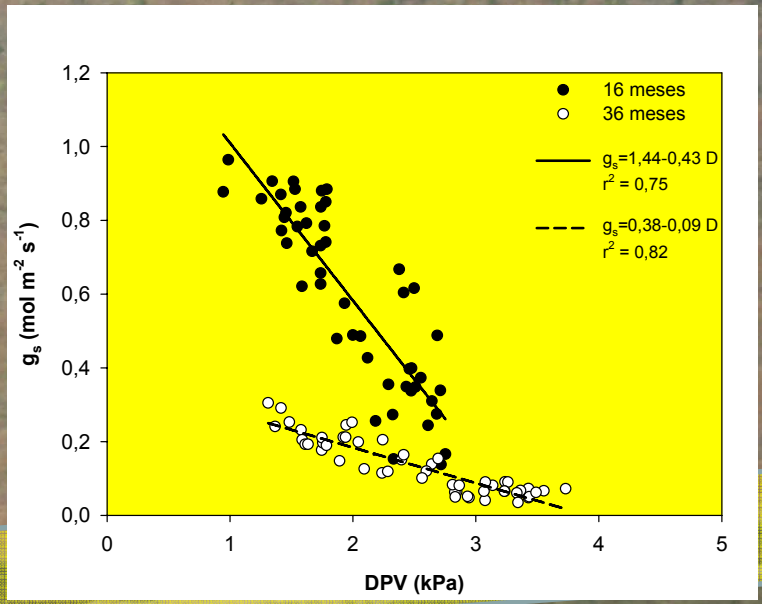


Drainage = PPT – WNPP / WUE

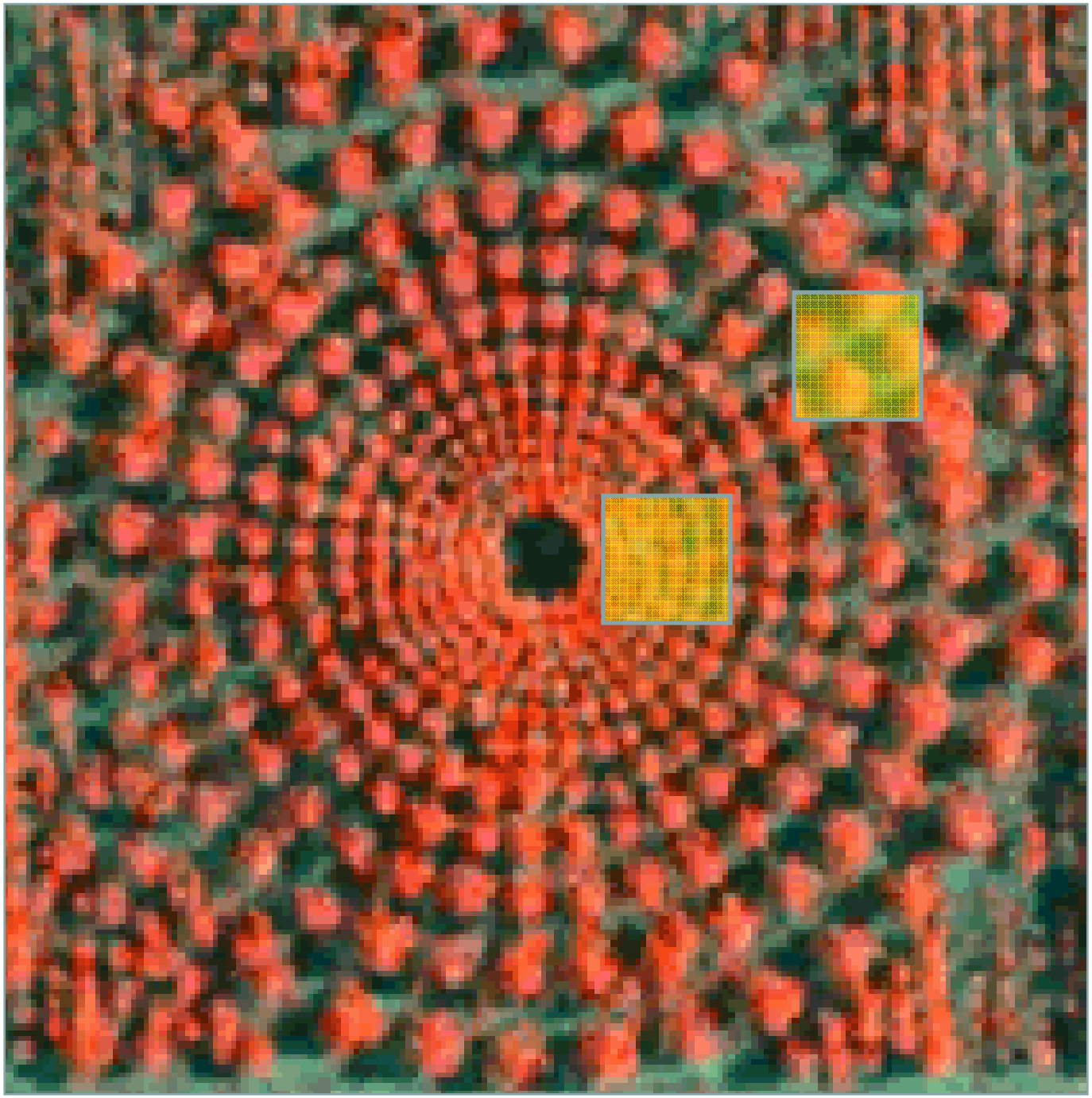
August 2008

October 2008



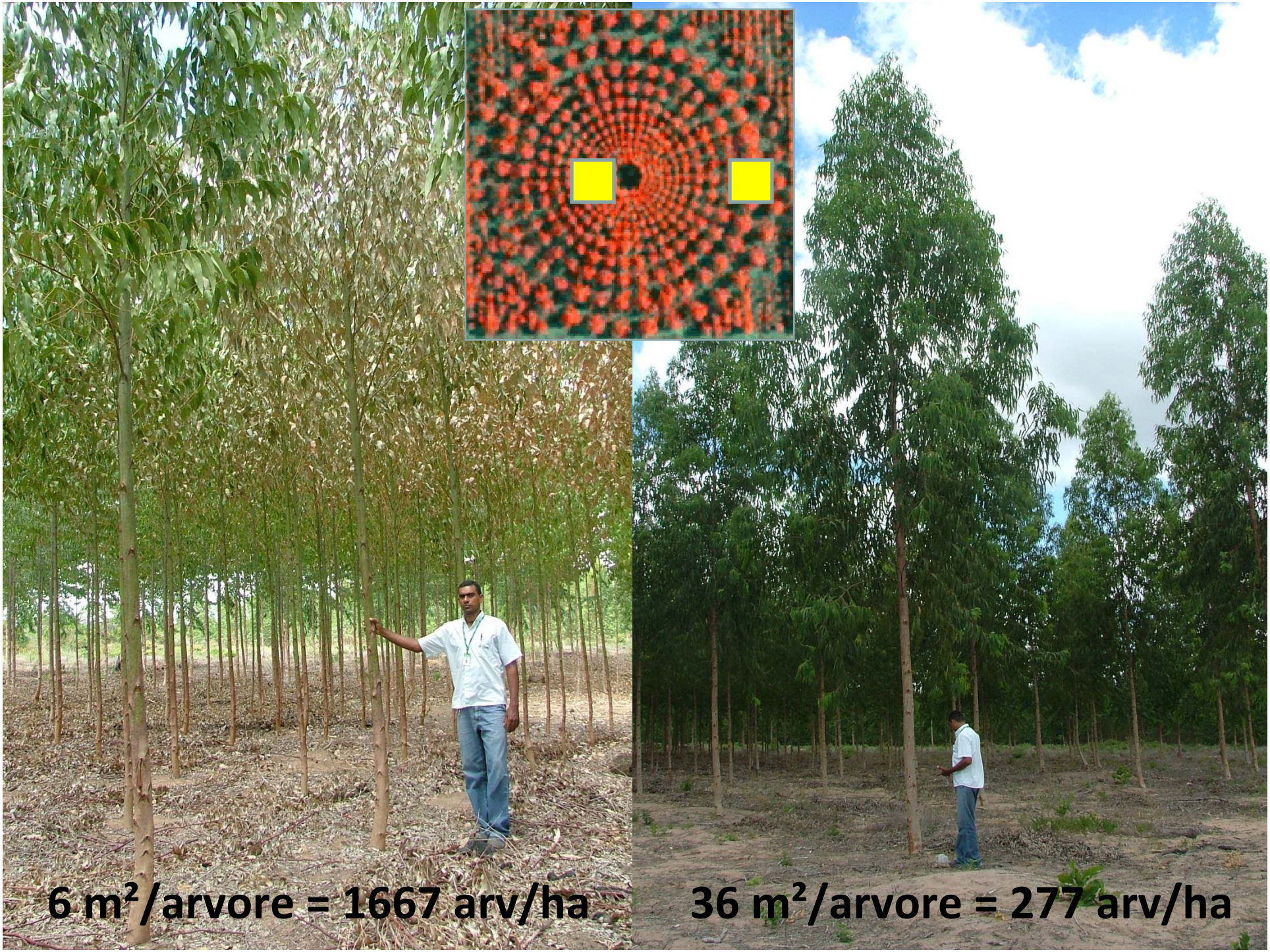


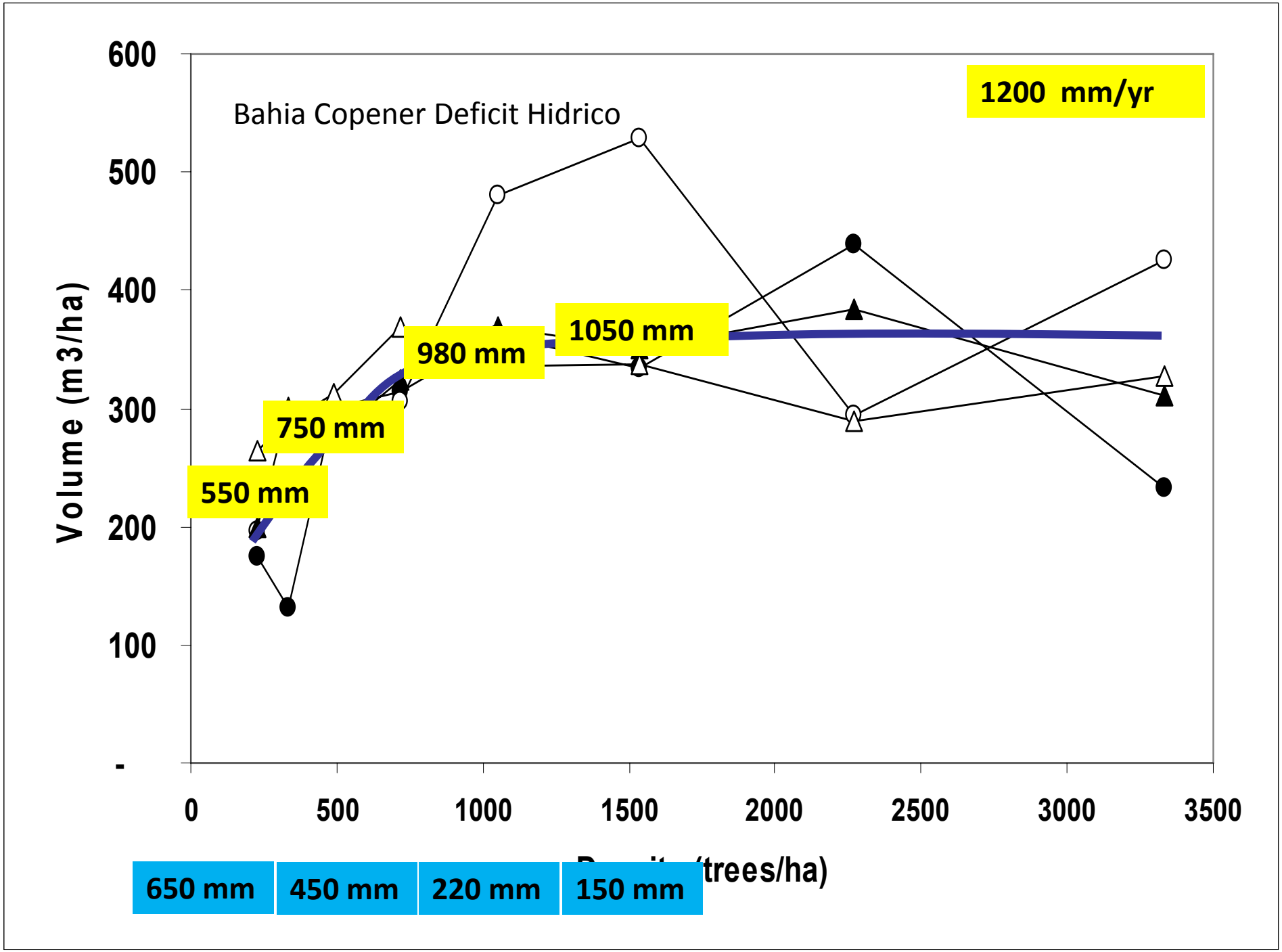
“Leaves Kill Trees”

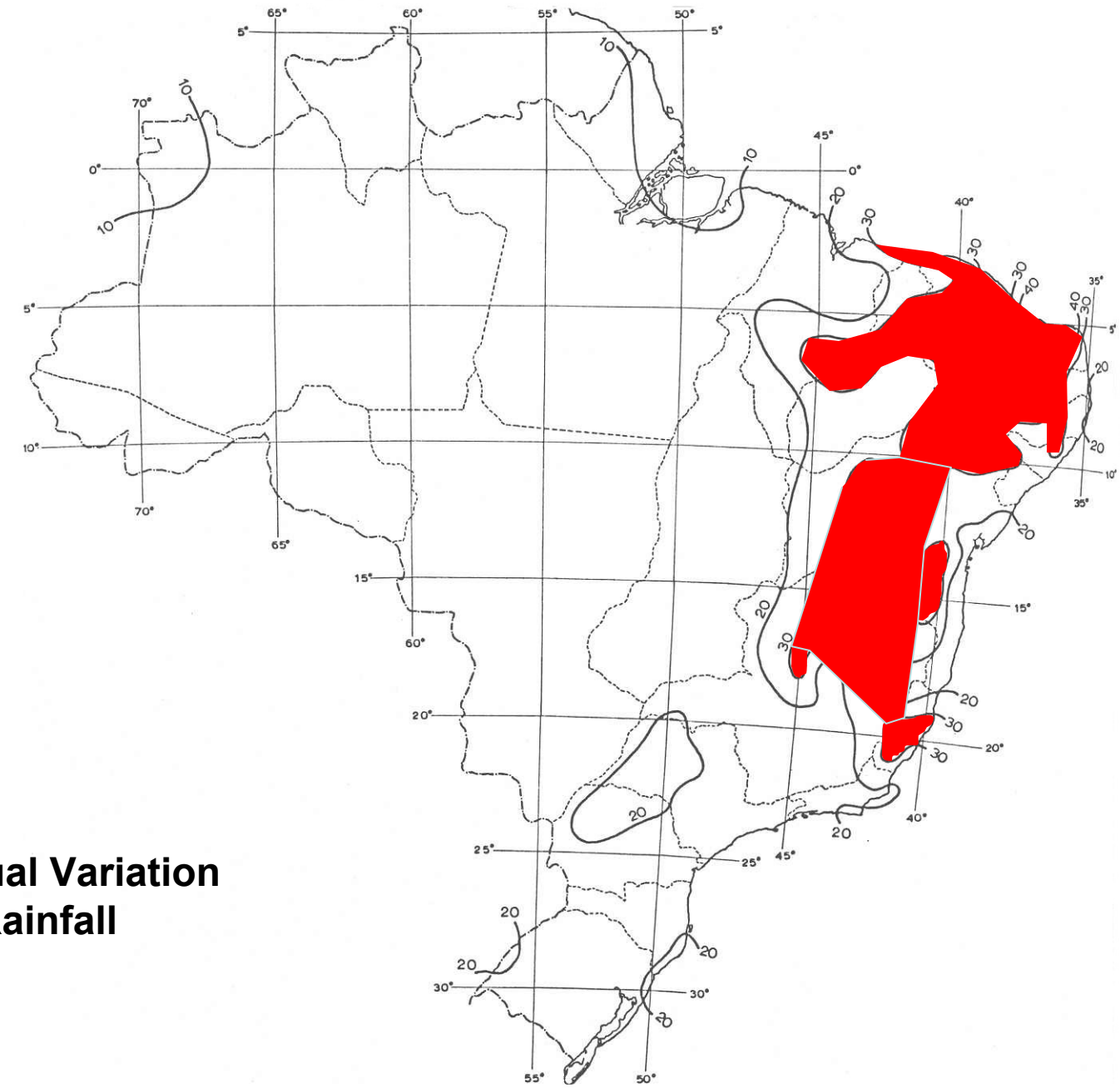


IAF = 2.5 m^2f/m^2s

IAF = 4.5 m^2f/m^2s

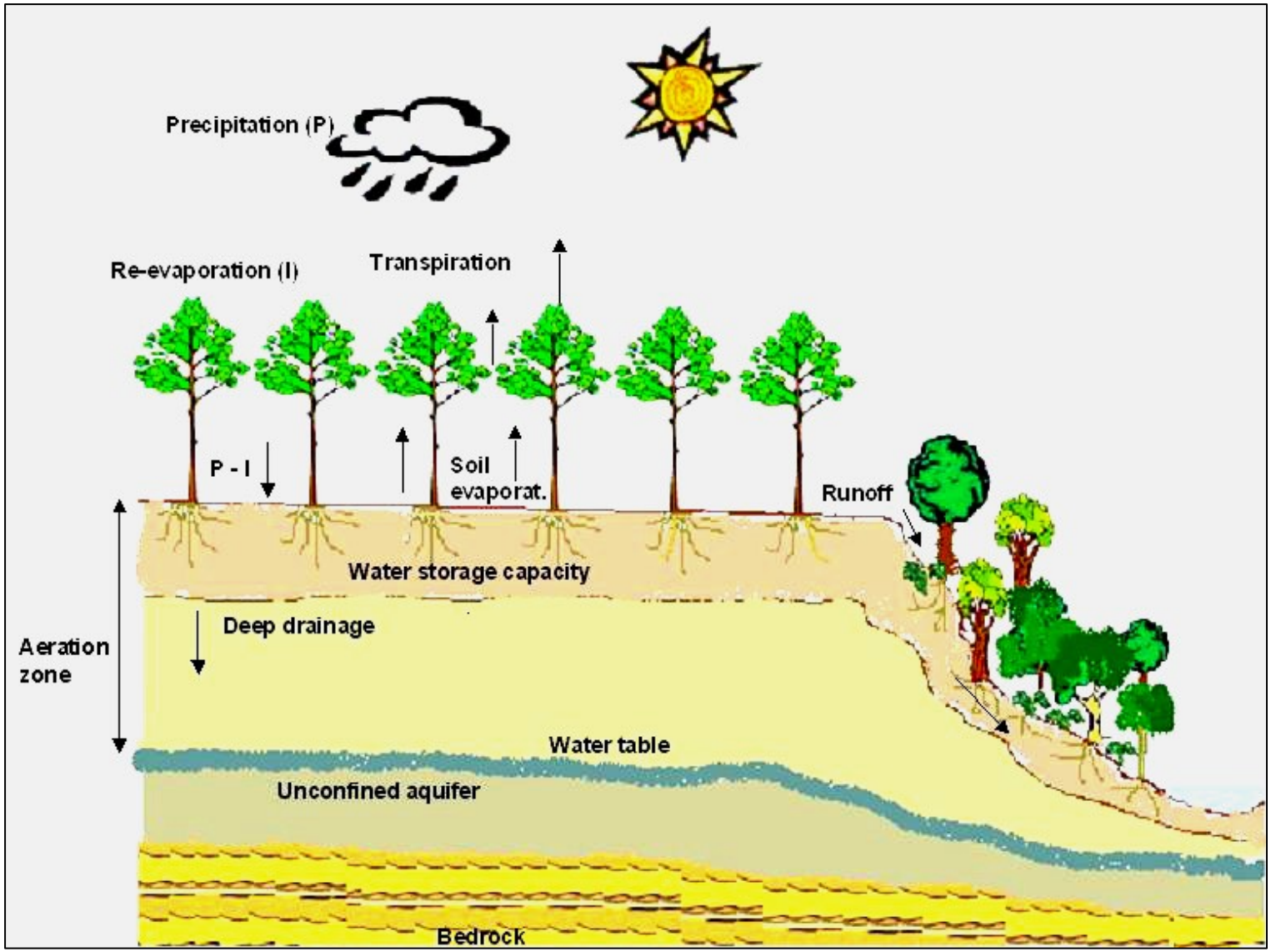

6 m²/arvore = 1667 arv/ha
36 m²/arvore = 277 arv/ha


Bahia Copener Deficit Hidrico
1200 mm/yr
1050 mm
980 mm
750 mm
550 mm
650 mm
450 mm
220 mm
150 mm
Volume (m3/ha)
600
500
400
300
200
100
-
0
500
1000
1500
2000
2500
3000
3500
trees/ha)

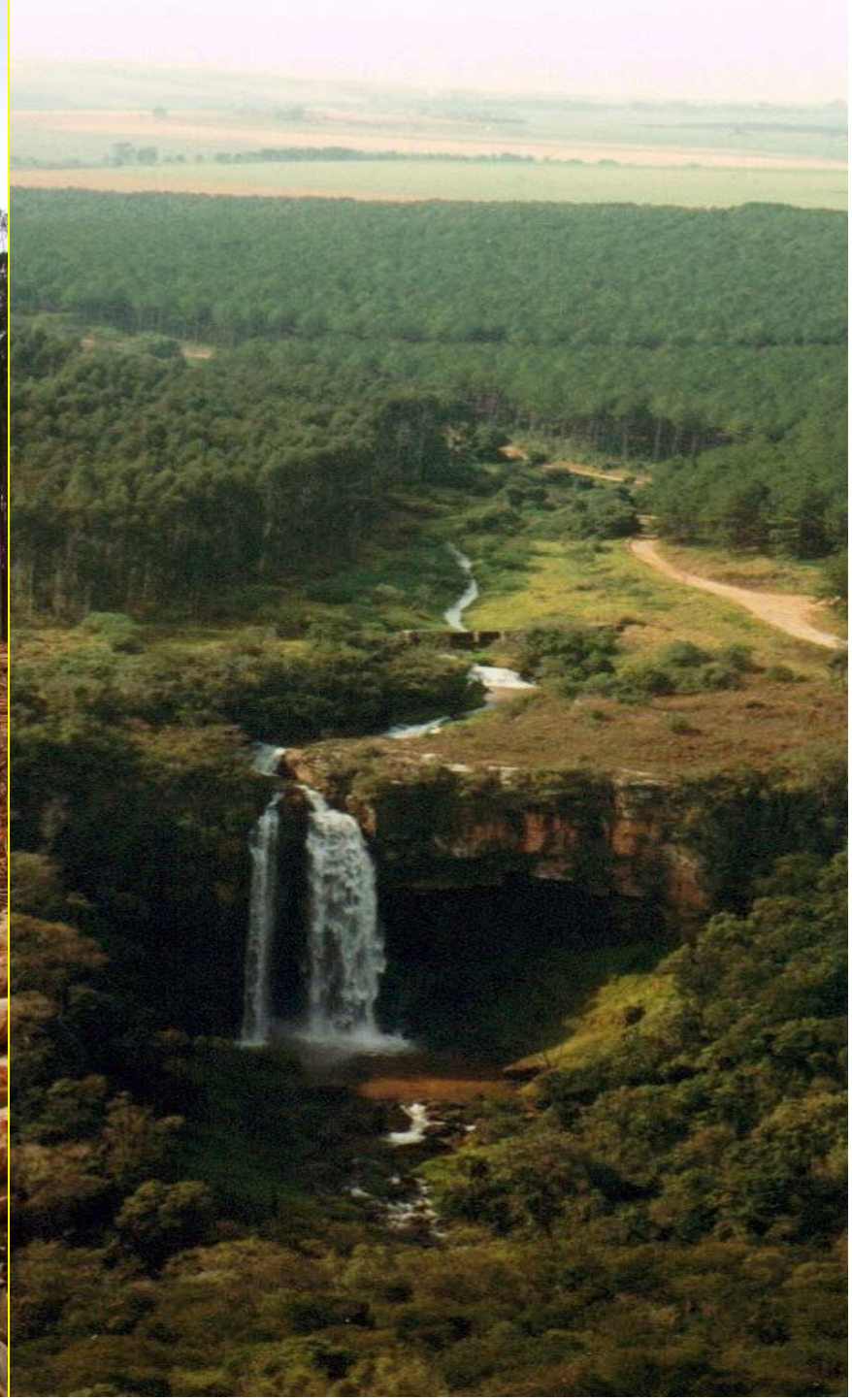


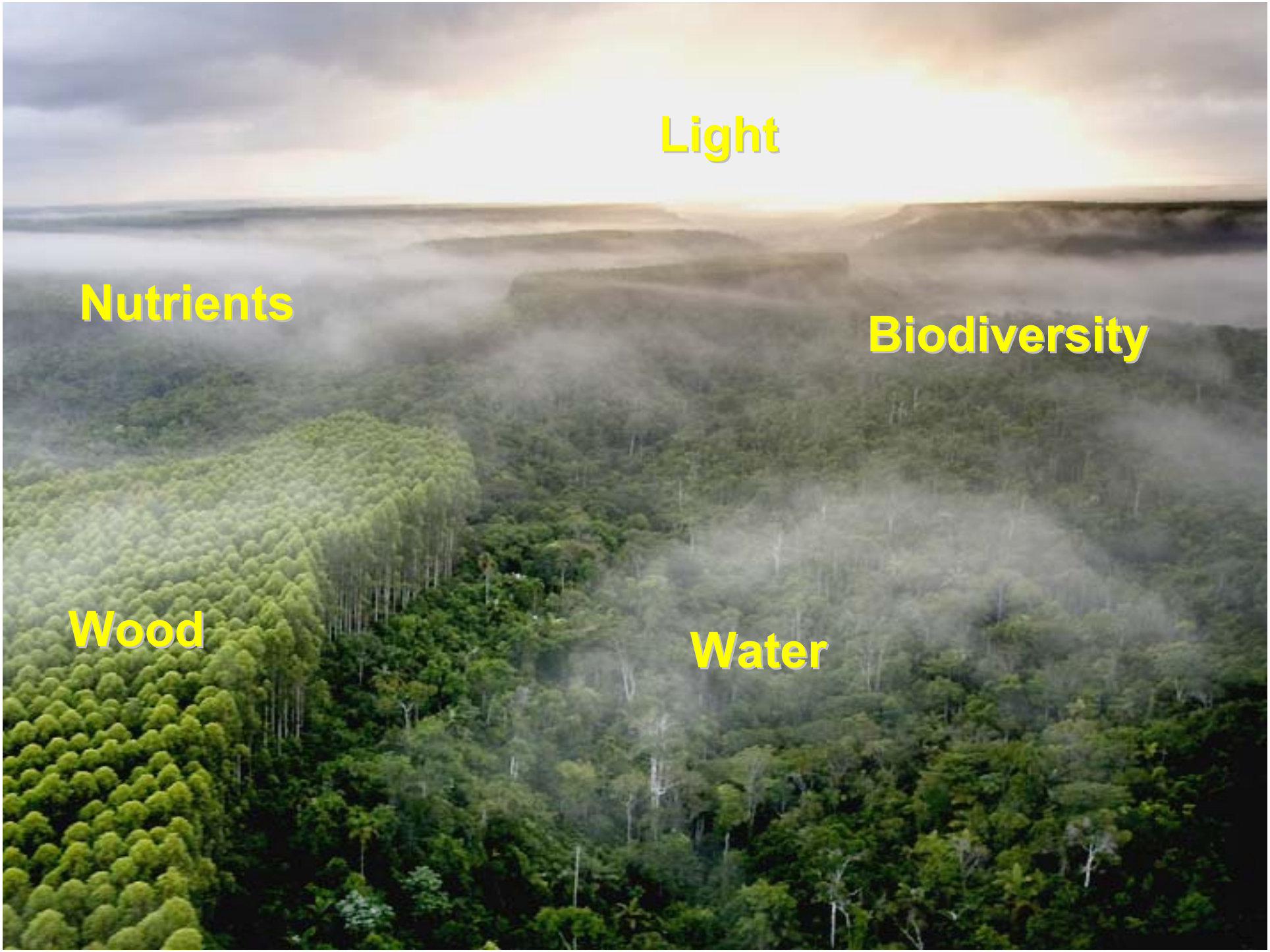
Interannual Variation in Rainfall

Modelling Knowledge is Needed

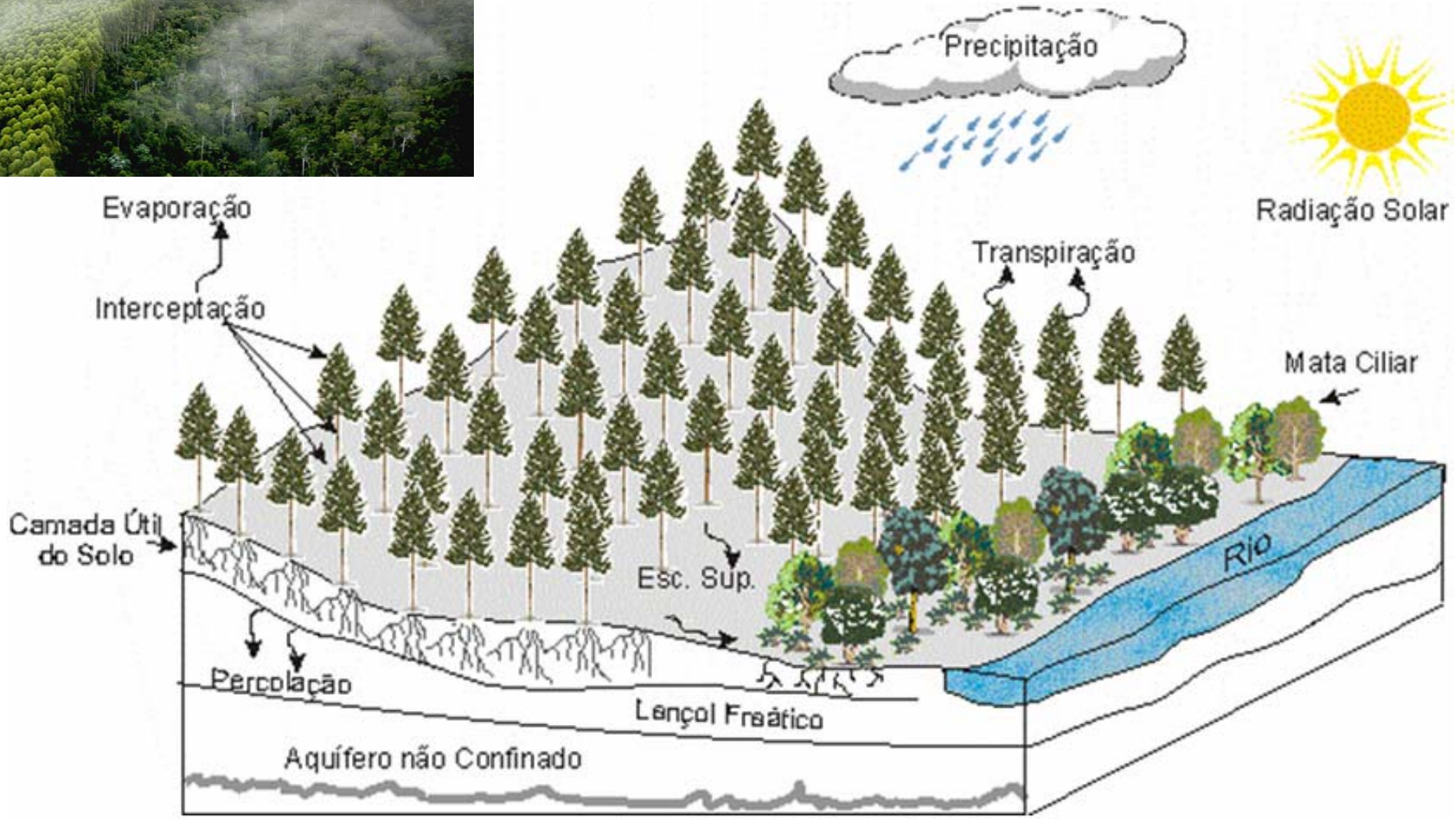


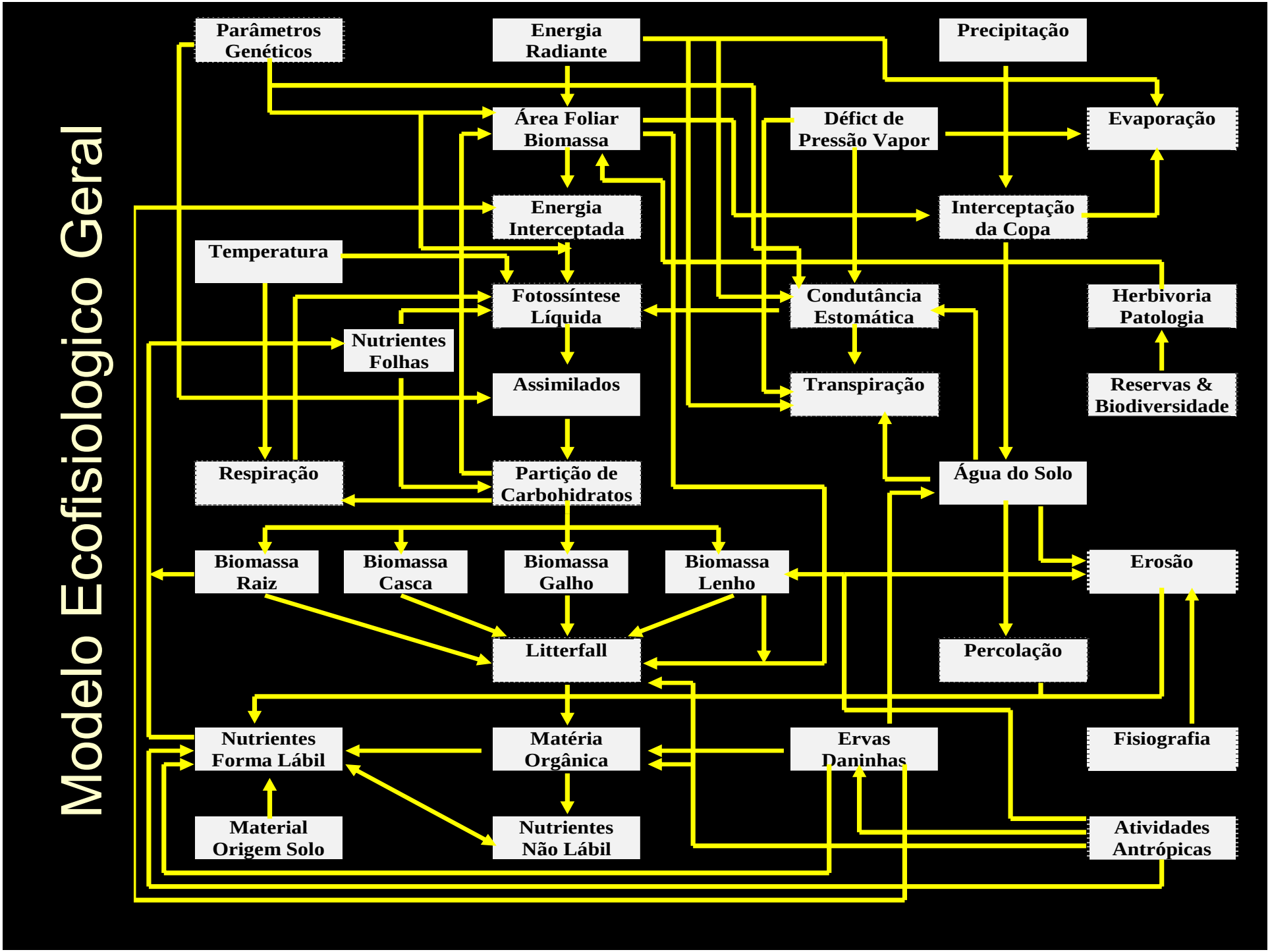
Operational Decisions are Needed




Light
Nutrients
Biodiversity
Wood
Water

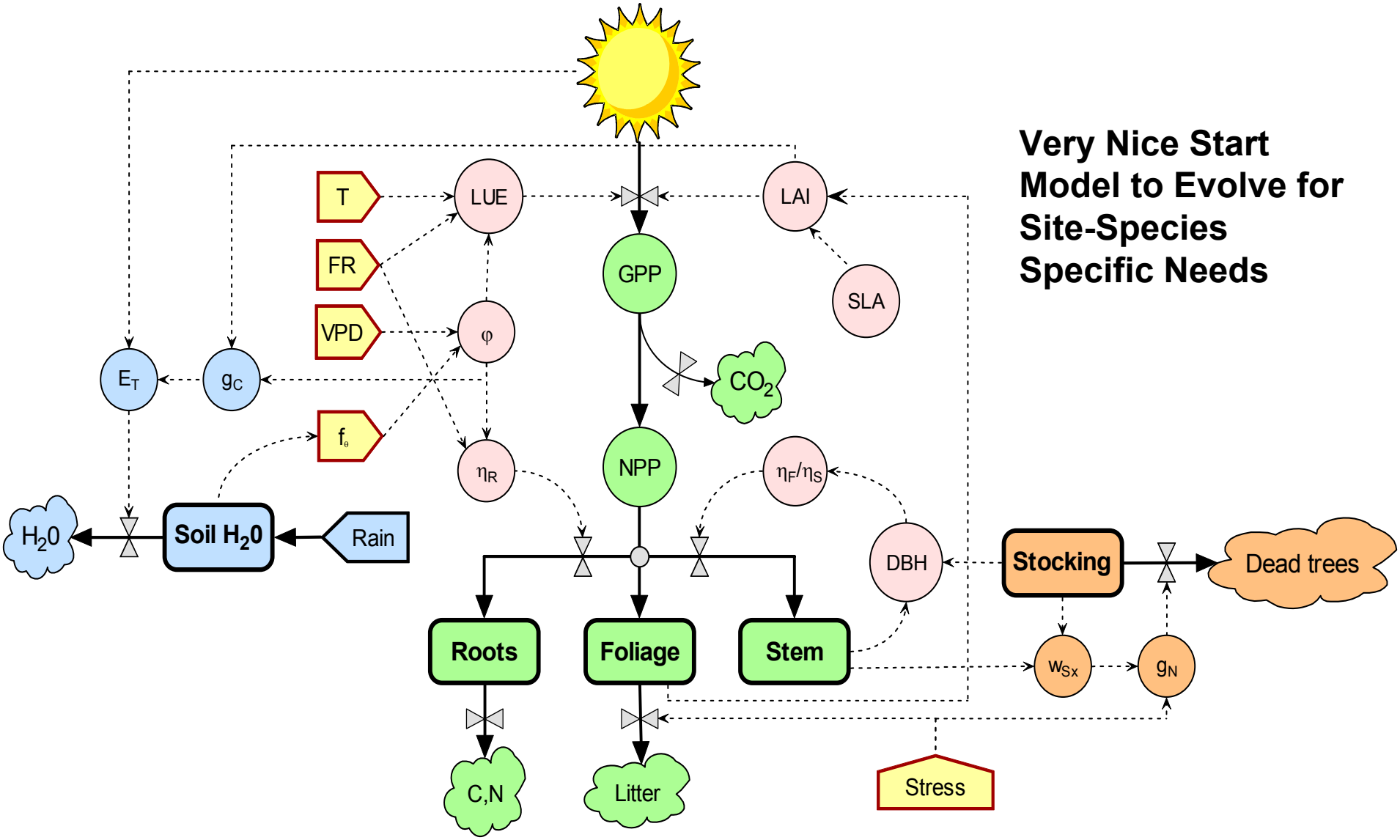
Model


Precipitação
Radiação Solar
Evaporação
Interceptação
Transpiração
Mata Ciliar
Camada Útil do Solo
Esc. Sup.
Rio
Percolação
Lençol Freático
Aquífero não Confinado


Modelo Ecofisiologico Geral
Parâmetros Genéticos
Energia Radiante
Precipitação
Área Foliar Biomassa
Défict de Pressão Vapor
Evaporação
Energia Interceptada
Interceptação da Copa
Temperatura
Fotossíntese Líquida
Condutância Estomática
Herbivoria Patologia
Nutrientes Folhas
Assimilados
Transpiração
Reservas & Biodiversidade
Respiração
Partição de Carbohidratos
Água do Solo
Biomassa Raiz
Biomassa Casca
Biomassa Galho
Biomassa Lenho
Erosão
Litterfall
Percolação
Nutrientes Forma Lábil
Matéria Orgânica
Ervas Daninhas
Fisiografia
Material Origem Solo
Nutrientes Não Lábil
Atividades Antrópicas

3-PG - 1997

J.J. Landsberg [a,*], R.H. Waring [b]

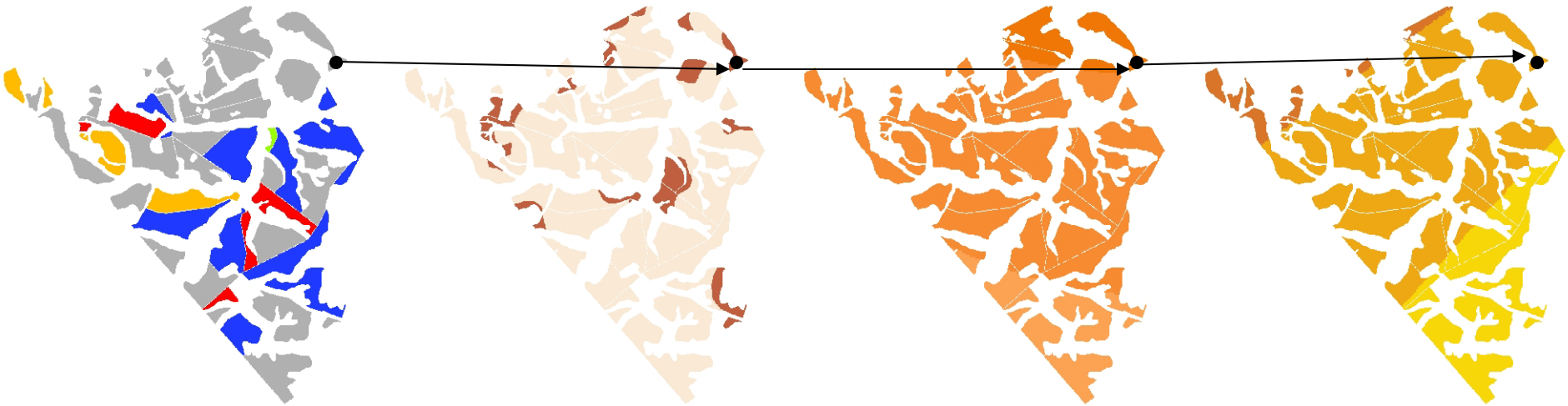


Very Nice Start Model to Evolve for Site-Species Specific Needs

Model Purposes

Phase	Known	Want to Know	Utility
"Understanding"	Input and Output	Process	Experiments
"Prediction"	Input and Process	Output	Monitoring
"Control"	Output and Process	Input	Management

Modelo 3 EV



Clone - CCQE

- entre 0,055 - 0,060
- entre 0,060 - 0,065
- entre 0,065 - 0,070
- entre 0,070 - 0,075
- entre 0,075 - 0,080

Fertilidade

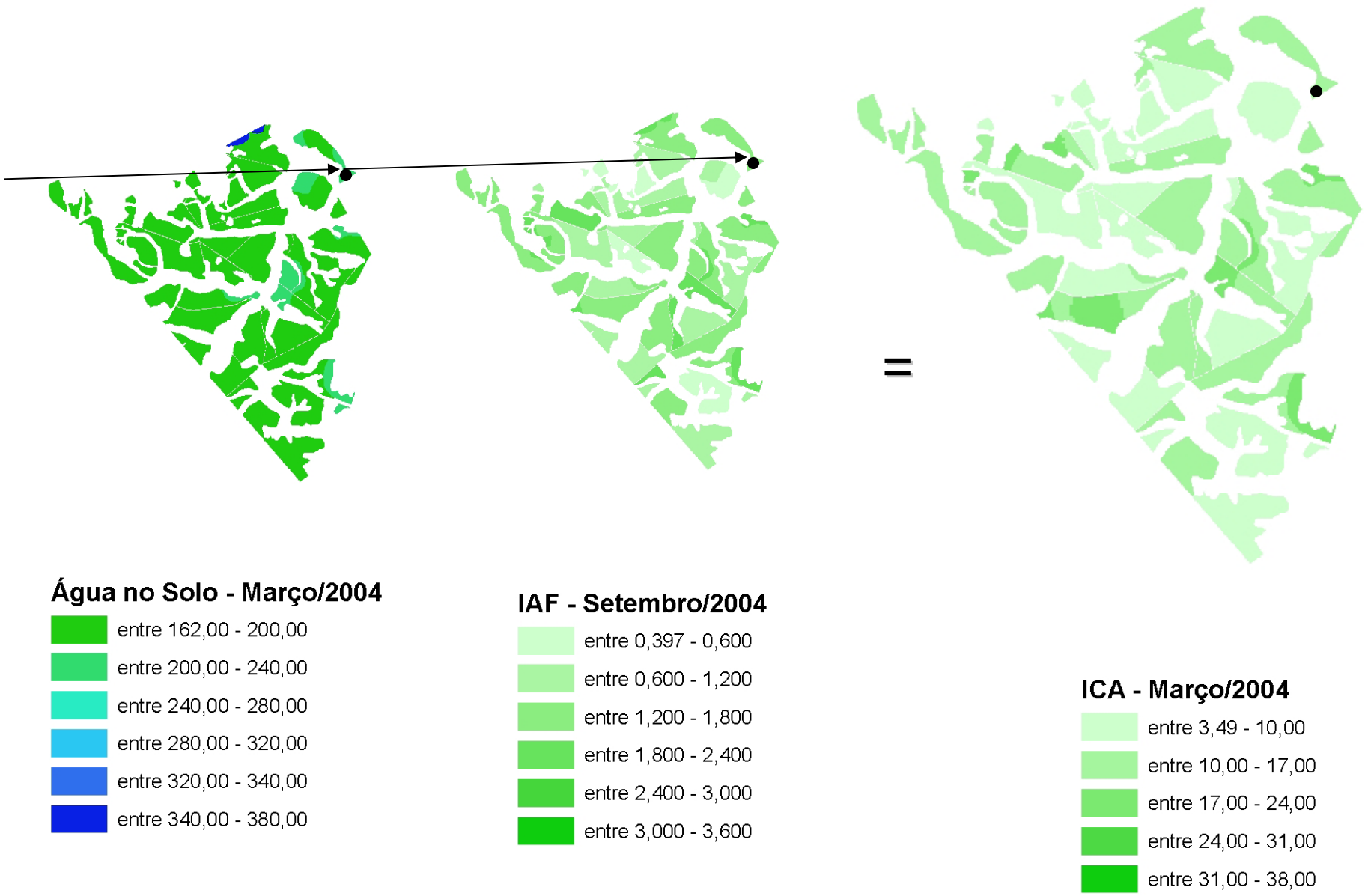
- entre 0,32 - 0,35
- entre 0,35 - 0,40
- entre 0,40 - 0,45
- entre 0,45 - 0,50
- entre 0,50 - 0,55
- entre 0,55 - 0,60

Radiação - Setembro/2004

- entre 10,19 - 10,20
- entre 10,20 - 10,22
- entre 10,22 - 10,24
- entre 10,24 - 10,26
- entre 10,26 - 10,28
- entre 10,28 - 10,30

Precipitação - Março/2004

- entre 277,00 - 280,00
- entre 280,00 - 283,00
- entre 283,00 - 286,00
- entre 286,00 - 289,00
- entre 289,00 - 292,00
- entre 292,00 - 297,00
- entre 297,00 - 300,00
- entre 300,00 - 303,00
- entre 303,00 - 306,00
- entre 306,00 - 309,00


Água no Solo - Março/2004
entre 162,00 - 200,00
entre 200,00 - 240,00
entre 240,00 - 280,00
entre 280,00 - 320,00
entre 320,00 - 340,00
entre 340,00 - 380,00
IAF - Setembro/2004
entre 0,397 - 0,600
entre 0,600 - 1,200
entre 1,200 - 1,800
entre 1,800 - 2,400
entre 2,400 - 3,000
entre 3,000 - 3,600
=
ICA - Março/2004
entre 3,49 - 10,00
entre 10,00 - 17,00
entre 17,00 - 24,00
entre 24,00 - 31,00
entre 31,00 - 38,00

=

Água no Solo - Março/2004

- entre 162,00 - 200,00
- entre 200,00 - 240,00
- entre 240,00 - 280,00
- entre 280,00 - 320,00
- entre 320,00 - 340,00
- entre 340,00 - 380,00

Água no Solo - Setembro/2004

- 0,00000 - 70,00000
- 70,00001 - 140,00000
- 140,00001 - 210,00000
- 210,00001 - 280,00000
- 280,00001 - 350,00000

IMA = 65 m³/ha/ano
Water = 280.000 L/yr

IMA = 50 m³/ha/ano
Water = 350.000 L/yr

Visão no

Produto

(madeira)

Visão no

Processo

(uso e eficiência do uso de recursos naturais + madeira)

CONCLUSIONS

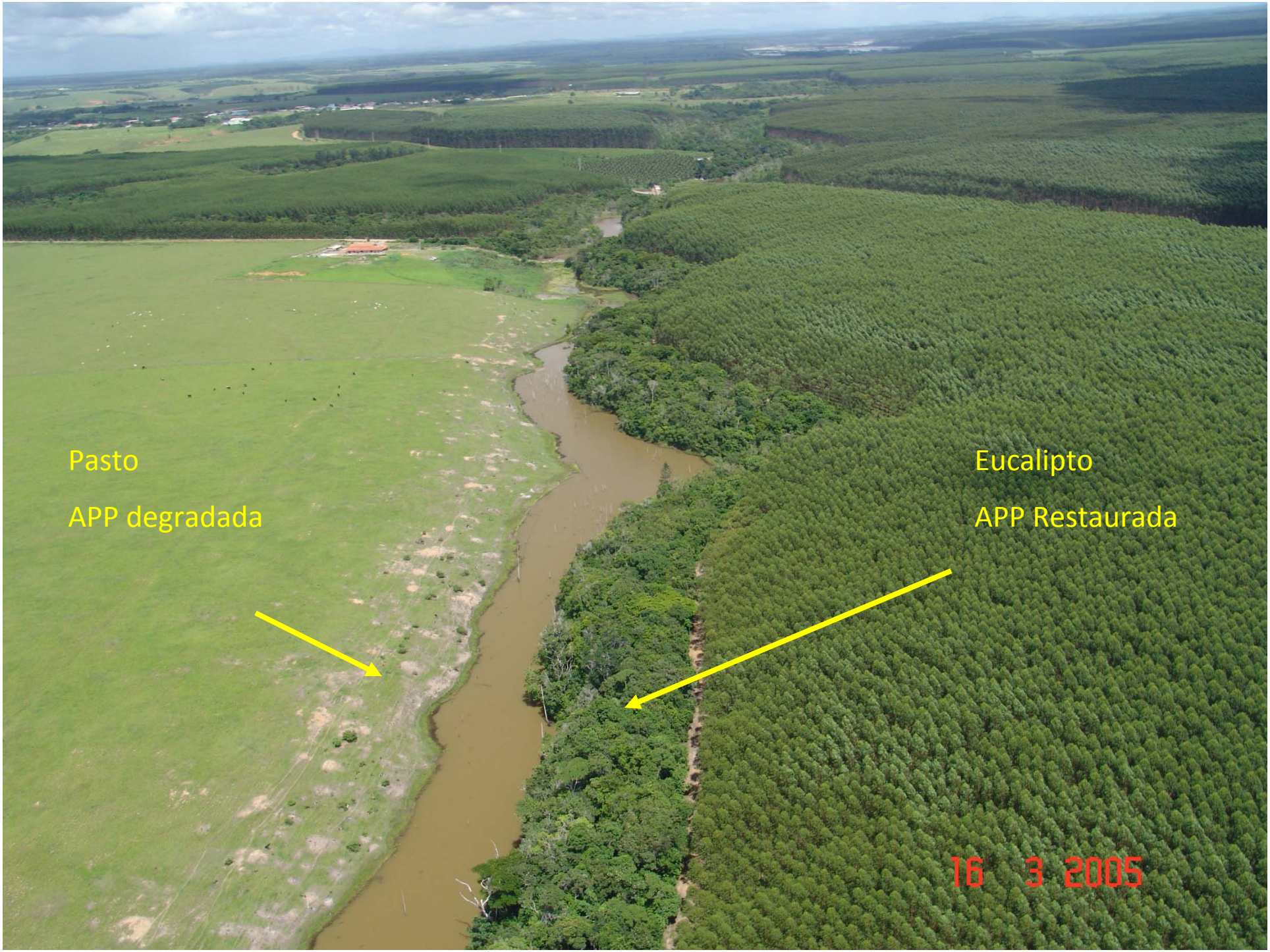
- ***Eucalyptus*** **forest are very efficient in using water (high WUE)**

- **However its high growth (WU) can impact drainage and its own growth in tropical-specific sites**

- **Modelling WU and WUE of such forests under different genetics and silvicultural practices are need for the planning of both Wood and Water production in an economic and ecological point of view**

Conclusões–Manejo Florestal Integrado

- As *Florestas Plantadas* são e serão cada vez mais partes integrantes da paisagem
- A forma do uso do solo, e não as *Florestas Plantadas,* causa a maior parte dos impactos ao ambiente
- Os processos ecofisiológicos, e sua modelagem nas diversas escalas espaciais/temporais são essenciais para o gerenciamento produtivo e ambiental dos ecossitemas: bens e serviços
- Os profissionais florestais deverão ter bases técnicas e ferramentas de gestão para administrar as tomadas de decisão multiproduto e multiserviços (o verdadeiro Manejo Florestal)


Pasto
APP degradada
Eucalipto
APP Restaurada
16 3 2005

Obrigado