“Lessons” from CAFNET:

An international project documenting environmental services of coffee agroforestry in Central America, India and East Africa.

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LA RECHERCHE AGRONOMIQUE POUR LE DÉVELOPPEMENT

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

CAFNET

CAFNET: Connecting, enhancing and sustaining environmental services and market values of coffee agroforestry in Central America, East Africa and India.

Funded by EU "Environment in Developing countries" 2007-2011

Europe : Cirad

30 researchers were involved in this project
35 Masters students and 12 PhD students from Latin America, East Africa, India and Europe

India : Univers **f India**
& Institut Fra

Central America: Catie, Promécafé (Costa Rica, Nicaragua, Guatemala)

East Africa: Icraf, Coffee institutes (Kenya, Uganda et Rwanda)

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Context

Common interests for enhancing viability of coffee sector via agroforestry in all 3 regions: Central America, East Africa & India

- Agroforestry management as key for coffee plantation sustainability
- Role of shade trees in coffee quality, central for farm economic viability through diversification of farmers' revenues (timber, fuel wood, NTPs, fruits ..)
- Documentation & valuing of environmental services (including biodiversity) to insure economic reward to farmers via eco-certification, national and international schemes

Context …

Multiplicity of isolated initiatives and “good practices” schemes (Starbucks, Rainforest, UTZ Certified, Organic, Bird-friendly, Fair Trade, Nestlé Nespresso, 4C)

Contrasting contexts between regions (> 50% of coffee farms eco-certified in Costa Rica and <0.5% in India)

Pilot schemes on Payment for Environmental Services

Lack of effective channels for synthesizing and transferring agroforestry research findings to stakeholders across continents

Overall objectives

1) to link sustainable management and environmental benefits of coffee agroforestry systems with appropriate remuneration for producers through better **access to eco-markets and payment for environmental services;**

2) to improve livelihoods for coffee farming communities while conserving natural resources in three major coffee regions located in world hotspots for biodiversity.

Plan of presentation

A few definitions

Highlight results of Cafnet in terms of documentation of environmental services

Tools developed for selecting & promoting tree on farms

Incentives and schemes for promoting tree on farms

Concluding remarks

Definitions

- **Agroforestry**: A system of land use in which trees or shrubs are grown among or around crops or on pasture

- **Environmental services**: The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. This includes both goods and functions.

Provisioning Services

Products obtained From ecosystems

- Food
- Fresh water
- Fuel
- Fiber
- Biochemical Products

Regulating Services

Benefits obtained from Regulation of ecosystem processes

- Climate regulation
- Hydrological regimes
- Reduction of natural hazards
- Pollution control
- Detoxification processes
- Pollination
- Pests & diseases control

Cultural Services

Material and non-Material benefits of ecosystems

- Spiritual and Inspirational
- Recreational
- Aesthetic
- Educational
- Historical
- Traditional Livelihoods and knowledge

Supporting Services

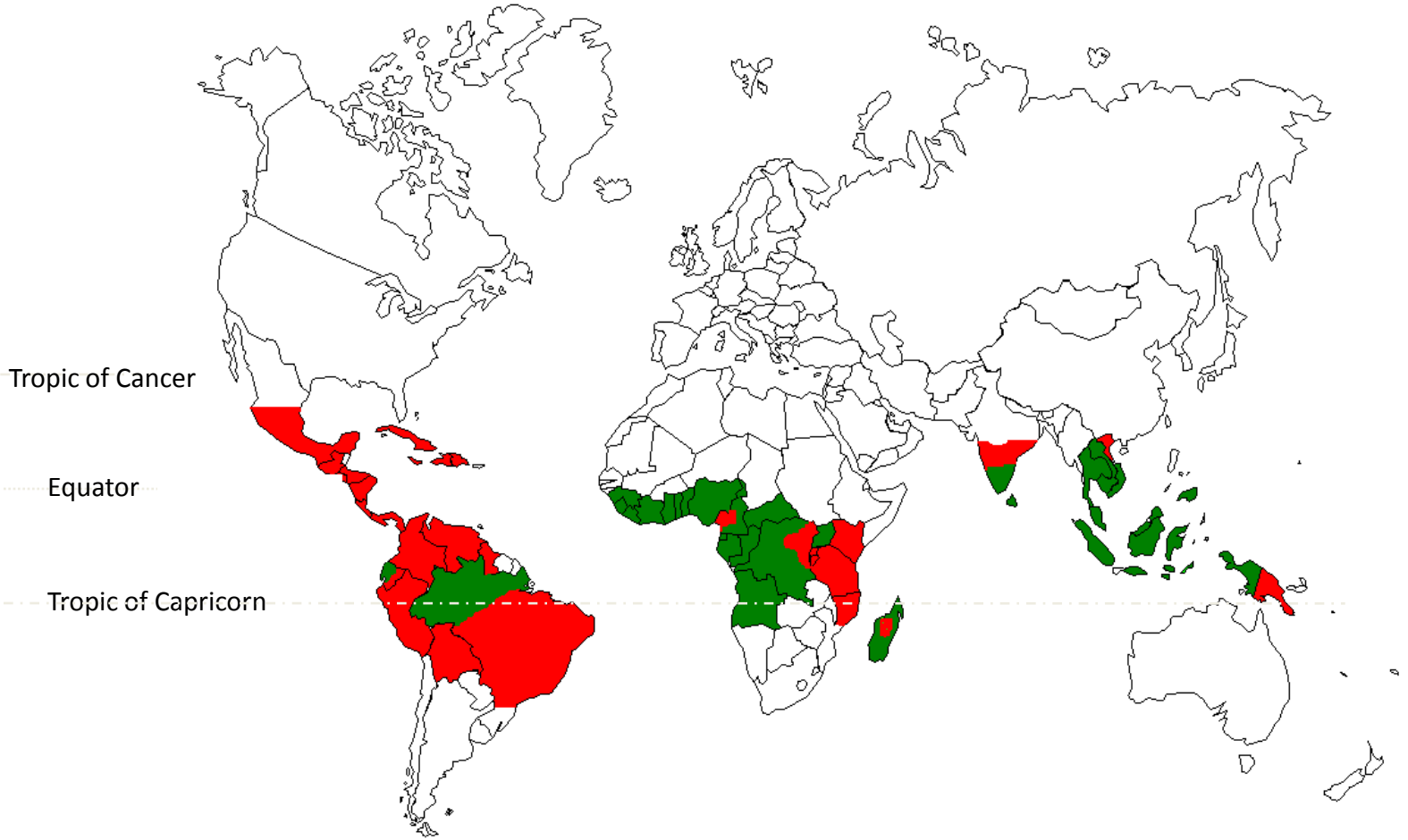
Services necessary for the production of all other ecosystem services:

- Soil Formation
- Nutrient Cycling
- Primary production

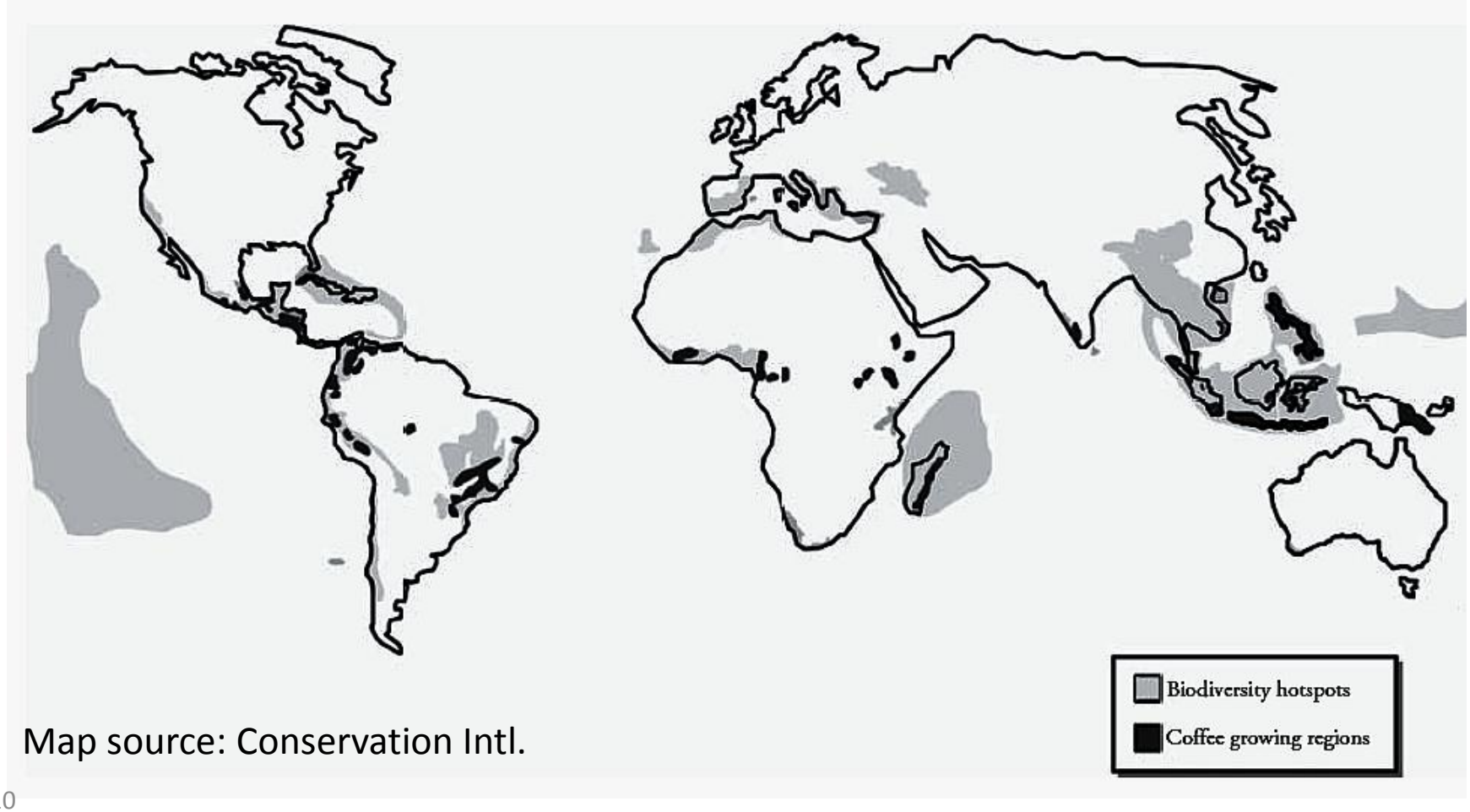
MEA 2006

Coffee cultivated areas

11 m Ha = 7 m Arabica + 4 Canephora (annual rate of deforestation ~15 m Ha)
In 60 countries and ~25 m coffee households
>80% coffee produced by small farms (<3 Ha)



Coffee is grown on 11 million ha >95% within biodiversity hotspots, where many endemic and threatened species live.



Map source: Conservation Intl.

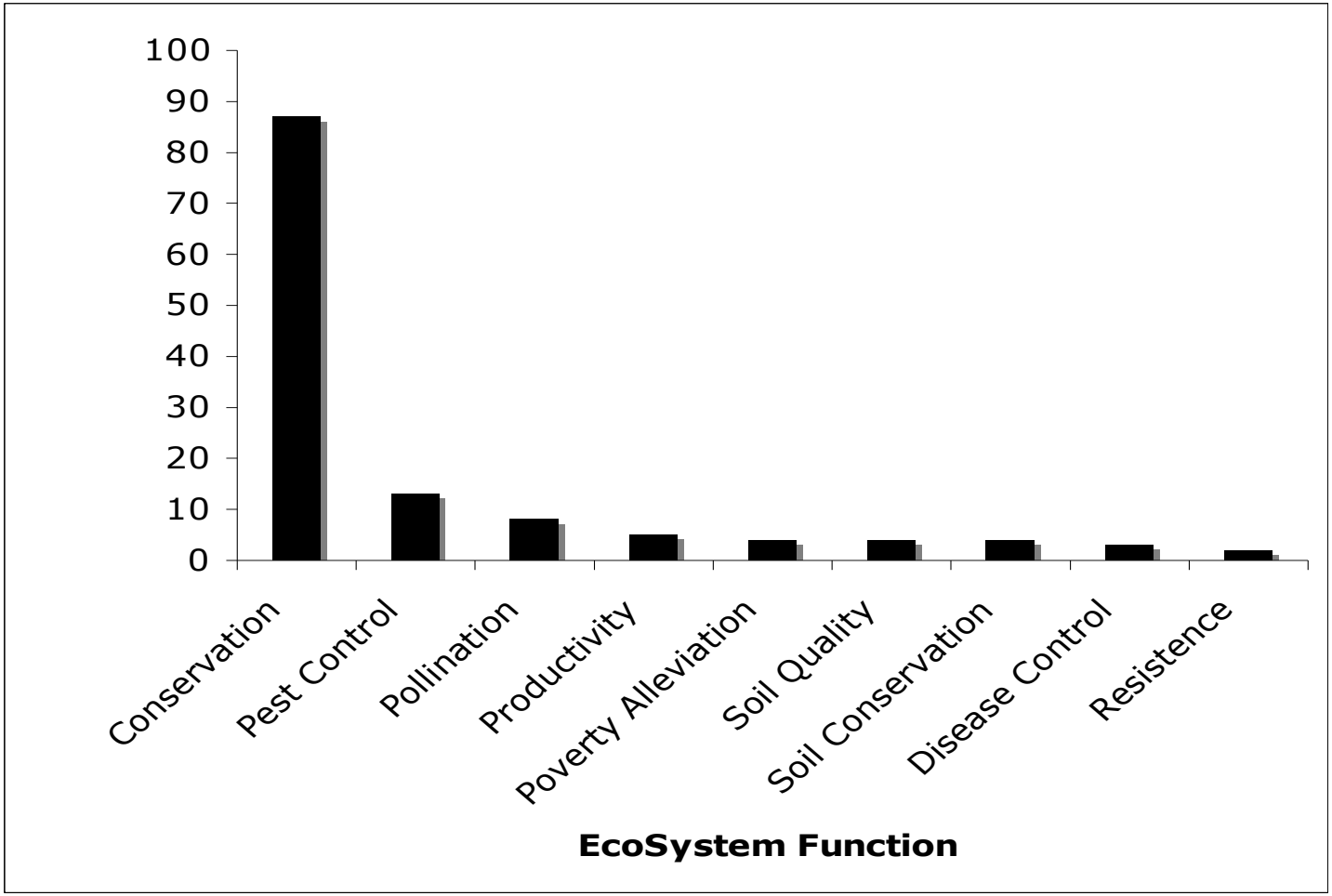
Coffee agroforestry is generally associated in the public mind to traditional or “rustic” coffee agroforests that harbor high biodiversity, but produce little coffee.

However, agroforestry systems are very diverse and range from highly productive systems to traditional multi-strata systems

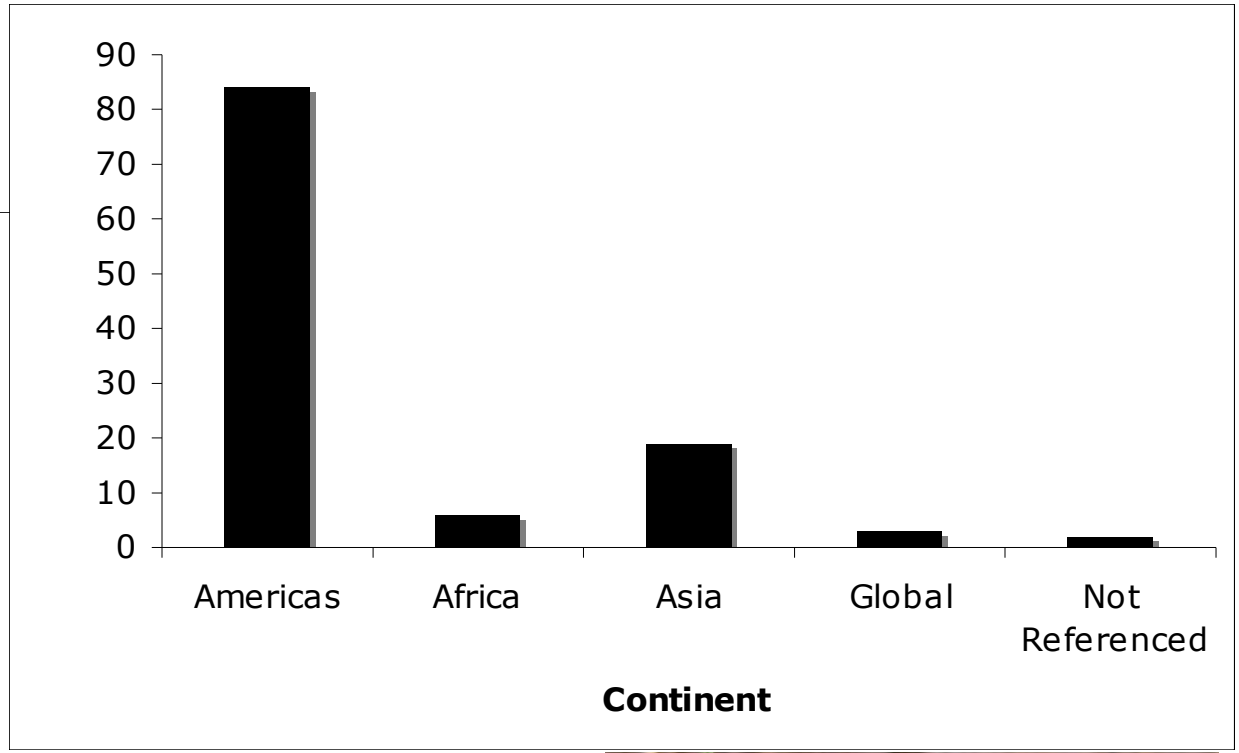
	MANAGEMENT SYSTEM	%SHADE* COVER	SHADE TREE* RICHNESS
A	RUSTIC	71-100	> 50
B	TRADITIONAL POLYCULTURE	41-70	21-50
C	COMMERCIAL POLYCULTURE	31-40	6-20
D	SHADED MONOCULTURE	10-30	1-5
E	UNSHADED (SUN) MONOCULTURE	0	0

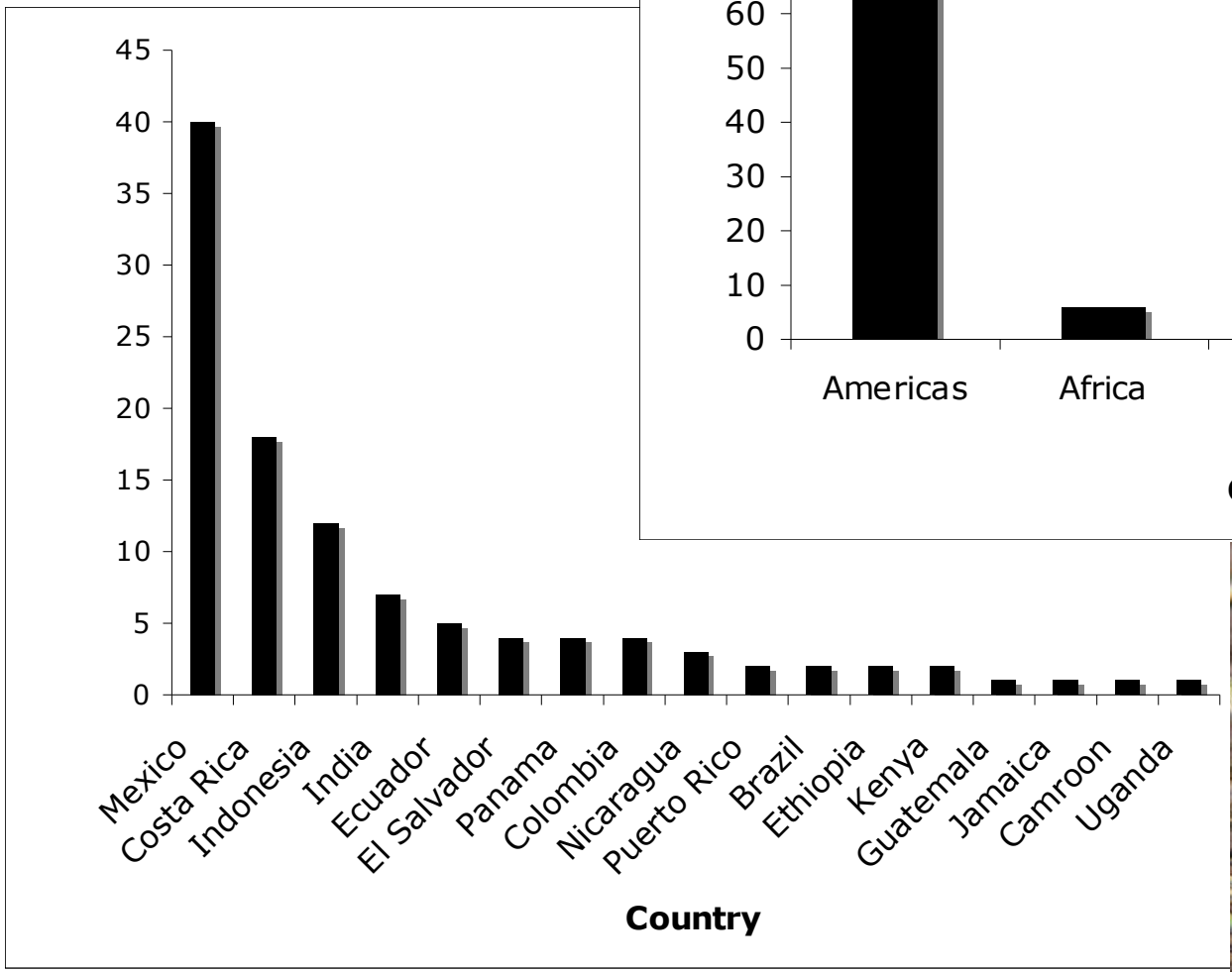
(Perfecto et al., 2005, modified from Moguel and Toledo, 1999)

Which Ecosystems Services have been studied in coffee AFS ?

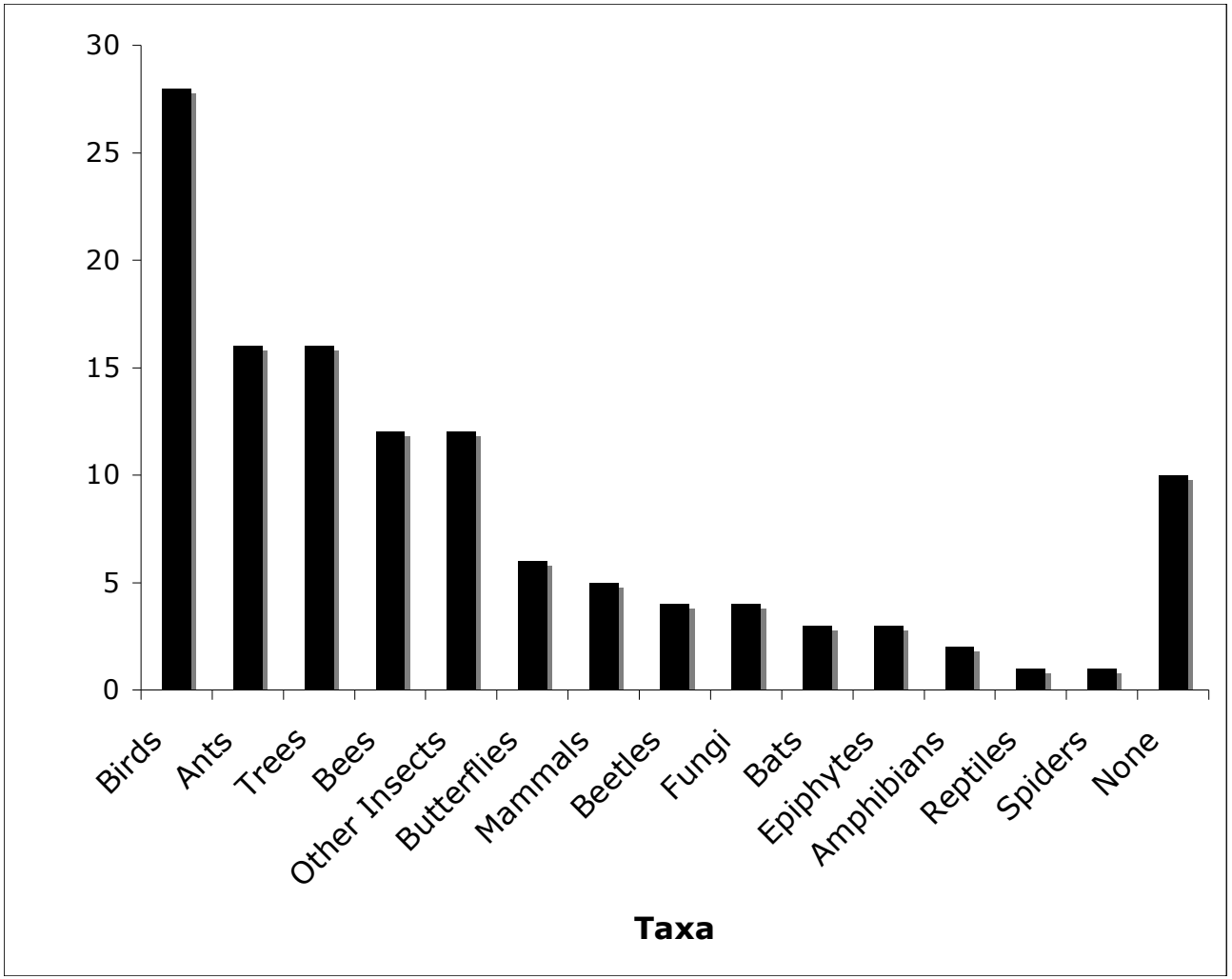


Published studies on “Biodiversity and Coffee”





Which taxonomic groups have been studied?



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Effects of shade trees on coffee production

- "Shade is not universally beneficial. The need for shade is a function of climate (it is especially important in hot and dry climate)" **Look 1888**

- General trends observed on "controlled" trials

- In optimum conditions

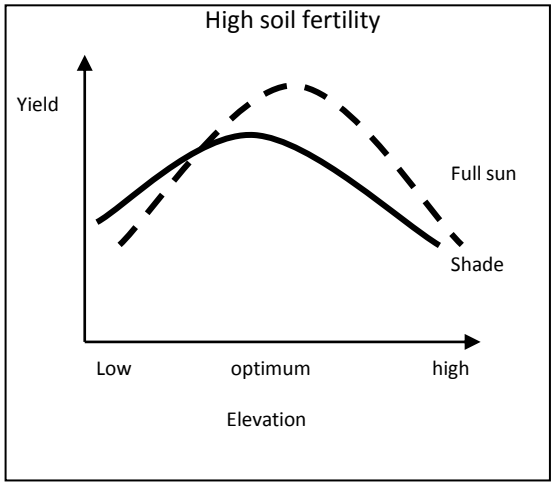
  Coffee production decreased by 20-40% when "optimal" shade level in the range of 20-40%

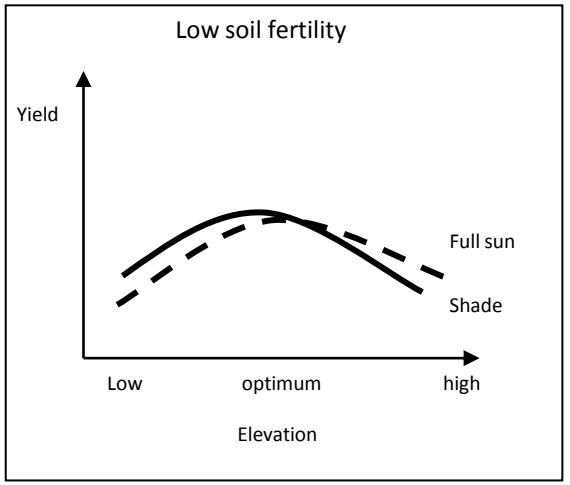
  But alternate bearing pattern reduced and coffee productive life span increased

- In sub-optimal conditions (prevailing worldwide)

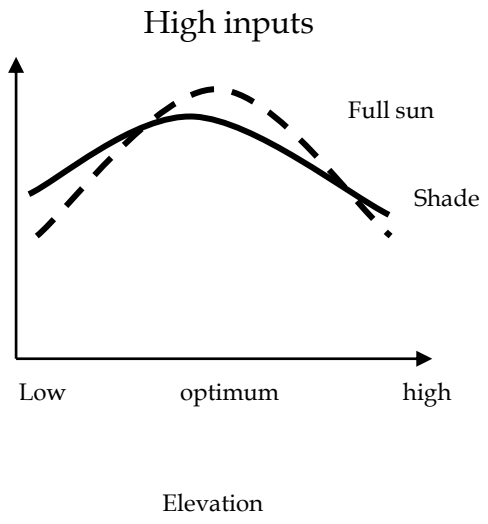
  Coffee production increased by 10-50% when "optimal" shade level in the range of 30-50%

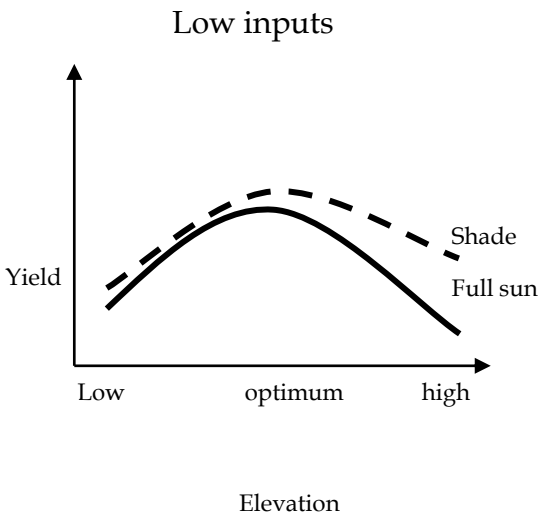
Theoretical response of coffee yield to shade and soil conditions



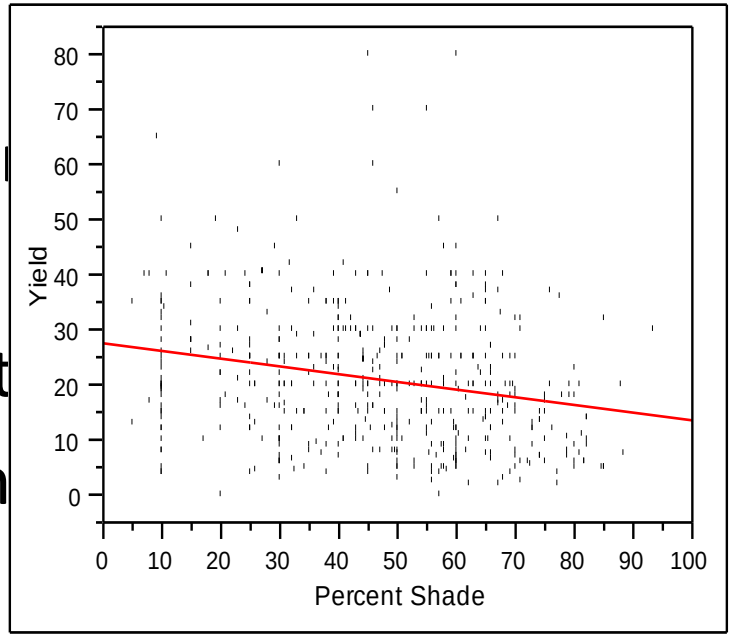


Theoretical response of coffee yield to shade and Management intensity



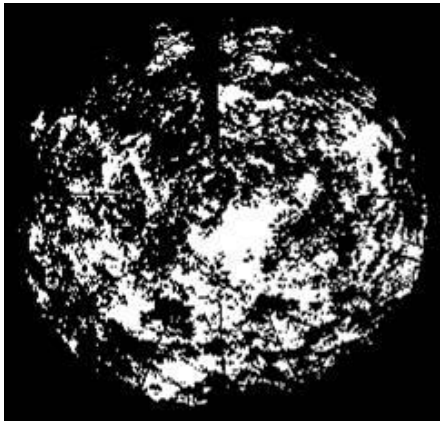


- From large surveys in CA, India, East Africa, no clear trend due to many factors:
  - Heterogeneous tree co
  - Altitudinal range
  - Difference in soil fertilit
  - Difference in managem pruning…)

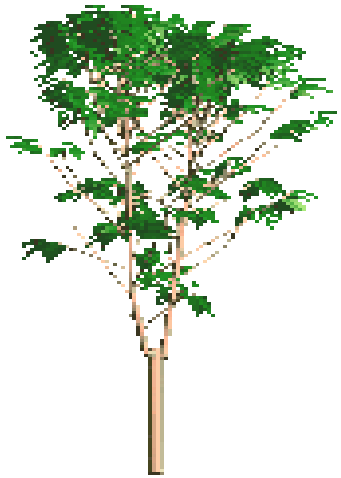


- So that it is interesting to focus on “outliers”

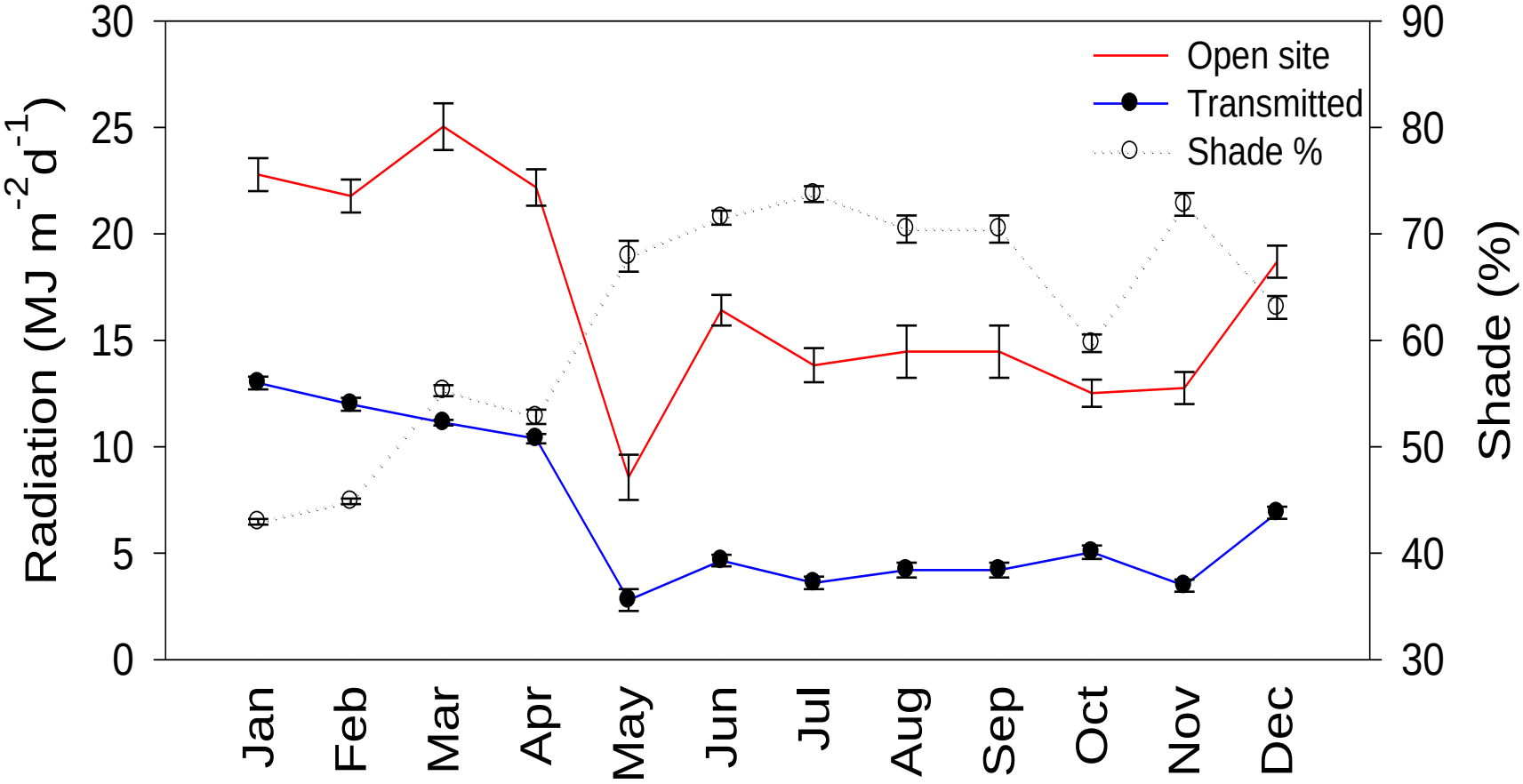
Shade and coffee ecophysiology



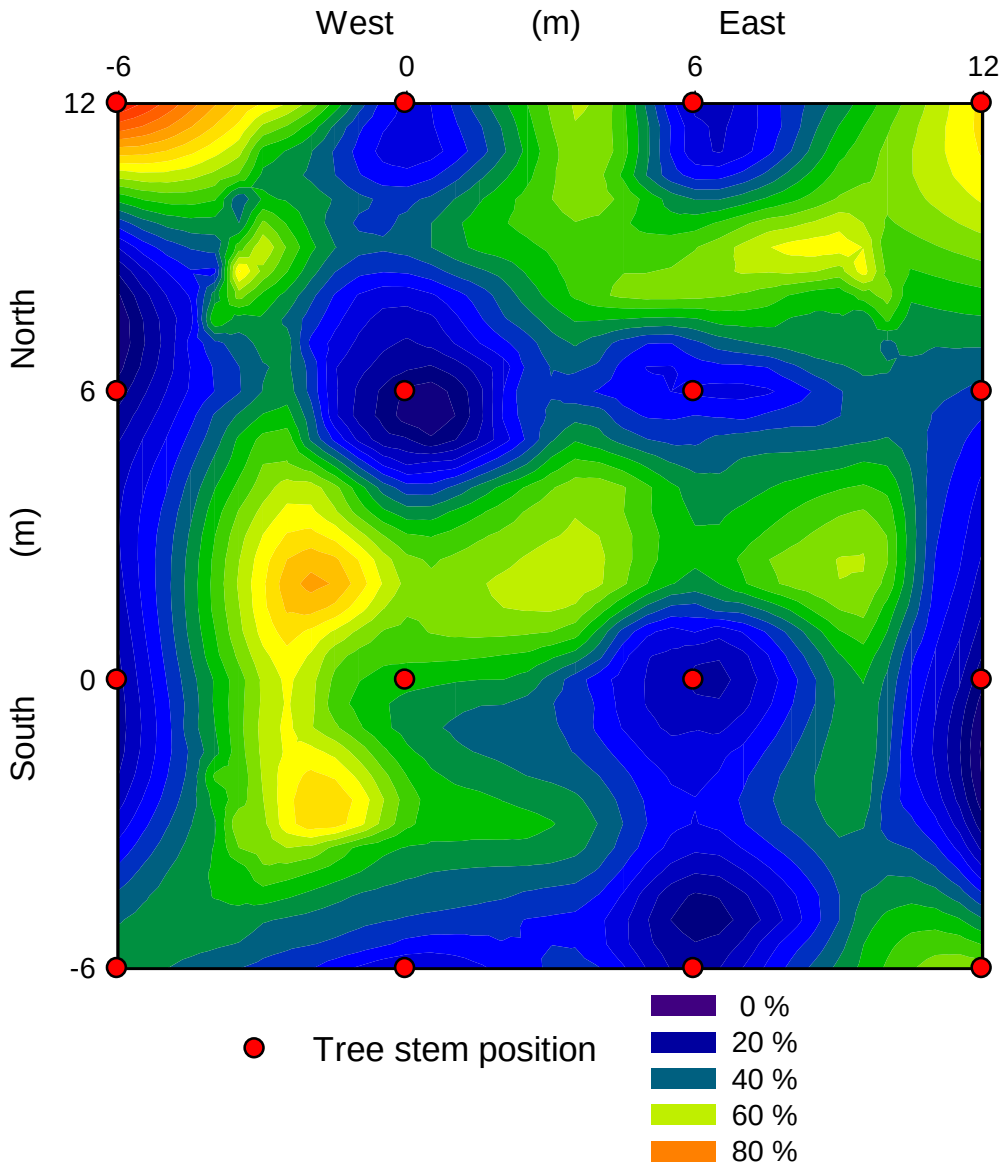
- Shade trees modify the microclimate
  - Light, air and leaf temperature, VPD
- Coffee physiology and production
  - Flowering, photosynthesis, carbon allocation, production pattern and yield,
- Shade tree modify water fluxes
  - Transpiration, interception, runoff, soil water
- Coffee quality
  - Bean size, bean content & cup quality



Influence of trees on transmitted radiation

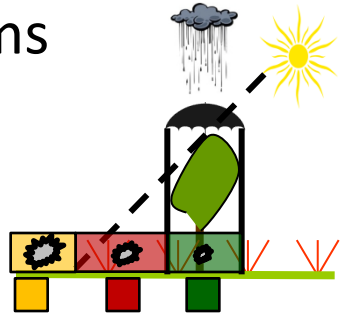


Spatial variation in the percentage of transmitted radiation through the shade canopy of Inga

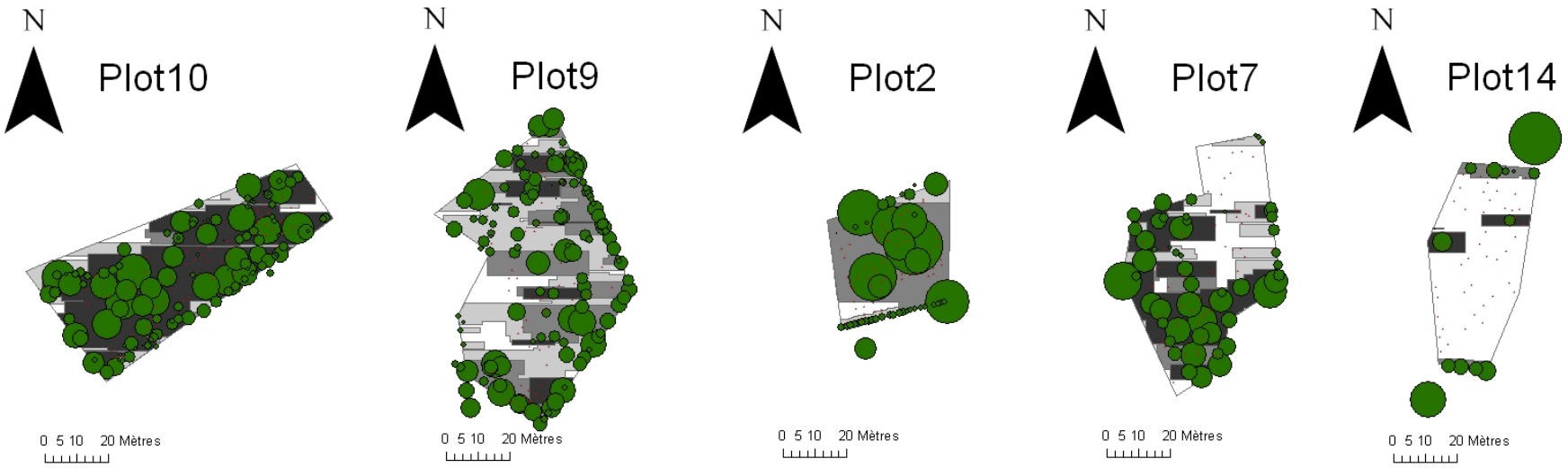


large variability in tree spatial arrangement in coffee systems (Kenya)

Difference in canopy porosity between tree species and hence light irradiance experienced by coffee plants



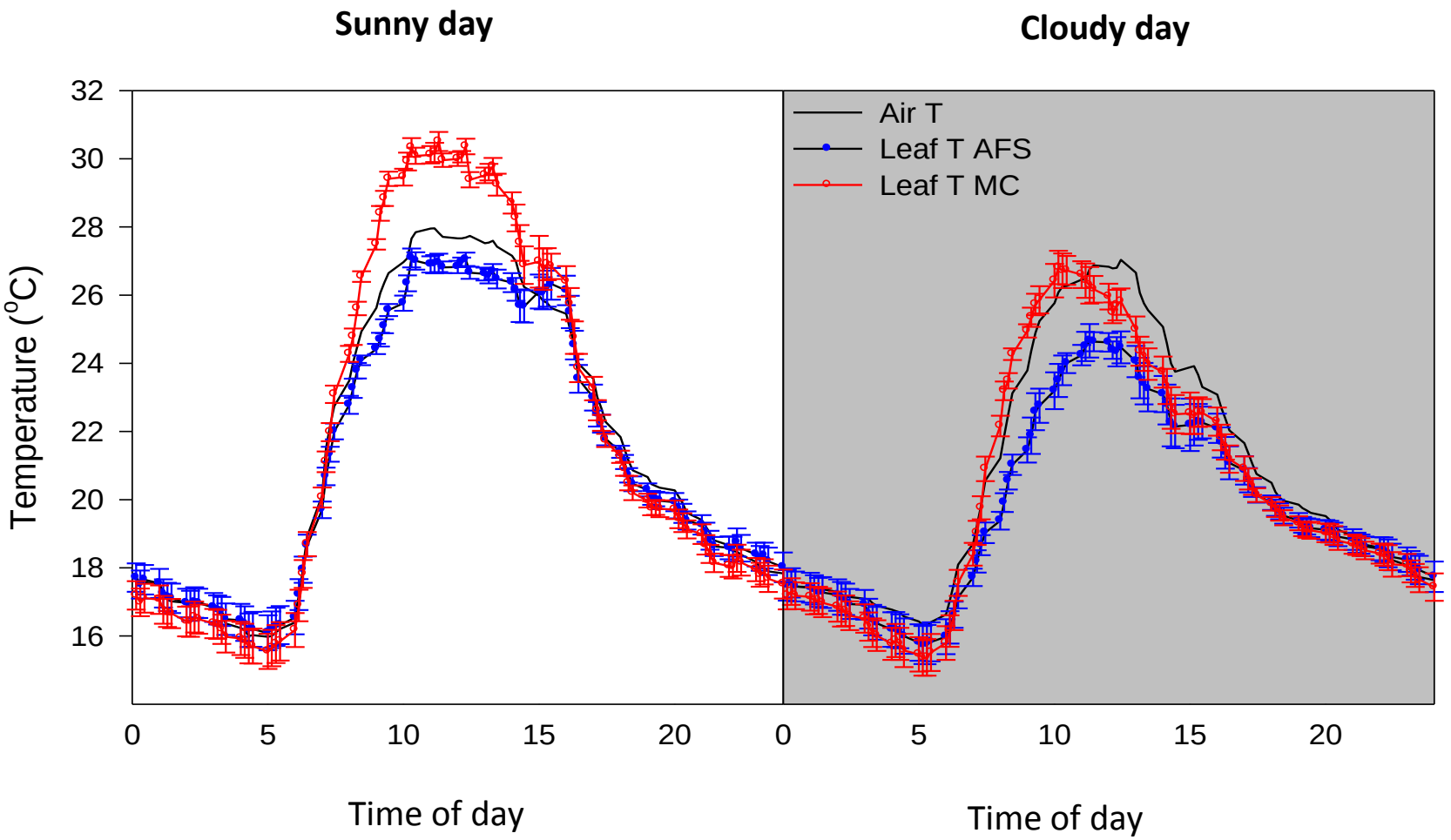
« canopy openness"



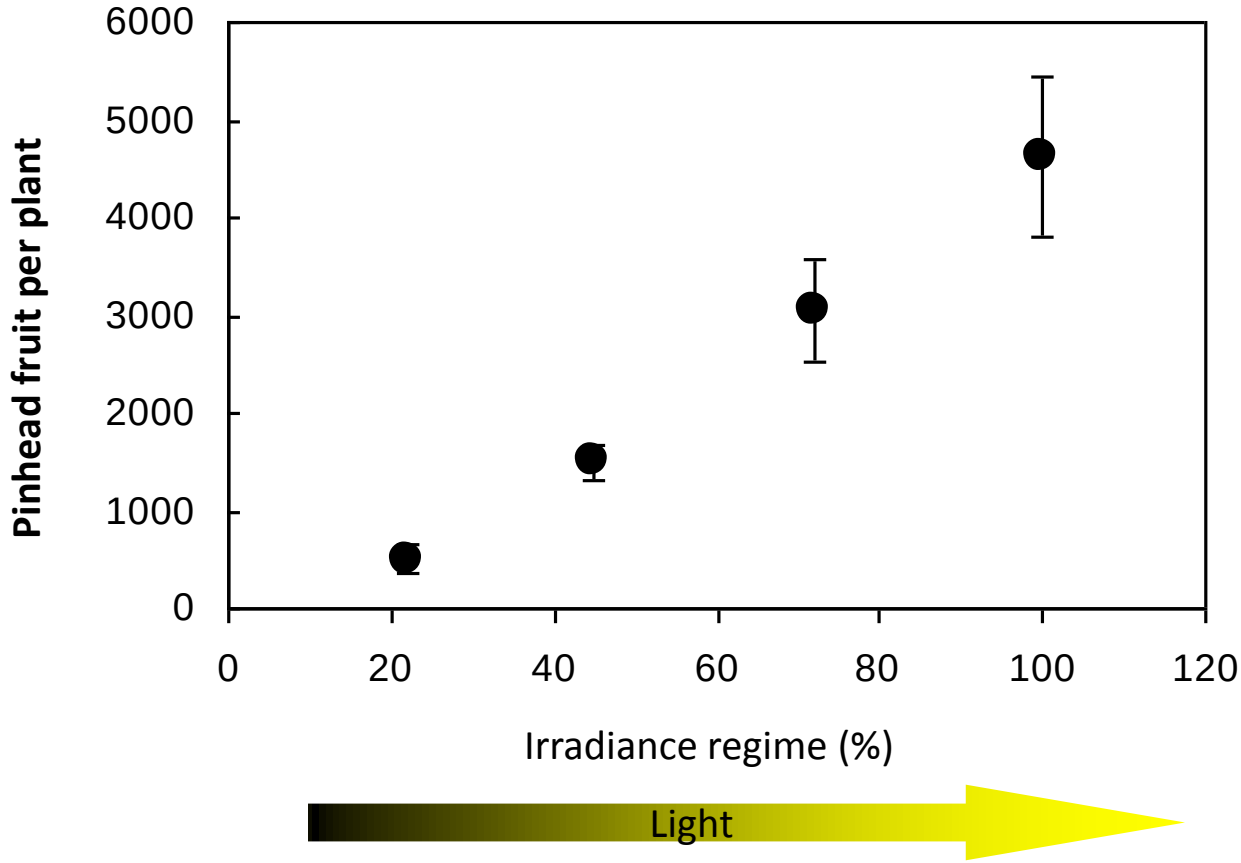
Group 4 **Group 3** **Group 1** **Group 2** **Group5**

Effect of shade tree on mean diurnal courses of coffee leaf temperature

- Reduction of maximal leaves temperatures under shade by up to 6°C, with an average reduction of 1 to 3.5°C



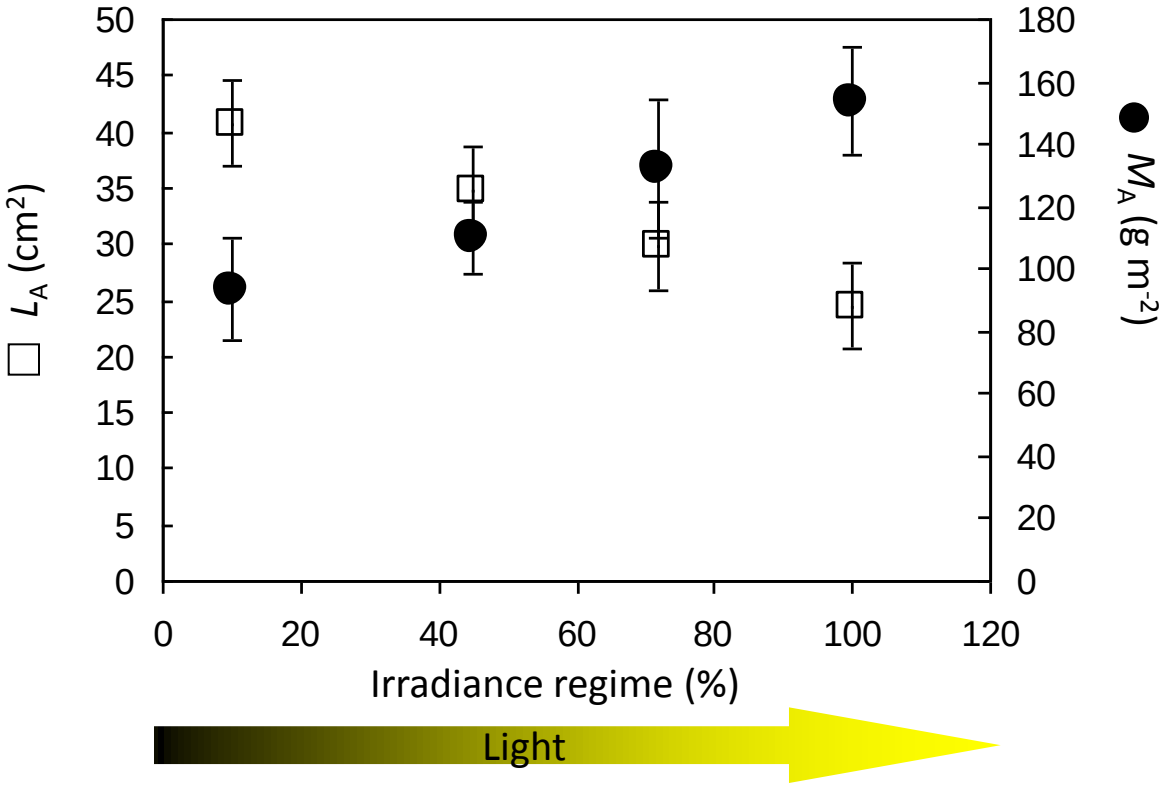
Strong negative effects of shade on flowering/fruit set



With increasing shade, longer internodes and fewer flowers per node

➔manipulate shade at flowering: tree pruning & mix of trees with different phenology

Shade effects on leaf area (L_A) □ and specific leaf weight (M_A) ●



Shade effect on leaf life span

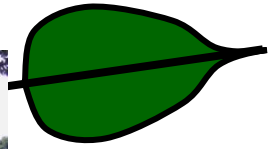
6-8 months in full sun

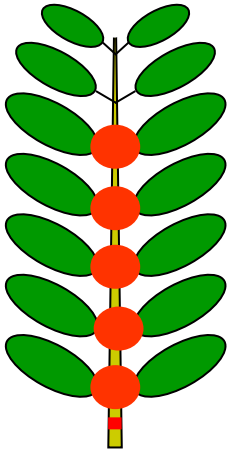
10-12 months in shade

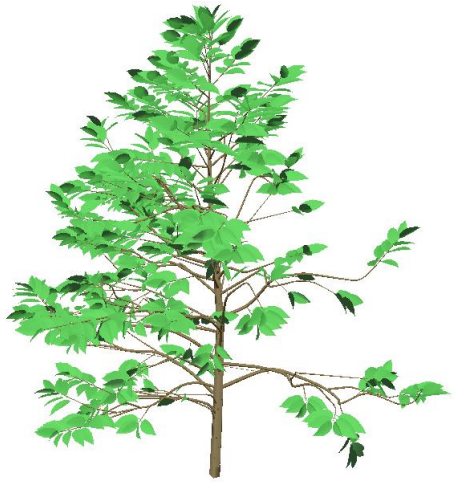
➔ stronger carbon sink in full sun

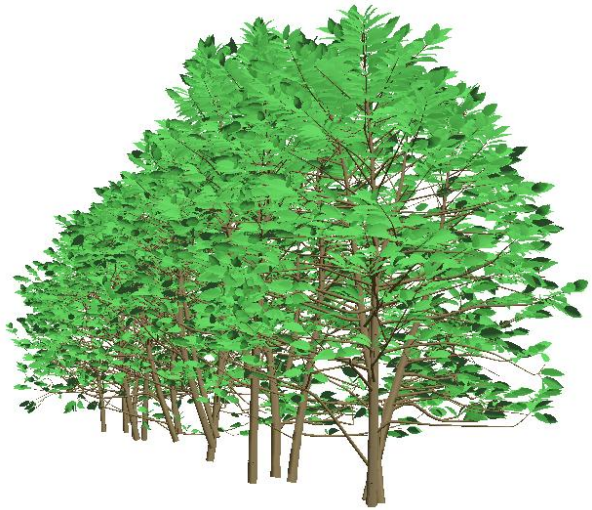
- Development of a coffee photosynthesis model integrating
  - Coffee phenological changes with light (acclimatizing of leaf/plant to shade)
  - Competition for C between fruits and vegetative sinks (alternate bearing)
  - and limitations in :
  - Stomatal conductance (gs) to Temperature & VPD
  - Photo-inhibition (Pi)
  - Feedback of fruit load on Pn

- Integration of the Pn model from leaf to plant and plot

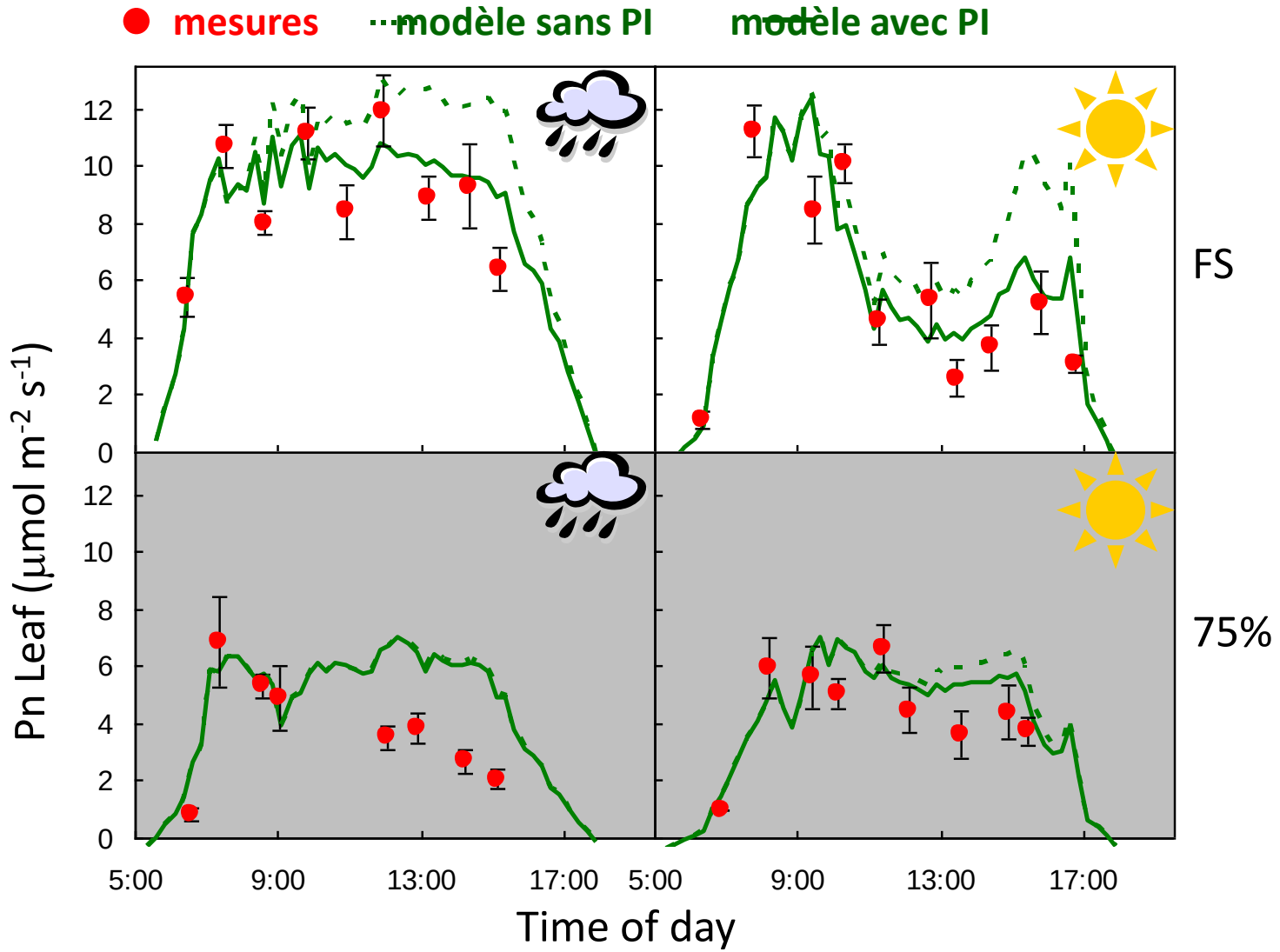




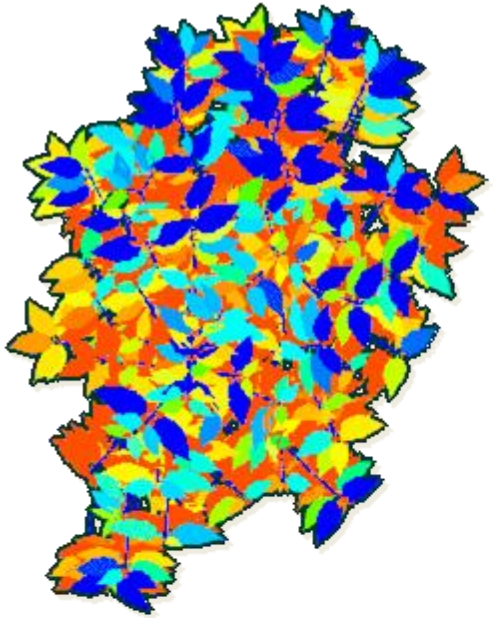




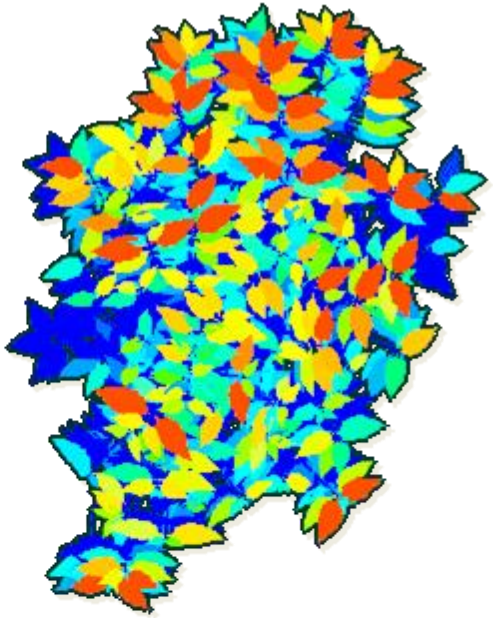
Modelling of coffee leaf net photosynthesis (Pn-g_s-PI) with adapted plants under contrasted light regimes



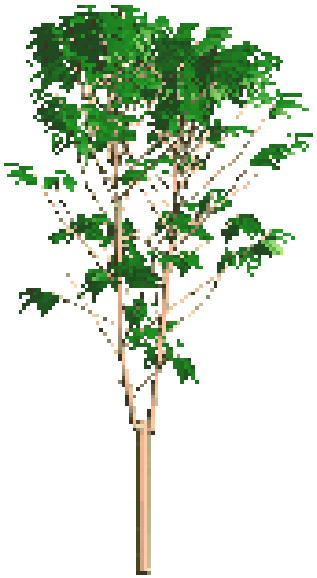
3-D model with AMAP-CIRAD (J. Dauzat)

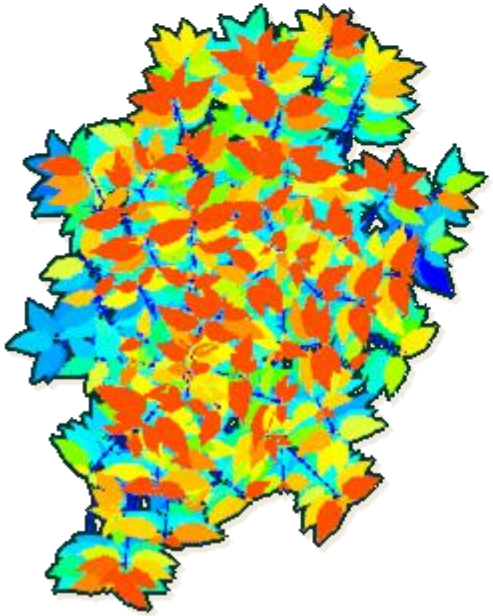


specific leaf transpiration

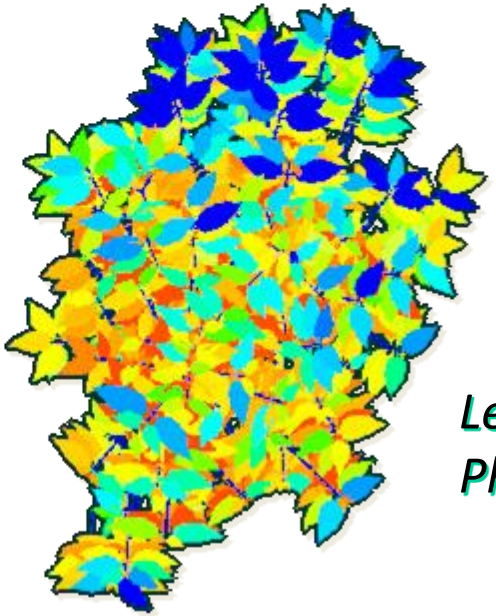


Leaf temperature

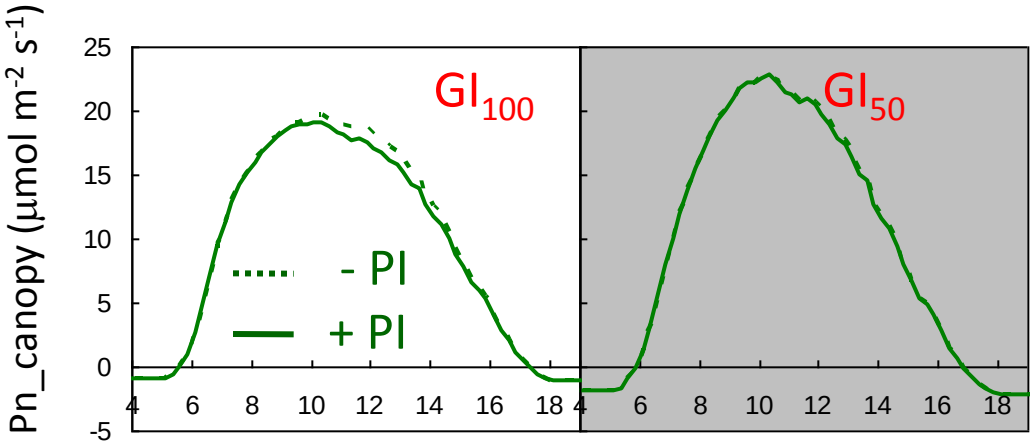


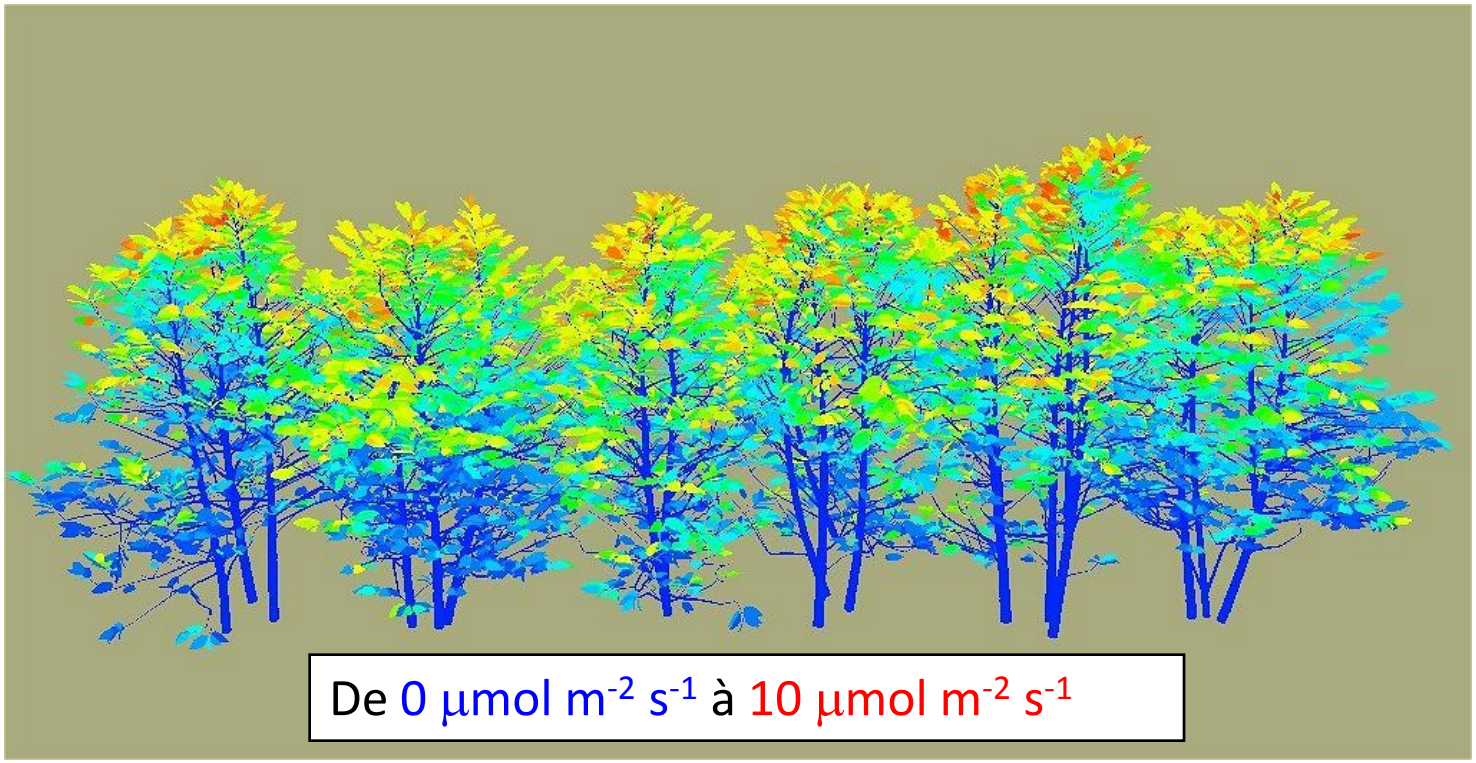


Leaf irradiation in PAR range



Leaf Photosynthesis

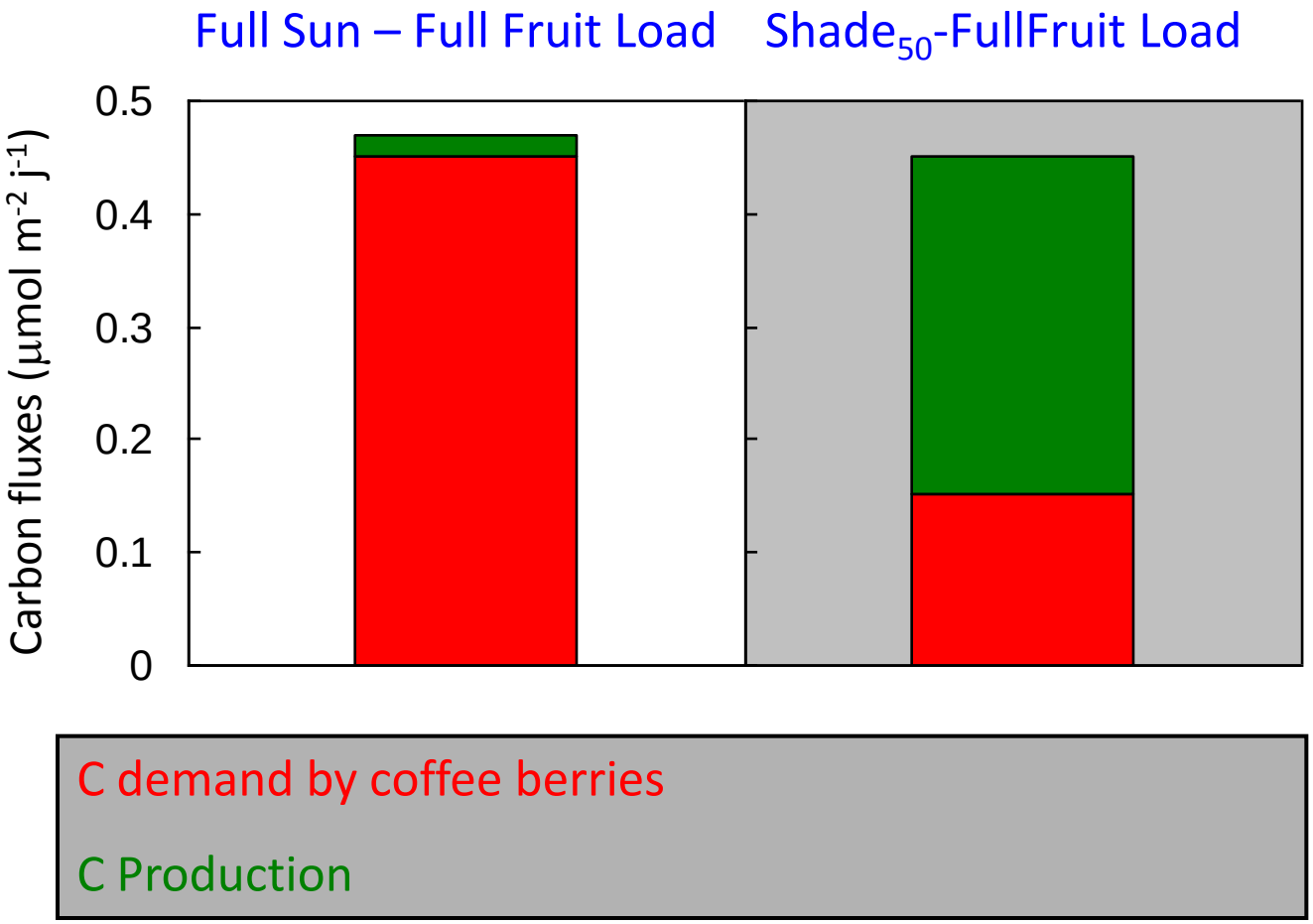




Pn for 50% shade at 2:00 pm

Comparison between C production and demand over a production cycle

and decision tool on shade management



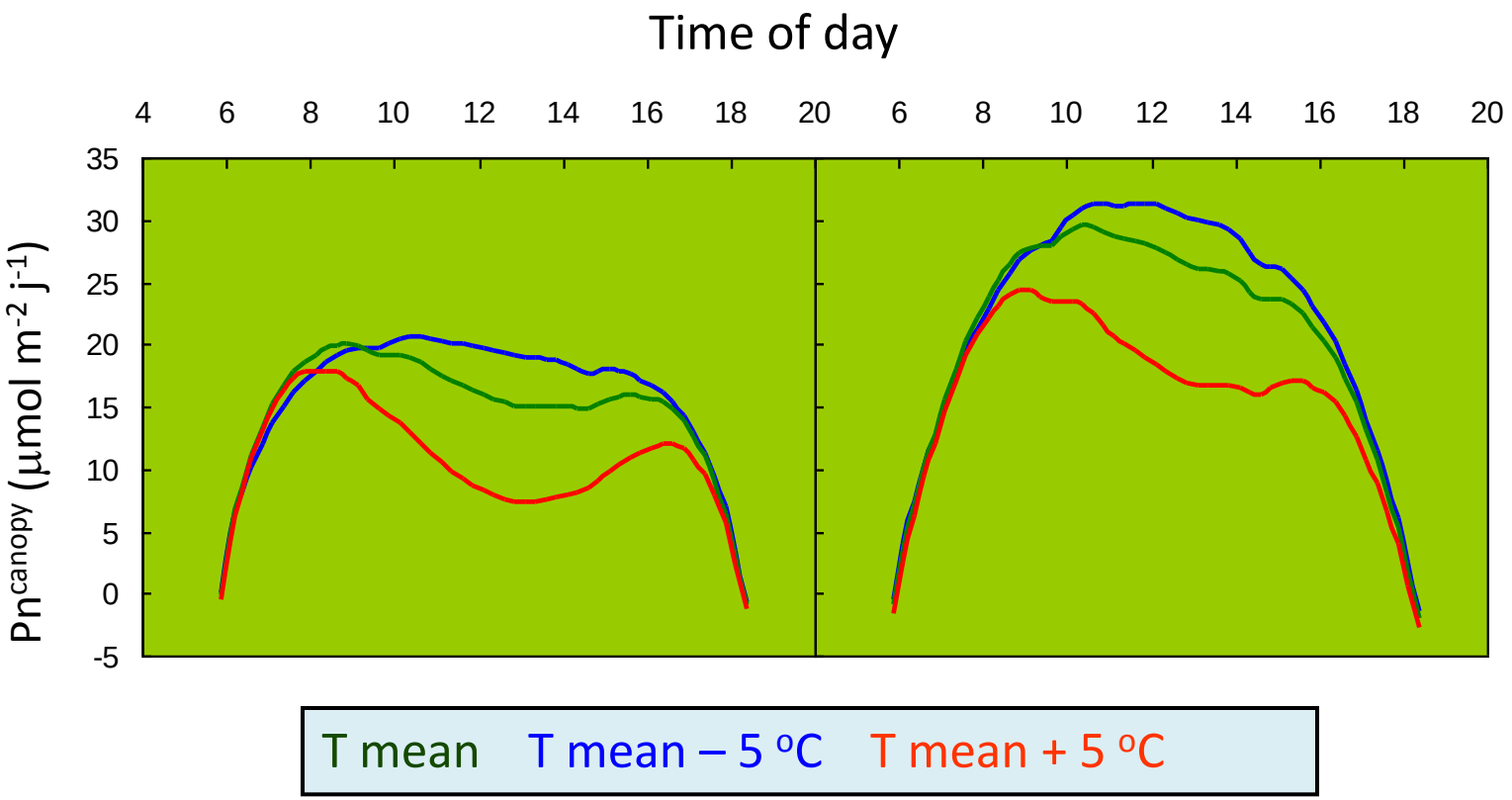
Full Sun

Fruit load

Shade 50%

Exploring the effect of climate change on coffee photosynthesis

Effect of increasing/decreasing air temperature



➔ Role of shade trees in buffering air temperature (0.8°C per 100 m)

Coffee quality

Shade improves quality in 2 ways:

Reduction in fruit load, hence lower competition between fruits, resulting higher coffee bean size, bean filling and beverage quality

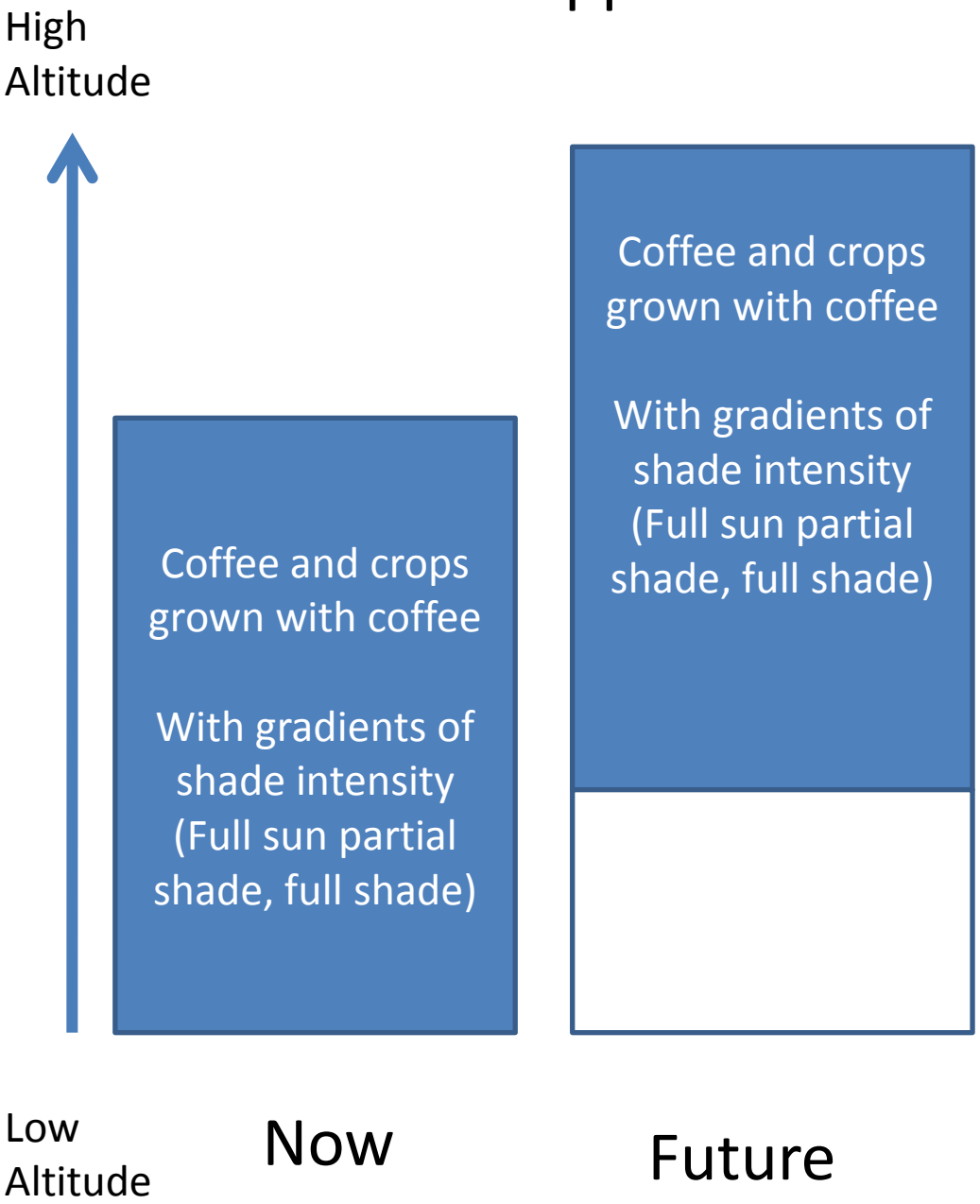
reduction in light exposure and temperature leads to slower and longer berry maturation period, thus better bean filling and higher complex sugars accumulation.

Coffee quality of AFS at 1000 m equivalent to Sun full coffee at 1300 m

Climate change
Rise in temperature likely to affect negatively coffee quality

➔ Displacement of high-quality zone to higher altitude or shade

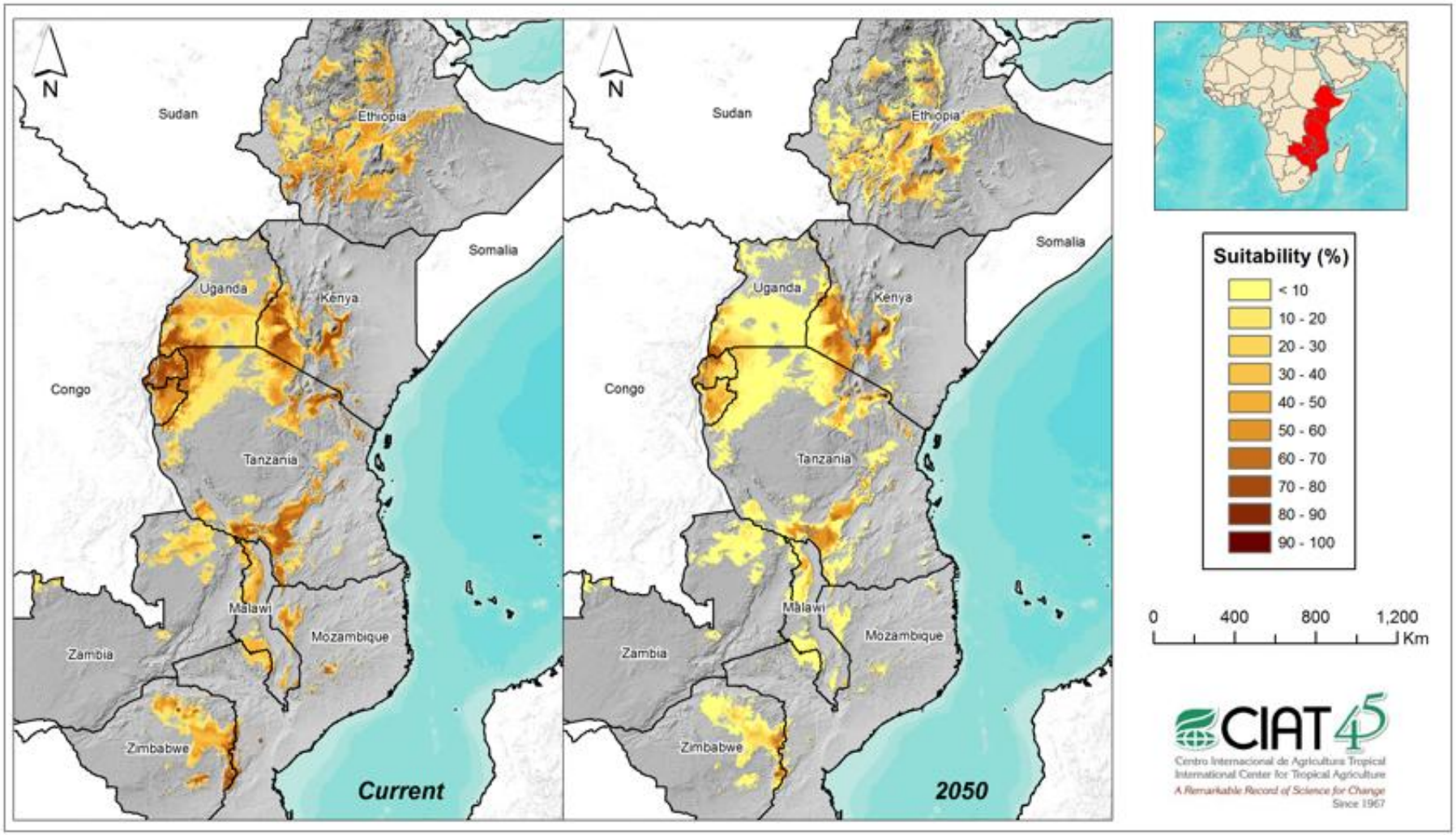
what happens with climate change?

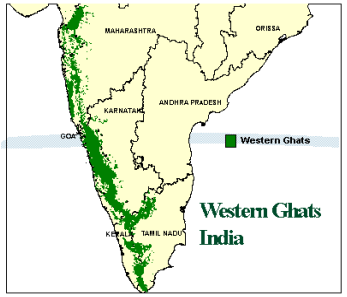


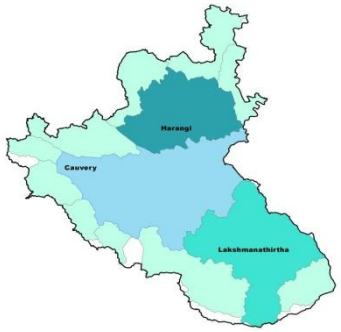
New coffee planting
- Deforestation issues?

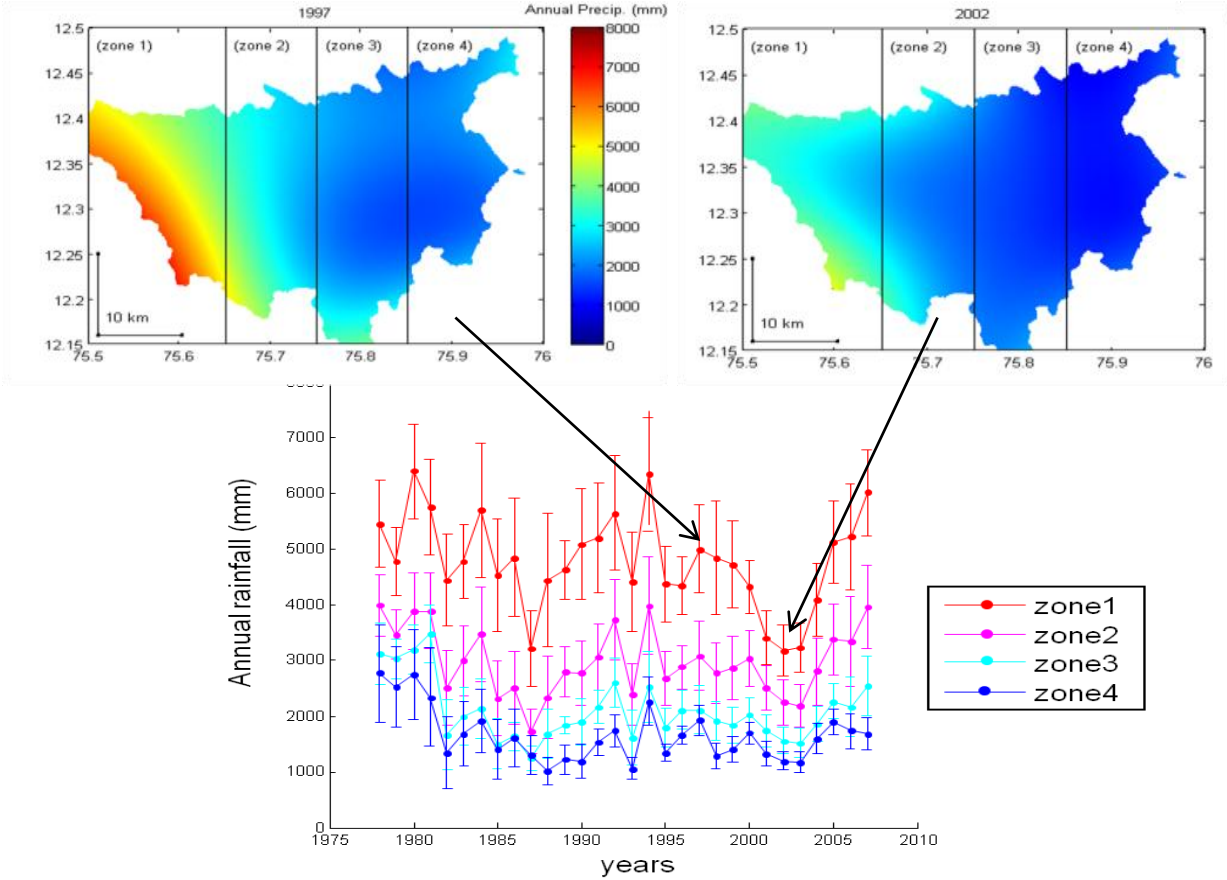
Post coffee landscapes.
Conversion to:
-Pasture
-Annual crops
-Urban
-Abandonment

Specialty Coffee
Managing Quality
Edited byThomas Oberthür, Peter Läderach,H. A. Jürgen Pohlan and James H. Cock









There is a strong fluctuation of annual rainfall with an apparent cycle of 12-14 years,

The length of the rainy season has been decreasing by 14 days over the last 35 years.

Higher proportion of “heavy rains”

Water dynamics in coffee systems

- Water issues
- Climate change and irregular rainfall pattern (lengthening of dry season)
- Competition vs complementarity
- Ideally, associate trees with deep-rooted system t tap water below coffee root zone
- Possible hydraulic lift

Water balance components in full sun and AFS

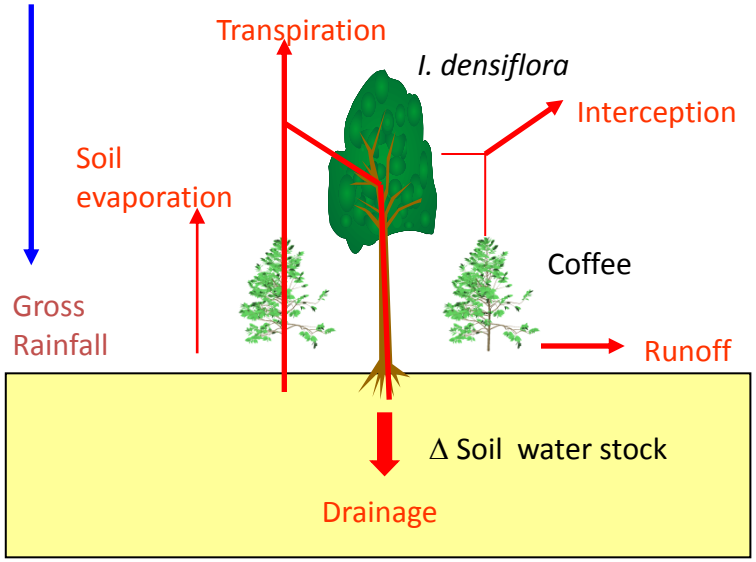
-Rainfall interception by canopy

-Soil water

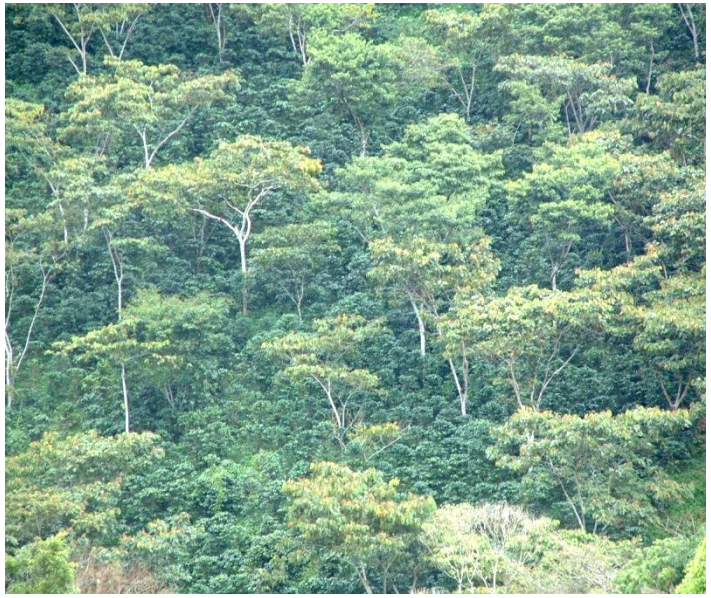
-Transpiration

-Runoff

Drainage



Order of magnitude of various components



	AFS	MC
Throughfall	77%	83%
Tree Stemflow	1%	-
Coffee Stemflow	10.5%	7%
Interception	11.5%	10%
Transpiration	34%	25%
Runoff	3%	8%
Drainage (>200 m)	50.5%	57%

Water dynamics in coffee systems

Monoculture

Transpiration : 24%

Interception : 8%

Runoff: 8%

Drainage: 63%

Coffea arabica + Inga densiflora

Transpiration : 31%

- Coffee : 17%
- Tree: 14%

Interception : 12%

Runoff : 4%

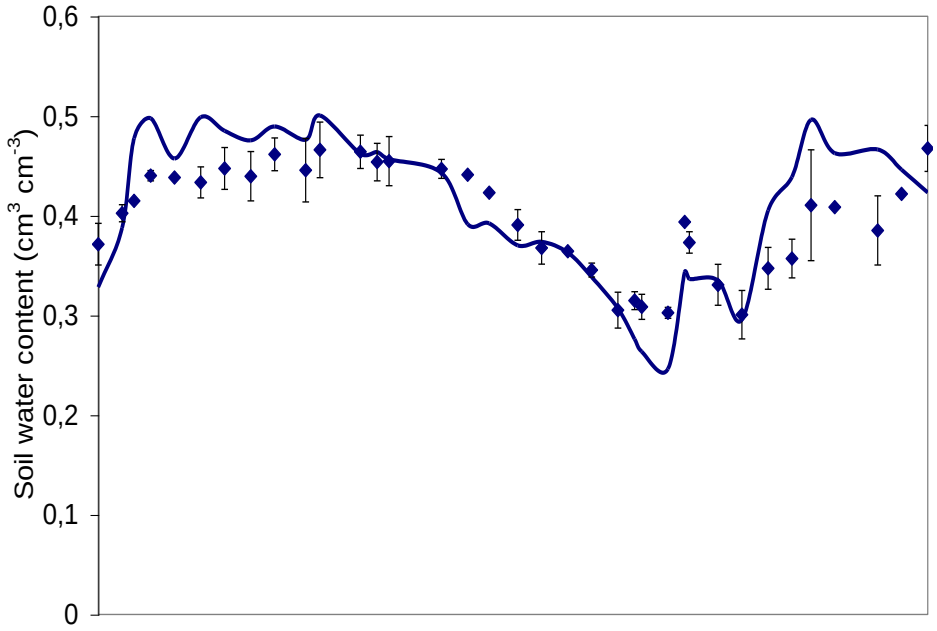
Drainage: 56%

(Siles, Vaast , Dreyer, Harmand, 2010; J. Hydrology)

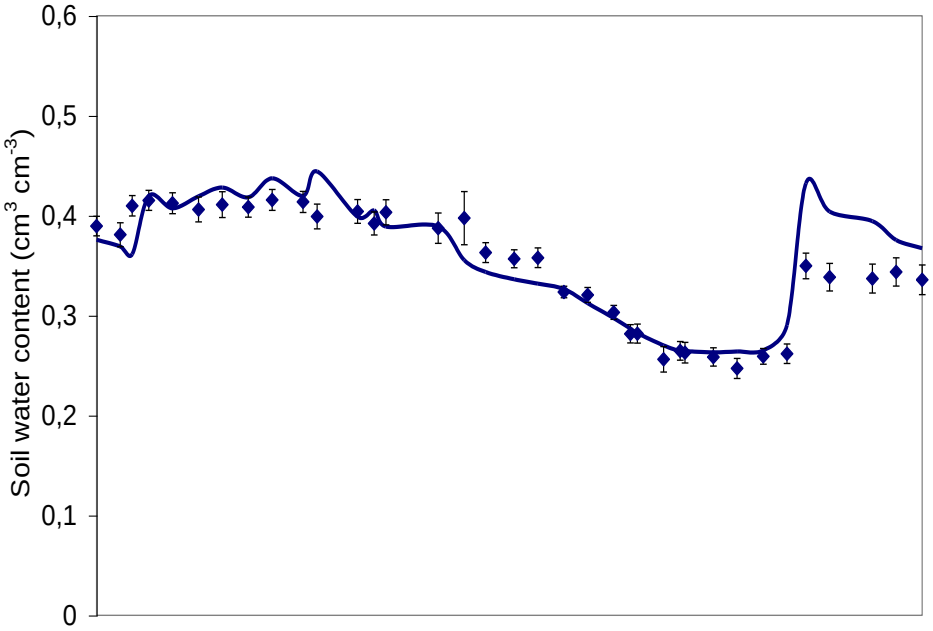
(Cannavo, Sansoulet, Harmand, Siles, Dreyer, Vaast, 2011; Agr. Eco. Env.)

Adaptation of Model “HYDRUS”

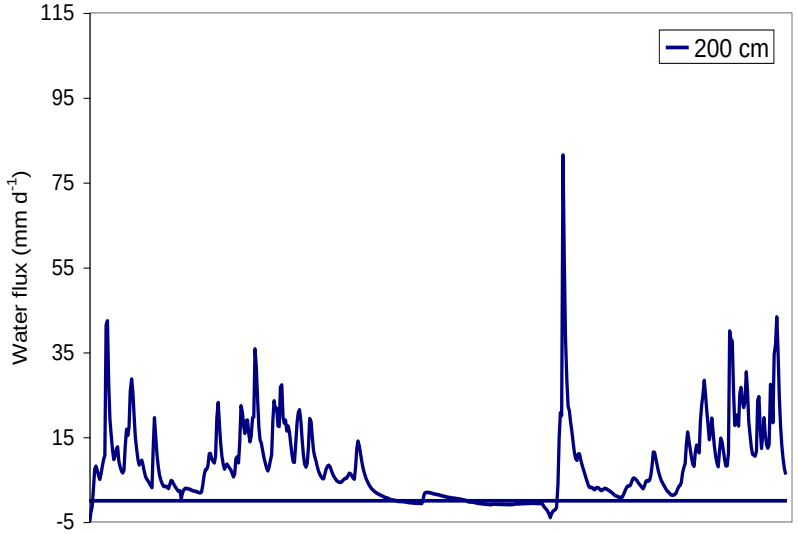
Comparison of simulated (solid line) and observed (circles) soil volumetric water contents in the 0-30 and 60-90 cm soil layers in AFS
with allocation of water uptake in the various soil layers according to root density



0-30 cm soil layer in AFS

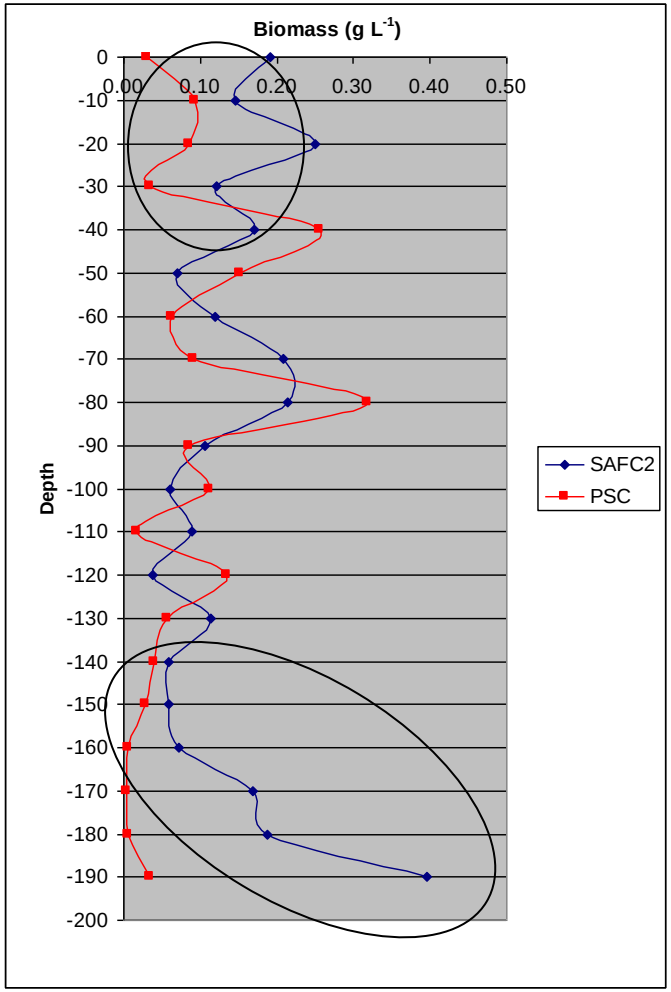


60-90 cm soil layer in AFS



Water drainage (in mm d^{-1}) at 200 cm soil depth in AFS

Competition/complementarity for water between coffee and shade trees



Explore climatic scenarios with model

1. Rainfall reduced to 40% of the actual rainfall regime (i.e. ~1300 mm yr^{-1})

➔ Severe reduction in drainage, but without water competition between coffee and shade trees,

1. Dry season extended by 4 to 6 weeks

➔ Water competition between coffee and shade trees

Effects of Trees on coffee Pests and Diseases

- Highly dependent on pest or disease, and not “clear cut”

- **Positive effects**
- White stem borer of Arabica (Coffee Board India) => cooler microclimate
- Leaf miner => cooler and more humid microclimate
- CBD of Arabica => rain interception by tree canopy (Mouen, Cilas et al in Cameroun)
- Nematodes => higher OM content and antagonistic soil micro-flora

- **Negative effects**
- Coffee berry borer negative at plot level, but microclimate favorable to antagonists (Beauveria), and tree barrier to spread at landscape level
- Leaf rust (and other fungal diseases) => enhanced development due more humid microclimate but fruit load effect, and to some extent tree barrier effect at landscape level

Effects of trees on soil fertility

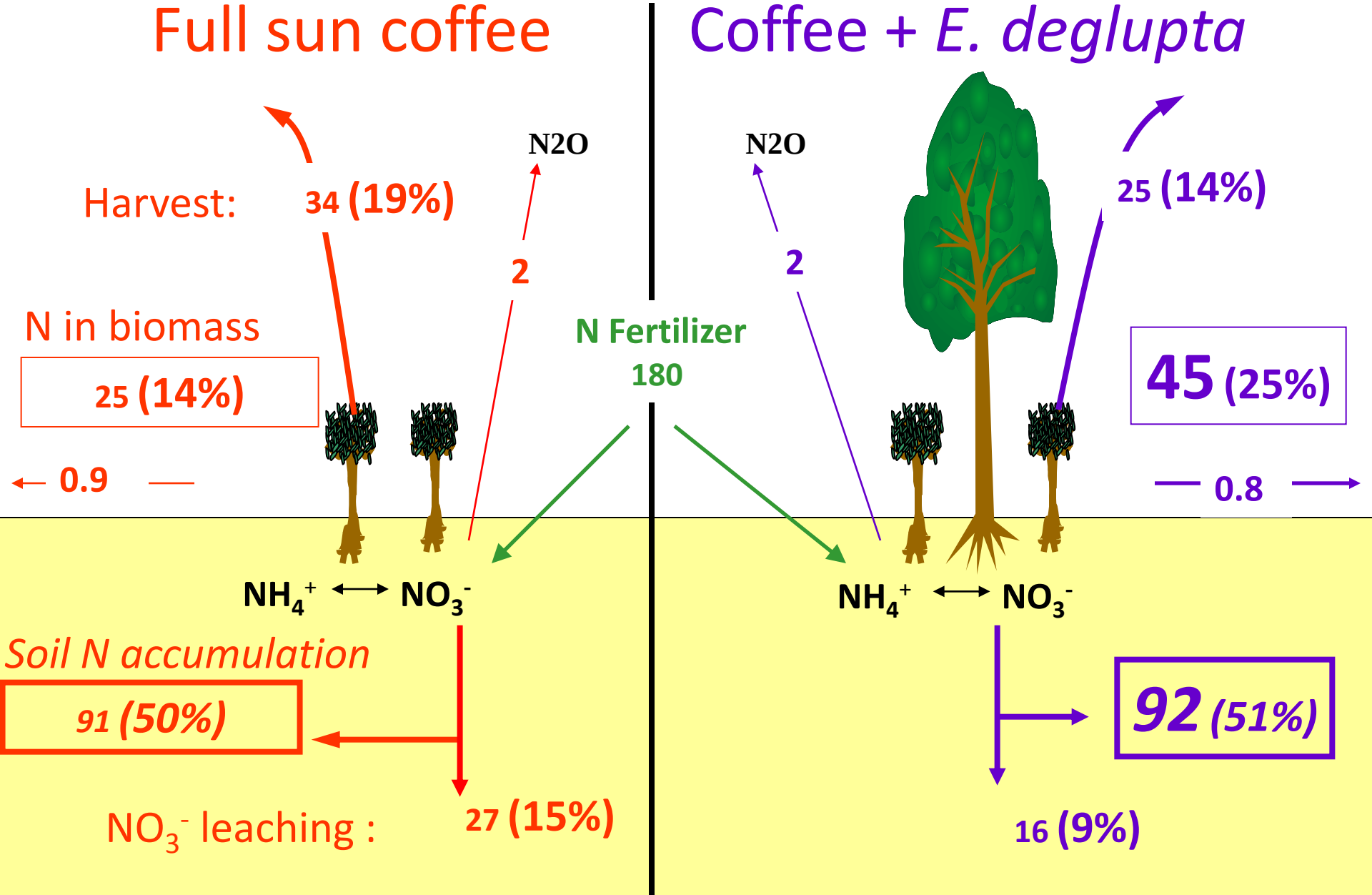
Via pruning and/or leaf fall, shade trees contribute to soil OM

Important for physical properties

and via decomposition => nutrient cycling

Due to high N coffee demand, a focus on fate of N fertilization
and contribution of legume (N-fixing) trees

Annual N budget (kg N ha^{-1})



N measured fluxes (kg N ha^{-1}) Yr1

Full sun coffee

Coffee + *I. densiflora*

Harvest:

38 (15%)

43 (15%)

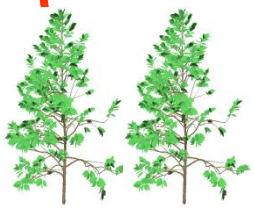
N in biomass

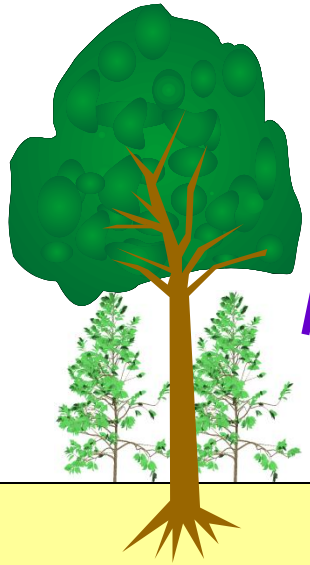
46 (18%)

115 (40%)

N Fertilizer

250





NO_3^- N leaching :

120 (48%)

95 (38%)

N measured fluxes (kg N ha^{-1}) Yr2

Full sun coffee

Coffee + *I. densiflora*

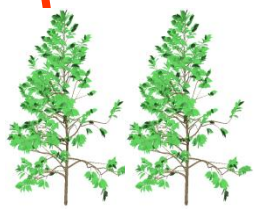
Harvest: **143**

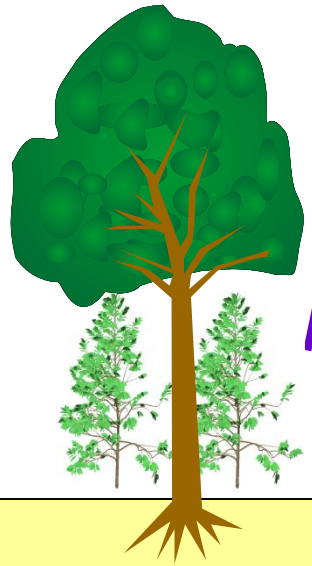
N in biomass **46**

N Fertilizer 250

95

115

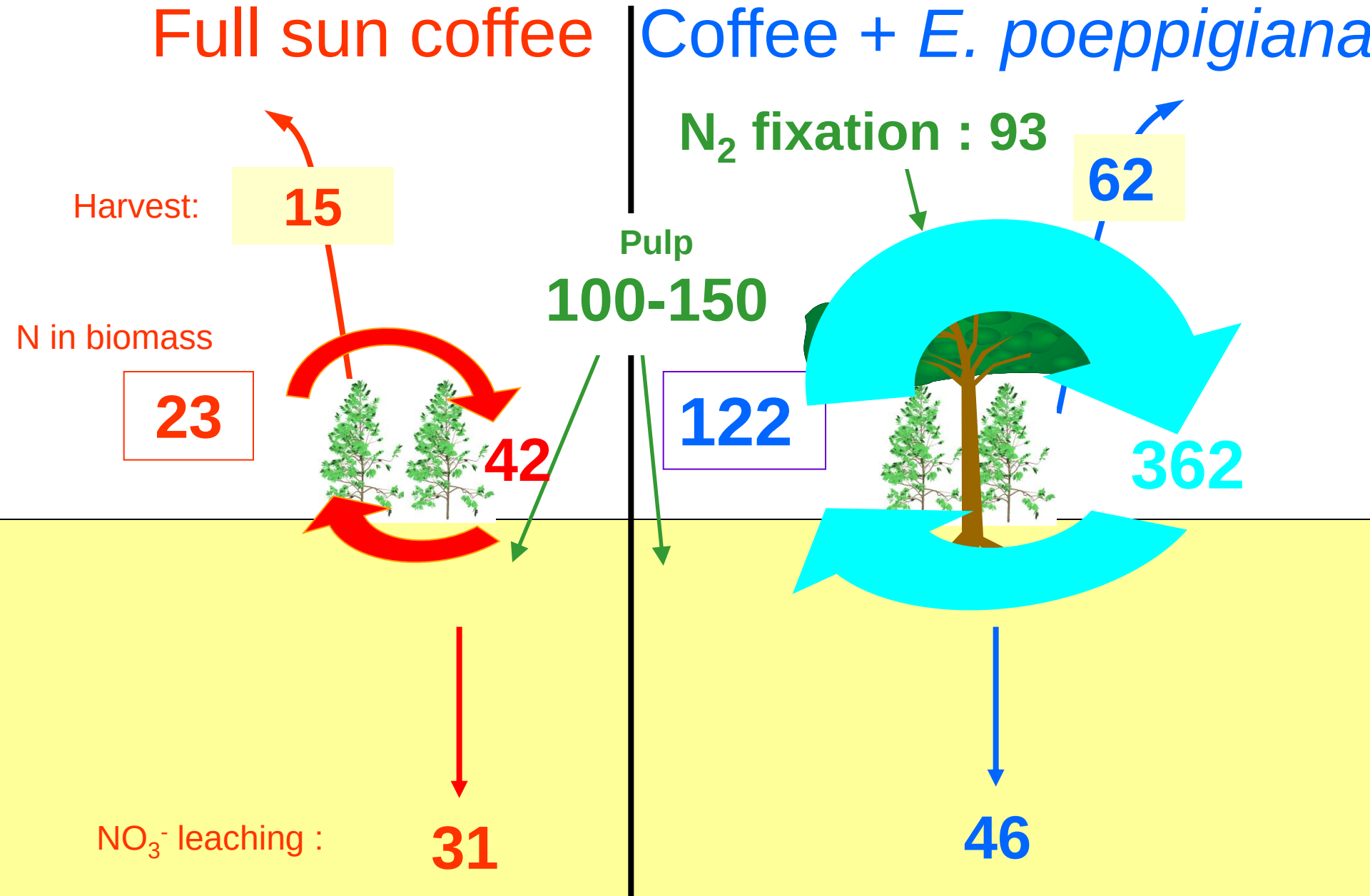




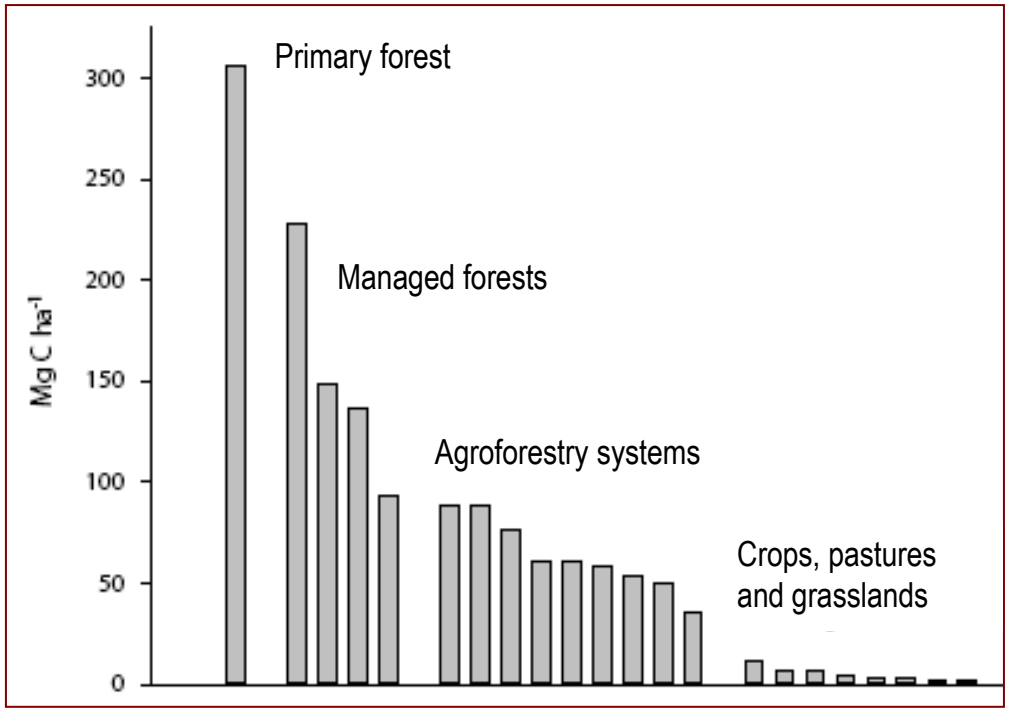
NO_3^- -N leaching: **80**

120

N budget (kg N ha^{-1}) Organic plot



Role of Coffee AFS in mitigation of Climate Change



Verchot et al. (2005)

Carbon sequestration in coffee systems

	Carbon stocks (t C ha-1)							
	Coffee[a]	Shade trees[b]	Litter	Weeds	**Total ABG**	Roots	Soil[c]	**Total System**
Range	5-16	0-120	1-12	0-10	**10-150**	1-10	**10-220**	**35-350**

[a] Coffee planting densities between 1250 and 6340 trees ha^{-1}
[b] Shade trees planting densities between 50 and 800 trees ha^{-1}
[c] Soil sampled between 0 and 45 cm depth.

Importance of previous land use

Carbon (t/ha)					
System	**Tree**	**Coffee**	**Soil**	**Litter**	**Total**
Forest	97	-	97	2,4	196
Arabica Native	88	4,8	112	1,6	206
Arabica Exotic	73	3,3	105	2,2	183
Robusta Native	78	13,0	90	1,8	182
Robusta Exotic	47	10,1	78	1,9	138

Native coffee AFS >300 trees/ha and 50 species
“Exotic” coffee AFS >200 trees/ha and 20 species
Mean yield Arabica 600-900 kg green bean/ha
Mean yield Robusta 800-1200 kg green bean/ha

N_2O emission in coffee systems with legume trees

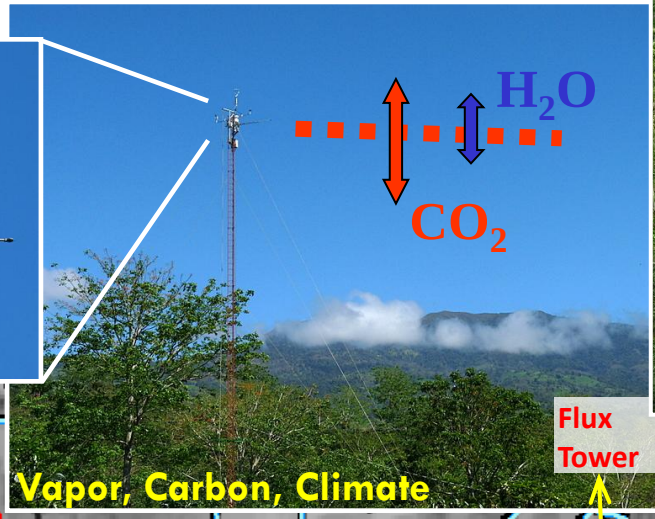
(Hergoualc'h et al 2007 & 2012)

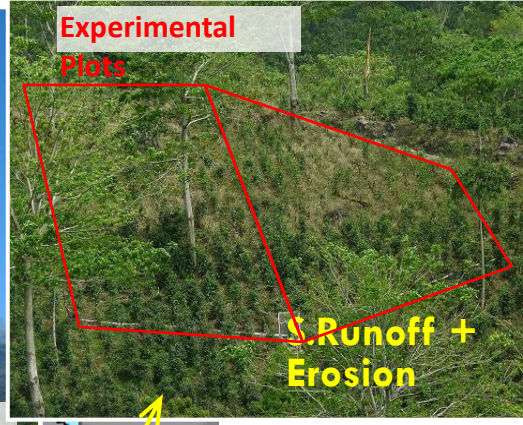
Fertilization	Coffee system	N_2O effluxes t CO_2-eq $ha^{-1}yr^{-1}$	C ABG t CO_2-eq $ha^{-1}yr^{-1}$	Net C rate t CO_2-eq $ha^{-1}yr^{-1}$
Mineral Fertilizer 250 kg N ha^1yr^1	AFS – *Inga densiflora*	2.7 (0.2)	13.2 (0.3)	10.5 (0.4)
	Monoculture	2.0 (0.0)	5.5 (0.6)	3.4 (0.6)
Organic Fertilizer 150 kg N ha^1yr^1	AFS - *Erythrina poeppigiana*	1.7 (0.7)	12.7 (0.5)	11.0 (0.9)
	Monoculture	0.9 (0.4)	3.1 (0.2)	2.2 (0.4)

Higher N_2O emission in coffee with legume shade trees than full sun coffee
But much higher net C sequestration rate in coffee AFS

Cafnet / CoffeeFlux

Experimental display



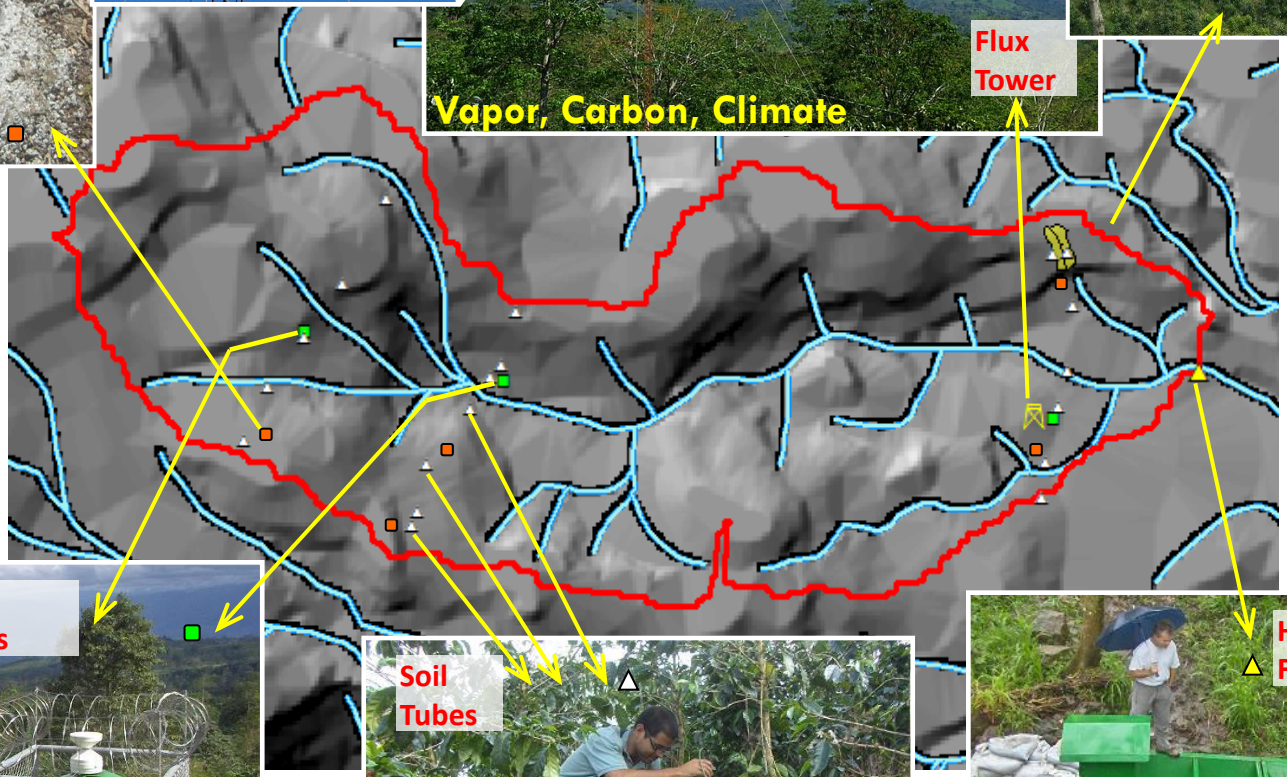


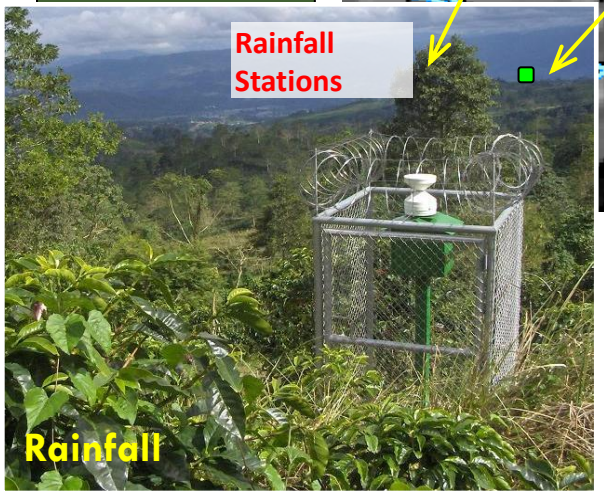
Soil properties experiments

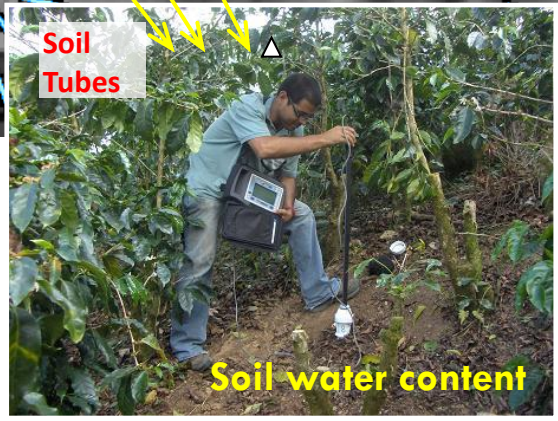
- Infiltrability
- Hydraulic conductivity

Plants + Trees flow experiments

- LAI
- Interception
- Throughfall
- Stemflow
- Sapflow







New approach & Tools for selecting & promoting tree on farms

- Impossibility of long-term testing of all candidate tree species => research in farmers' fields
- => combine research with farmers' traditional knowledge
- Modeling of farmers' behaviors to economical or legal drivers
- Prioritization of eco-hotspots

Tree Ranking

Role Playing Game

Farmers' tree knowledge
Why rank and not score?

- Farmer's knowledge is comparative – they are comfortable with comparisons
- Farmers can rank 10 trees for 12 attributes in a one hour session.

- Only rank trees that they have had direct experience of.

Physical attributes to rank trees against

General (for all trees)

- **Crown spread** (which trees have the widest crowns and which have the narrowest? Widest/narrowest)
- **Crown density** (which trees let a lot of sunlight through their leaves and branches, and which ones don't let sunlight come through? Least dense/most dense)
- **Easiness to prune** (which trees are easy to shape and which trees are not so easy to prune? Easiest/hardest)
- **Growth after pruning** (which trees can grow again easily once pruned and which ones do not grow well after pruning? Fastest/slowest)
- **Rooting depth** (which trees root deeply and which have shallower roots? Deepest/least deep)
- **Rooting spread** (which trees have the most spread out roots and which have roots that don't cover a big area underground? Widest/narrowest)
- **Growth rate** (which trees grow fastest and reach maturity the quickest and which trees are slow growing? Fastest/slowest)

Specific (for trees of a specific use)

<u>Firewood</u>

- **Burn length** (which wood burns for the longest time and which for the shortest time? Longest/shortest)

<u>Timber</u>

- **Strength** (which are the strongest and which are the weakest?)
- **Durability** (resistant to insect attack and rotting) (which wood lasts the longest and which rots and is attacked by insects easiest?)

<u>Mulch</u>

- **Leaf decomposition rate** (which are the fastest to decompose and which are the slowest? Fastest/slowest)
- **Benefit to the soil** (which are the best for soil and which are the worst? Highest/lowest)

List of trees (~30) used in Kenya

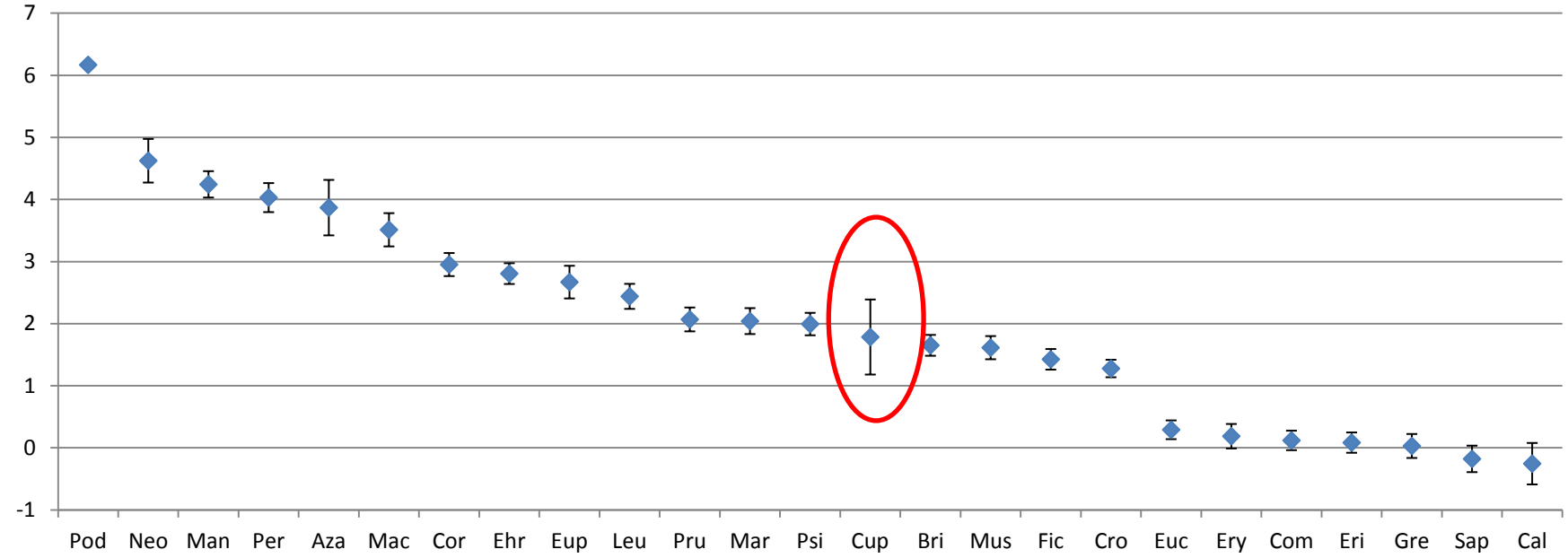
- *Acacia mearnsii*
- *Azadirachta indica*
- *Bridelia micrantha*
- *Callistemon citrinus*
- *Carica papaya*
- *Commiphora zimmermannii*
- *Cordia africana*
- *Croton megalocarpus*
- *Cupressus lusitanica*
- *Ehretia cymosa*
- *Eriobotrya japonica*
- *Erythrina abyssinica*
- *Eucalyptus saligna*
- *Euphorbia tirucalli*
- *Ficus natalensis*
- *Grevillea robusta*
- *Leucaena leucocephala*
- *Macadamia tetraphylla*
- *Mangifera indica*
- *Markhamia lutea*
- *Musa sapientum*
- *Neoboutonia macrocalyx*
- *Newtonia buchananni*
- *Persea americana*
- *Podocarpus falcatus*
- *Prunus africana*
- *Psidium guajava*
- *Sapium ellipticum*
- *Trema orientalis*

Attribute ranking

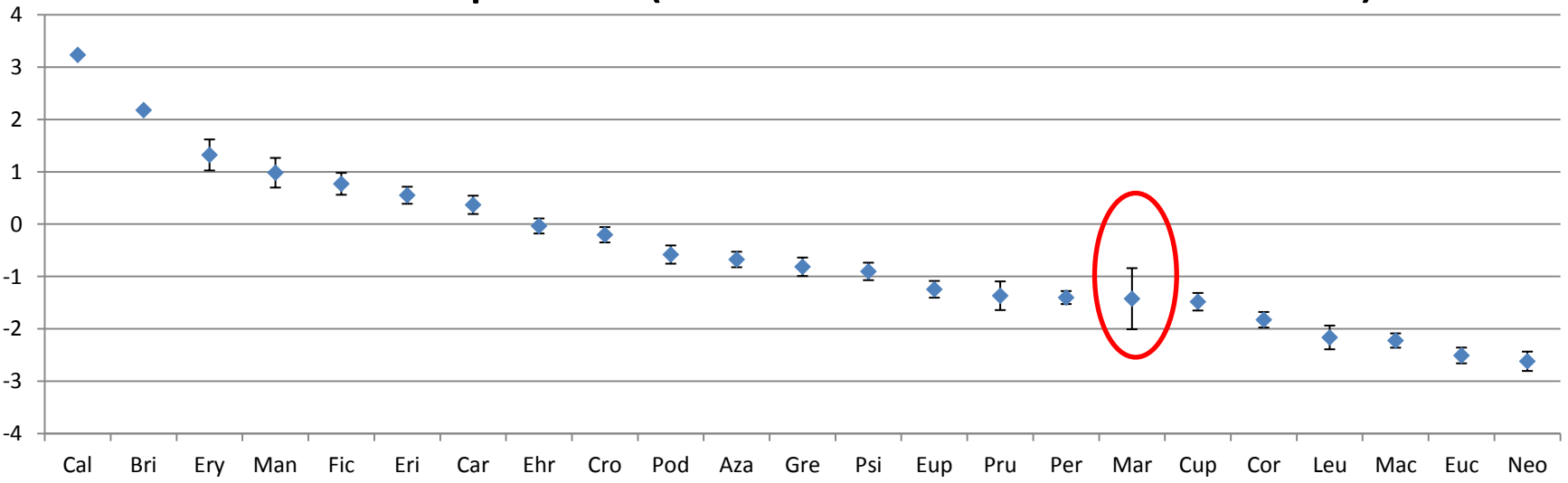
Trees ranked in order for each general attribute						
Crown spread	Crown density	Easiness to prune	Growth after pruning	Rooting depth	Rooting spread	Growth rate
Widest	Least dense	Easiest	Fastest	Deepest	Widest	Fastest
Persea americana	Commiphora zimmermanii	Musa sapientum	Grevillea robusta	Eucalyptus saligna	Eucalyptus saligna	Musa sapientum
Mangifera indica	Eucalyptus saligna	Persea americana	Persea americana	Grevillea robusta	Cupressus lusitanica	Eucalyptus saligna
Neoboutonia macrocalyx	Grevillea robusta	Grevillea robusta	Acacia mearnsii	Persea americana	Persea americana	Grevillea robusta
Grevillea robusta	Acacia mearnsii	Acacia mearnsii	Musa sapientum	Macadamia tetraphylla	Mangifera indica	Persea americana
Acacia mearnsii	Musa sapientum			Acacia mearnsii	Grevillea robusta	Mangifera indica
Cupressus lusitanica	Cupressus lusitanica			Cupressus lusitanica	Acacia mearnsii	Neoboutonia macrocalyx
Macadamia tetraphylla	Neoboutonia macrocalyx			Neoboutonia macrocalyx	Neoboutonia macrocalyx	Acacia mearnsii
Eucalyptus saligna	Mangifera indica			Musa sapientum	Macadamia tetraphylla	Cupressus lusitanica
Musa sapientum	Persea americana				Musa sapientum	Commiphora zimmermannii
Commiphora zimmermannii	Macadamia tetraphylla					Macadamia tetraphylla
Narrowest	Most dense	Hardest	Slowest	Least deep	Narrowest	Slowest

Comments and farmers' answers to questions to be recorded here: The farmer reported that commiphora doesn't have a tap root hence can't be include in rooting depth.

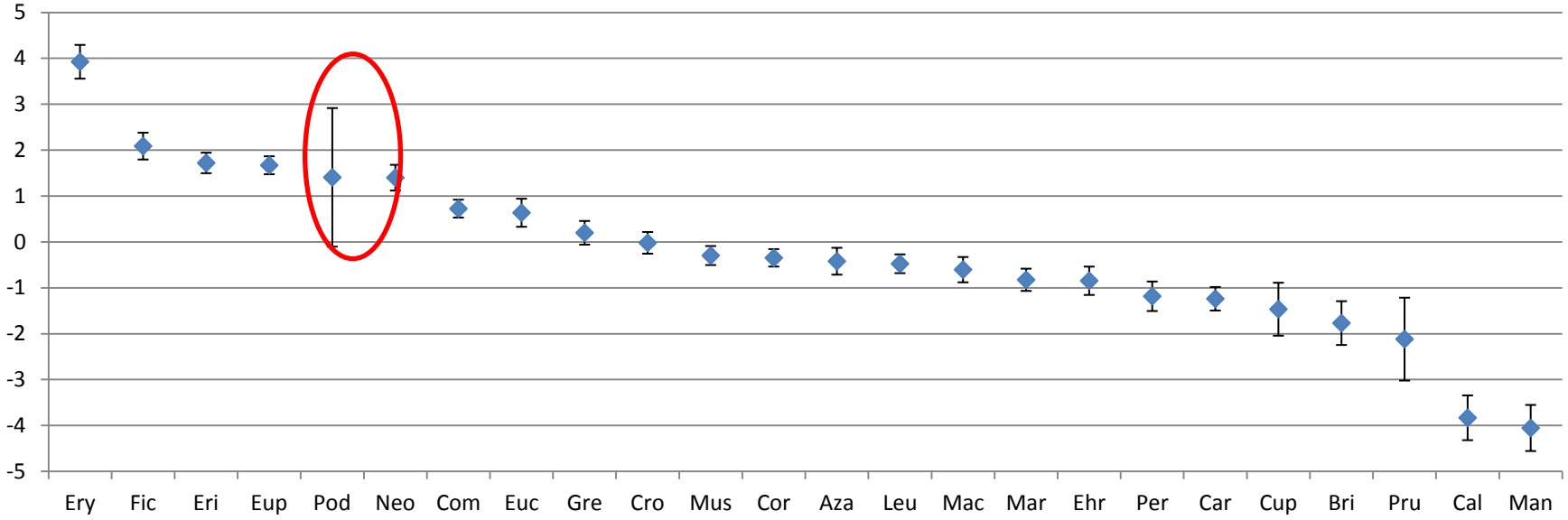
Crown density (from least dense to most dense)



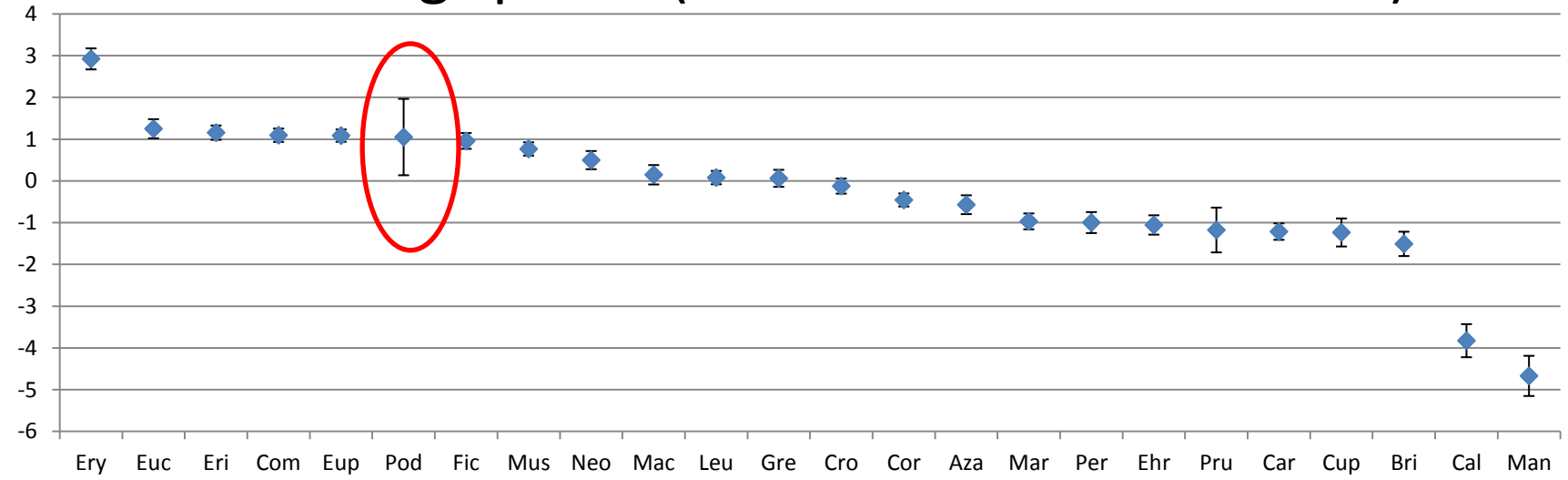
Crown spread (from widest to narrowest)



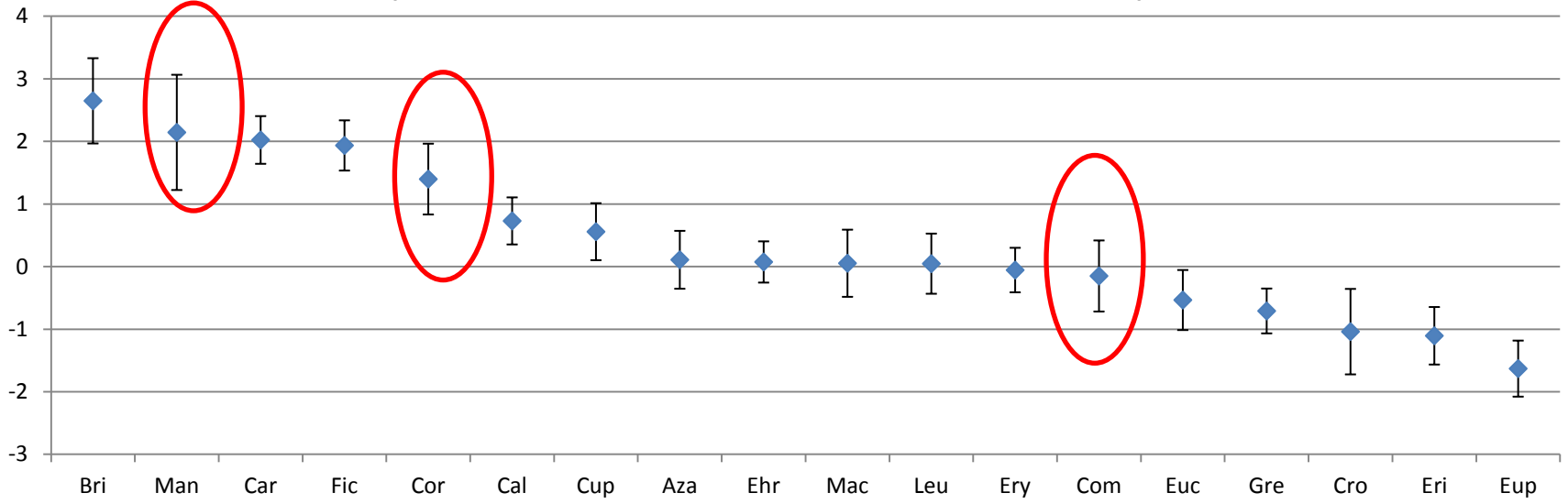
Rooting depth (from deepest to shallowest)



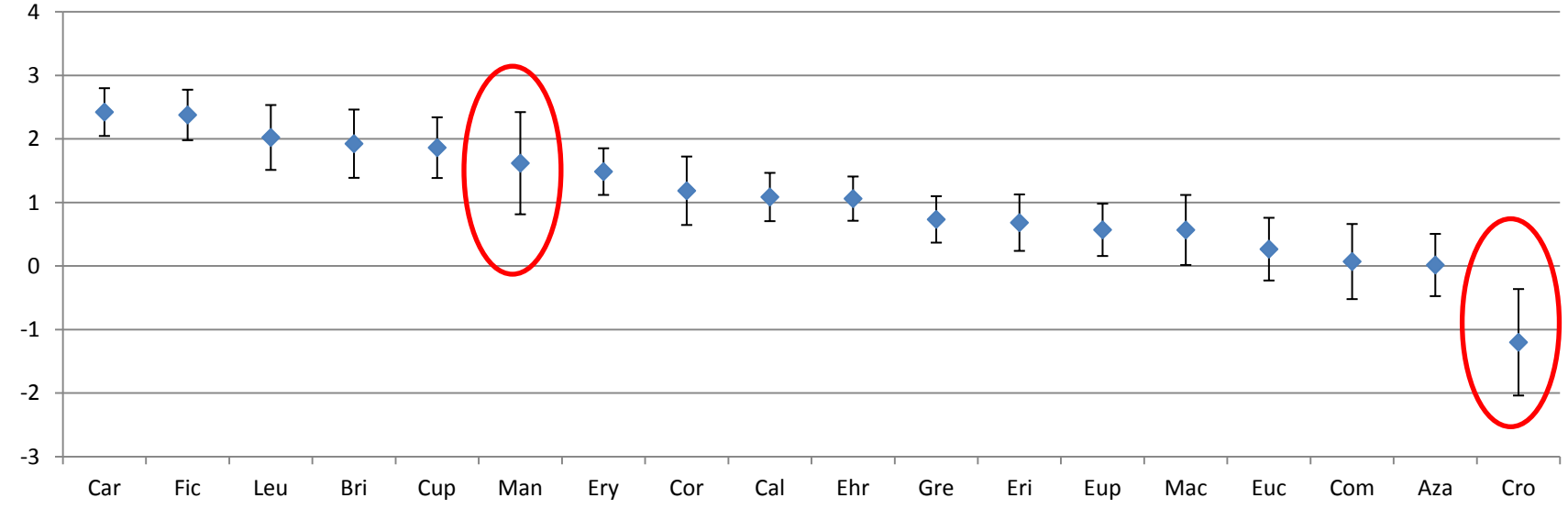
Rooting spread (from widest to narrowest)



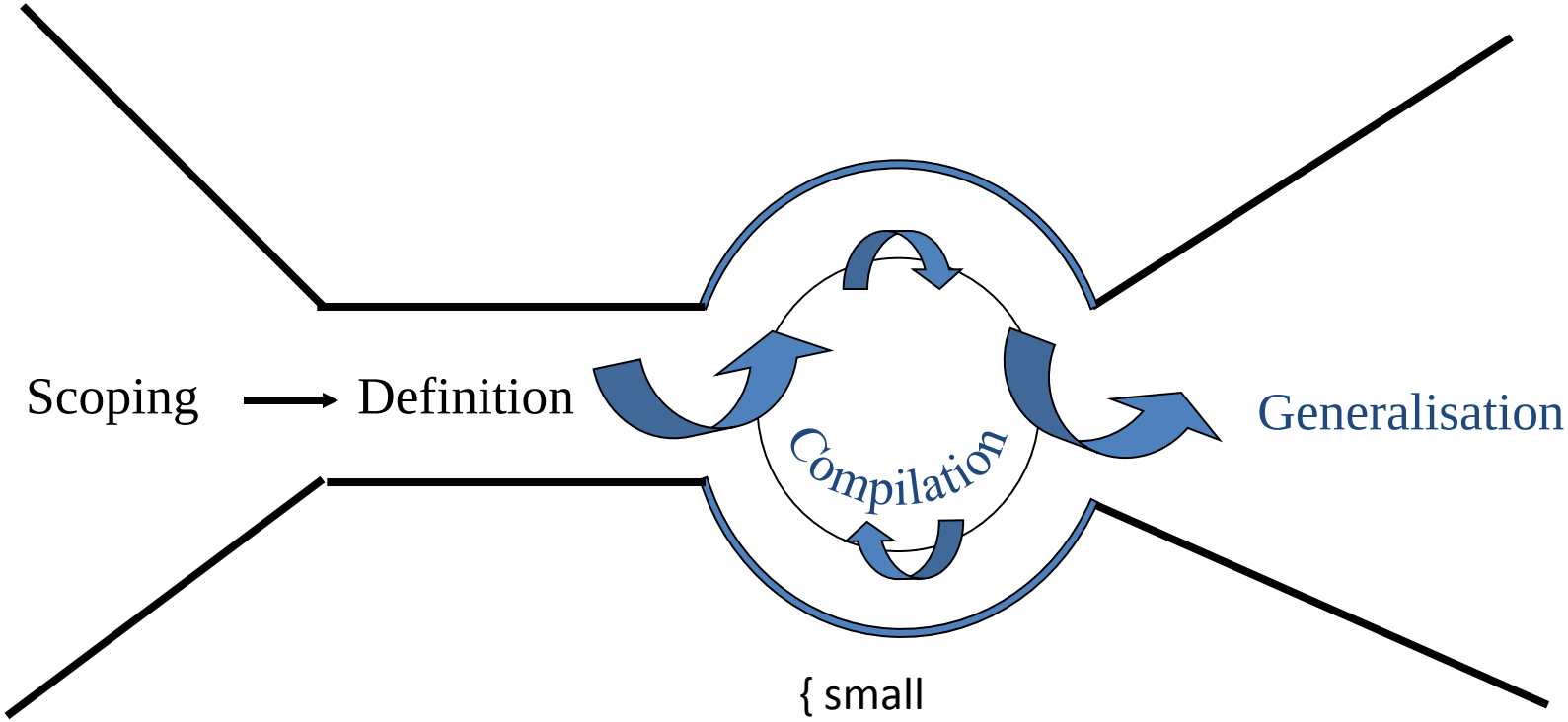
Mulch – leaf decomposition rate (fastest to slowest) (18 species ranked for mulch)



Mulch – benefit to soil (highest to lowest)



AKT (UW Bangor)- Acquisition strategy



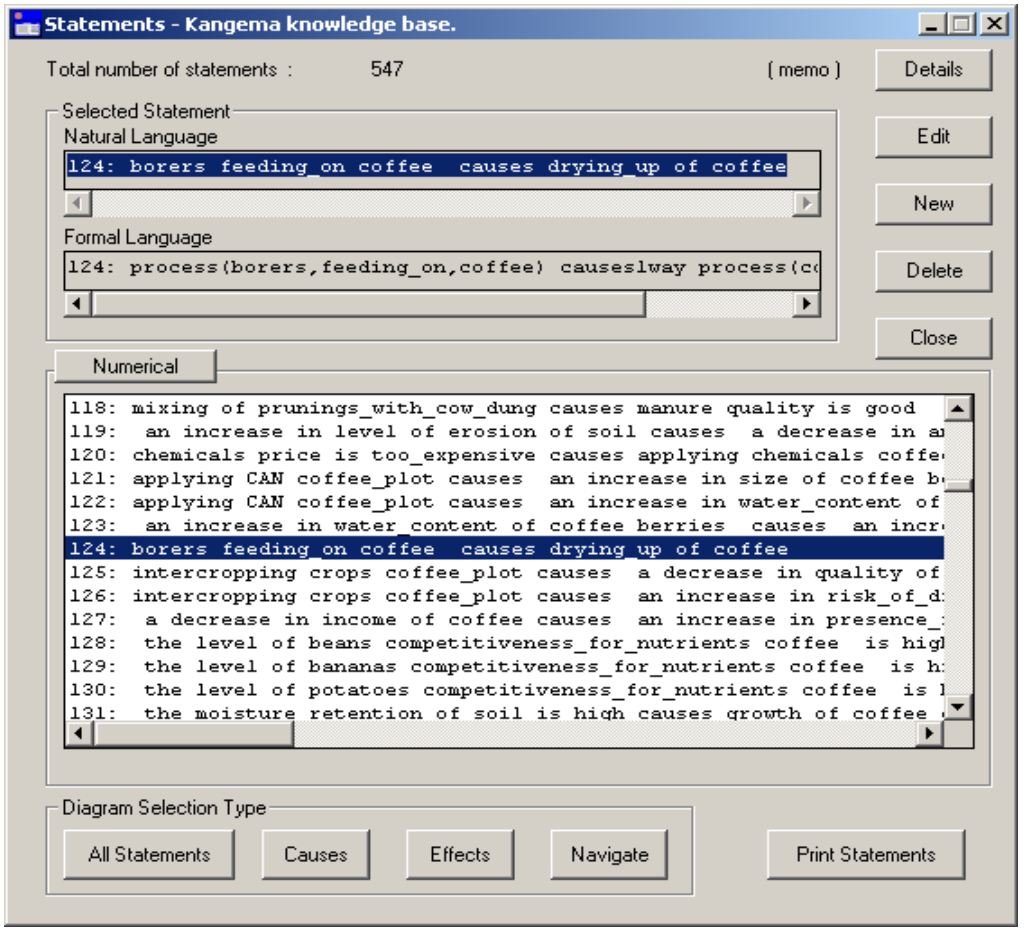
Secondary data
Key informants
Reconnaissance

Sample { small
{ stratified
{ purposive
Semi-structured interviews
Iterative, triangulated
Qualitative

Sample { large
{ stratified
{ random
Questionnaire
Quantitative analysis

Knowledge based systems

- Dissagregation
  - unitary statements
  - formal grammar
- Context
  - source
  - conditionality
  - local definitions and taxonomies of terms
  - images
  - diagrams showing connections amongst statements



Borers feeding on coffee causes it to dry up

Knowledge based systems

- Dissagregation
  - unitary statements
  - formal grammar
- Context
  - source
  - conditionality
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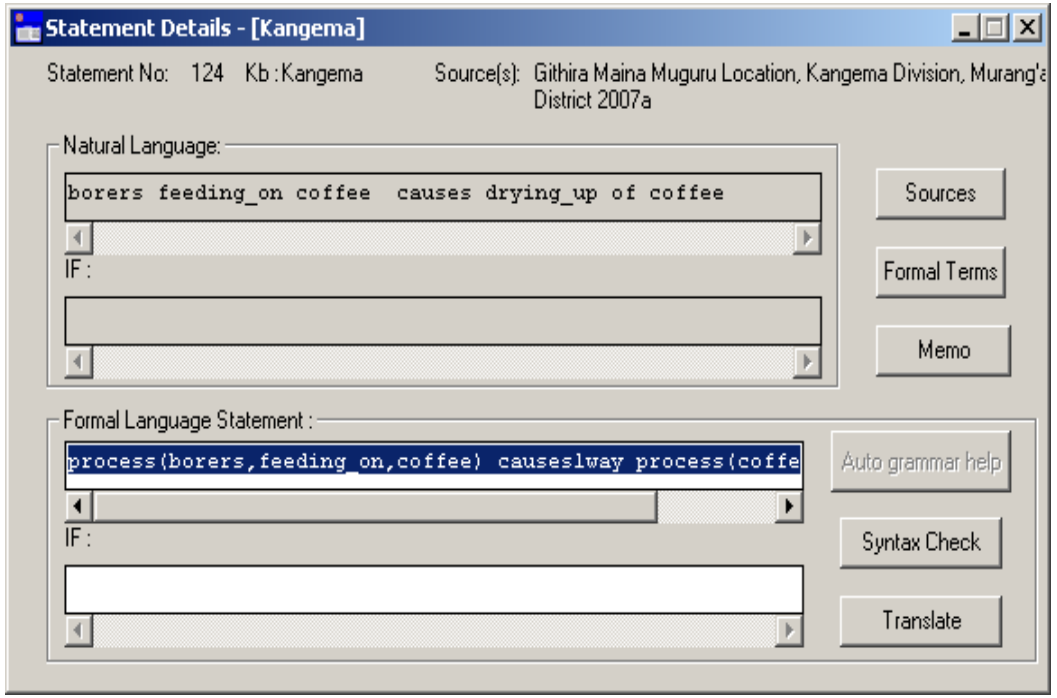
  - diagrams showing connections amongst statements



process(borers,feeding_on,coffee) causes1way process(coffee,drying_up)

Knowledge based systems

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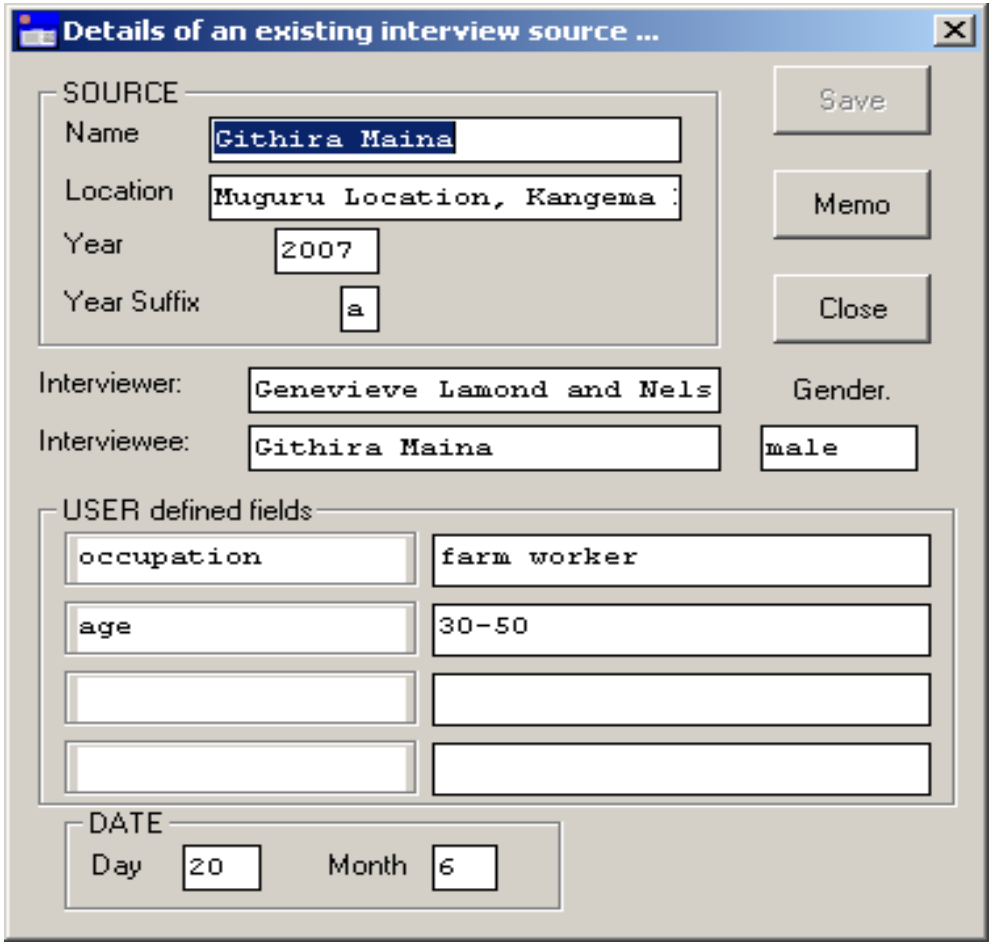

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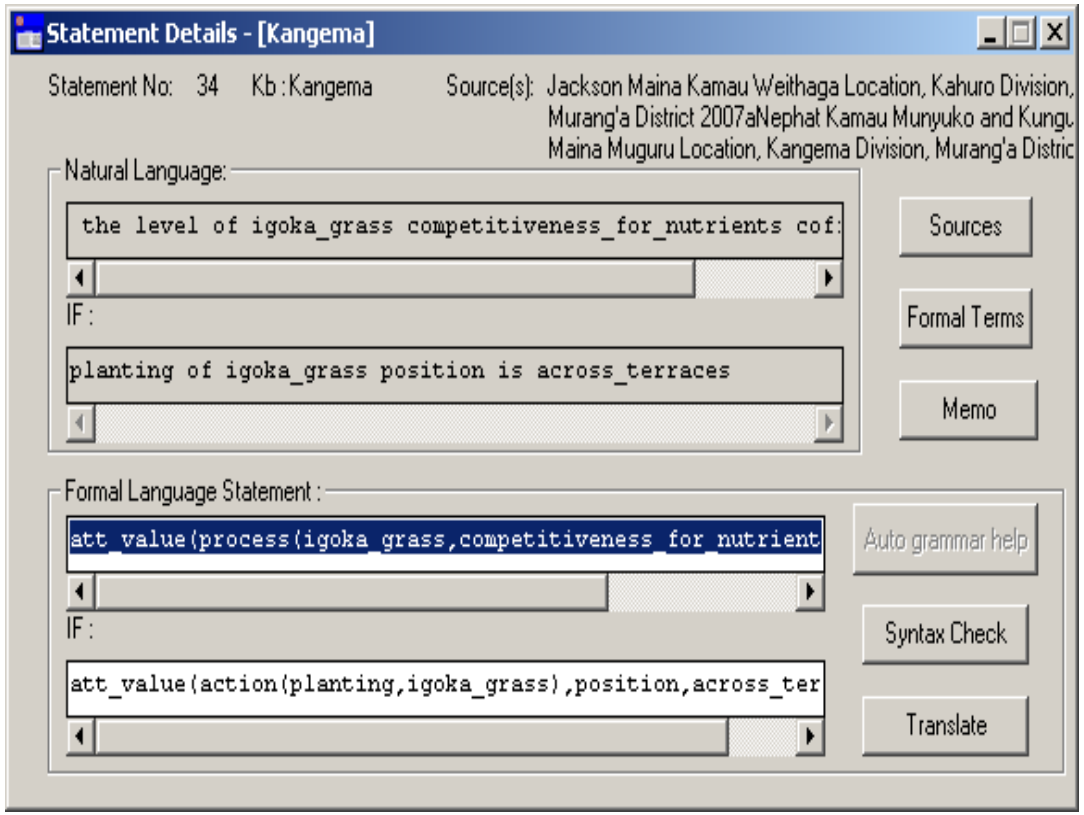

competitiveness of igoka grass for nutrients with coffee is high
IF igoka grass is planted across terraces

Knowledge based systems

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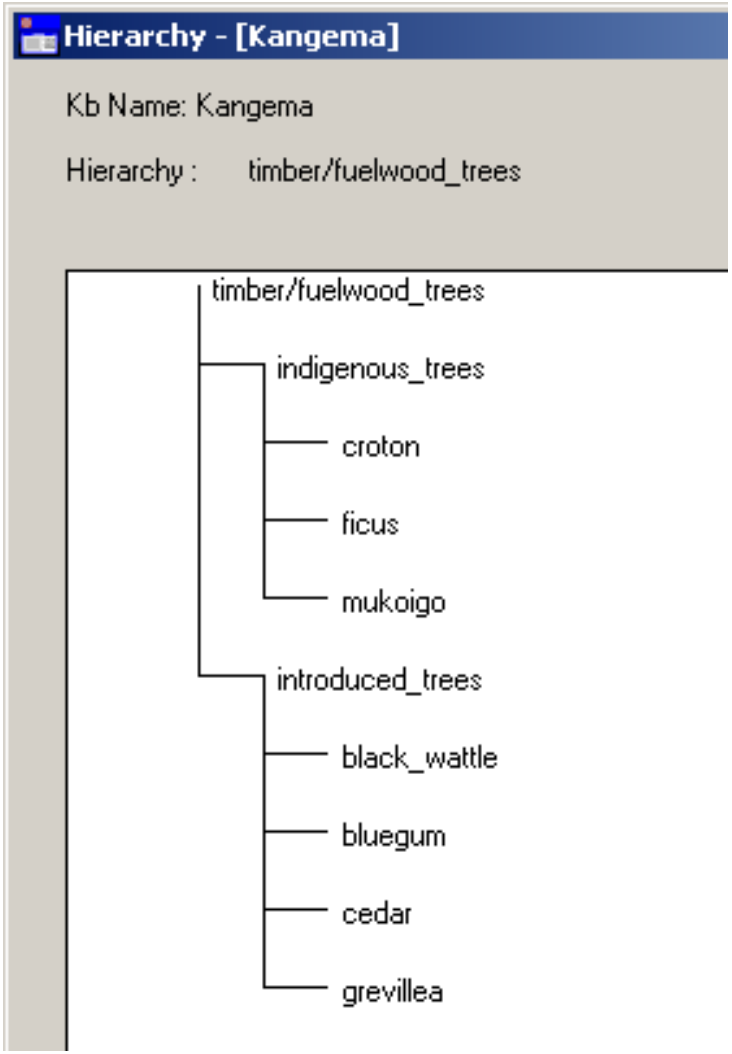

Knowledge based systems

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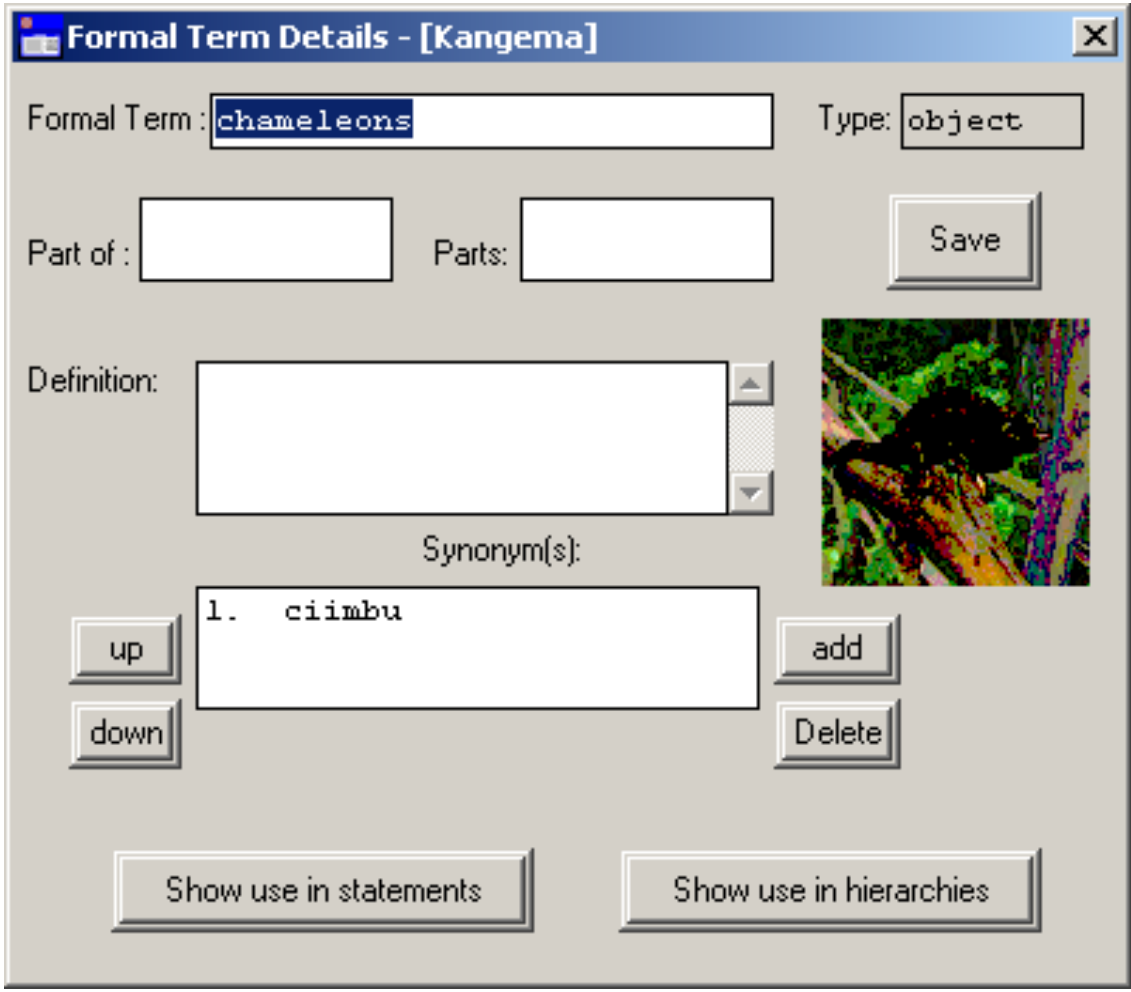

Knowledge based systems

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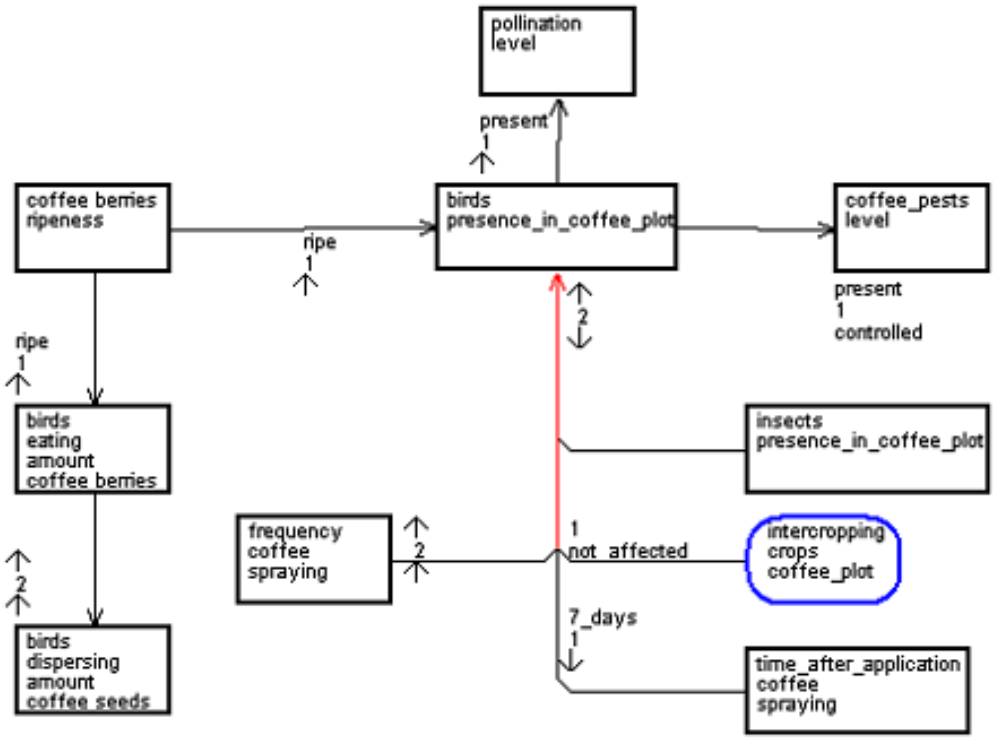
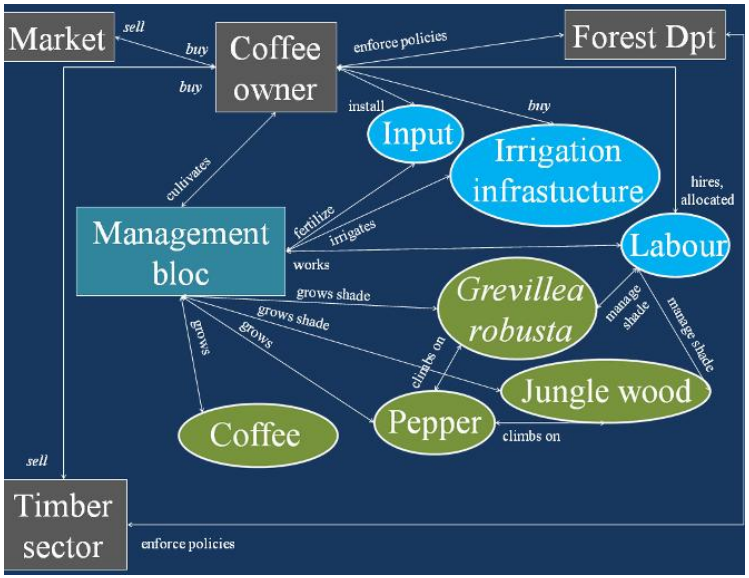


Conceptual Model



Role Playing Game

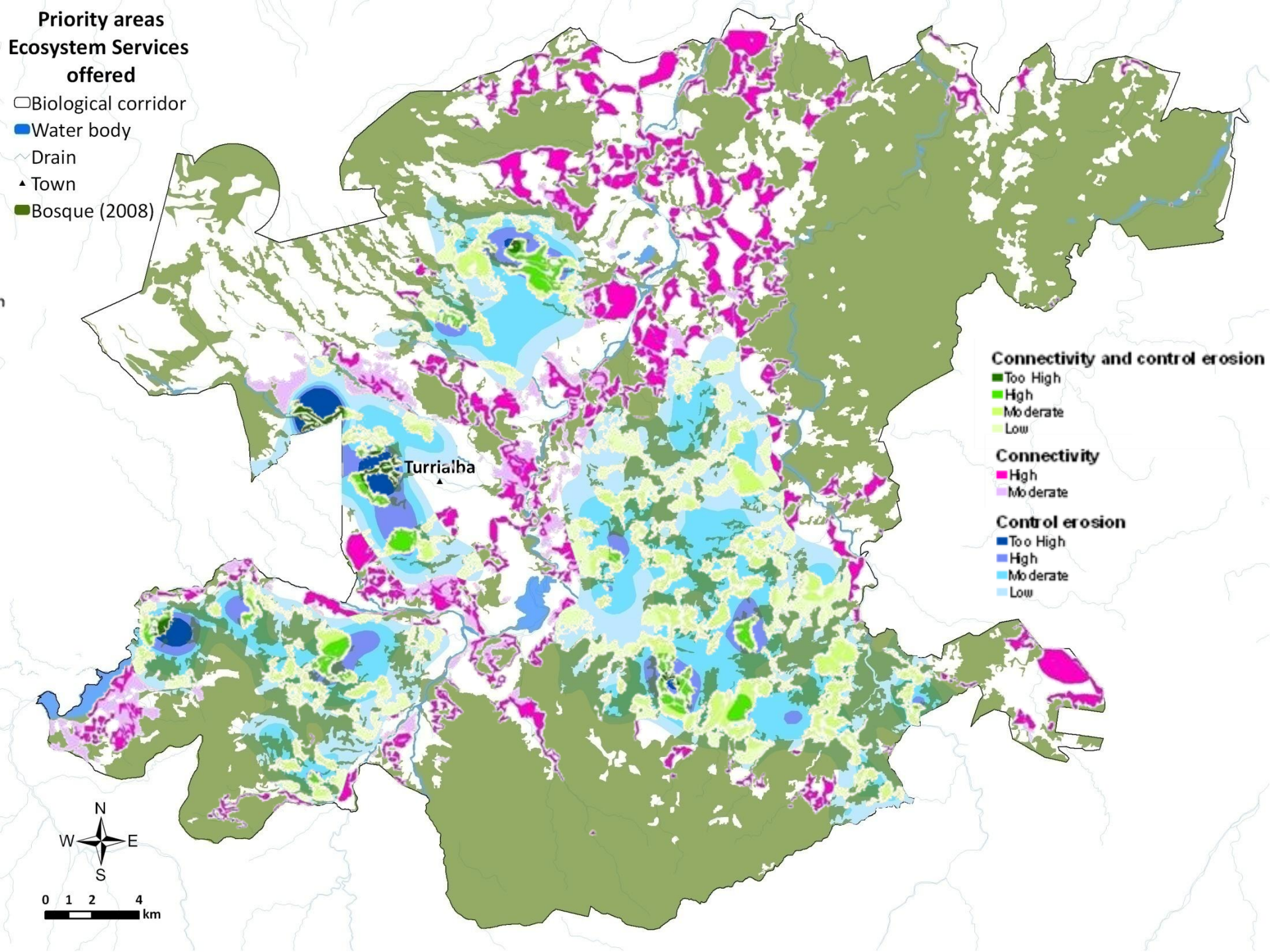
No Tree Rights except exotic species
Complete tree ownership
Low coffee price
High pepper price

67


PLAYER 1
PLAYER 4
PLAYER 6
COFFEE BOARD

Eco-certification and Payment for environmental services

- Eco-certification =>
  - Increasing environmental awareness
  - Better practices (yield) & promoting AFS
  - Low adoption (outside Latin America)
  - Too low economic reward
  - Lack of flexibility to local conditions
- PES => priorization on hot spots for ES provision within a landscape


Priority areas
Ecosystem Services
offered
Biological corridor
Water body
Drain
Town
Bosque (2008)
Turrialba
Connectivity and control erosion
Too High
High
Moderate
Low
Connectivity
High
Moderate
Control erosion
Too High
High
Moderate
Low
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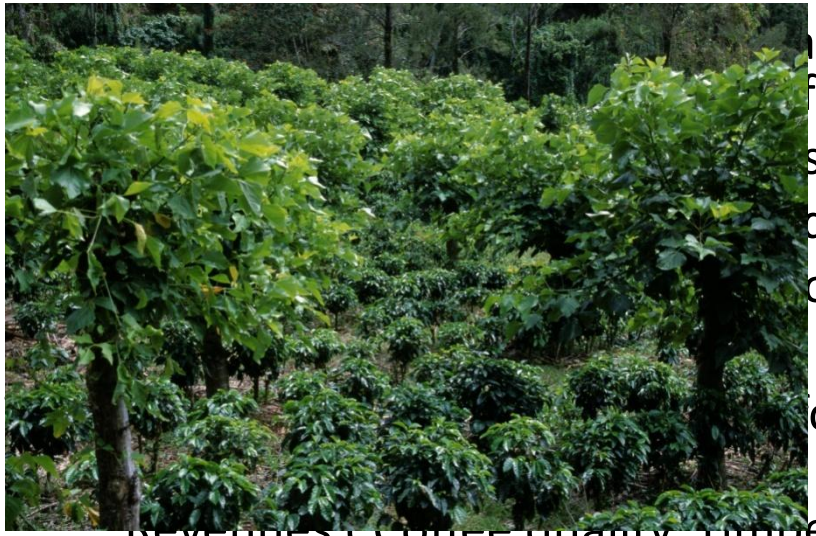
0 1 2 4
km

Concluding remarks (1)

- Traditional coffee agroforests important to preserve bidiversity, but priority is to **promote "intensified" coffee agroforestry systems to improve ES provision (including coffee production)**

- "Managed" Coffee AFS above world coffee yield average (examples of Costa Rica and India)

- 
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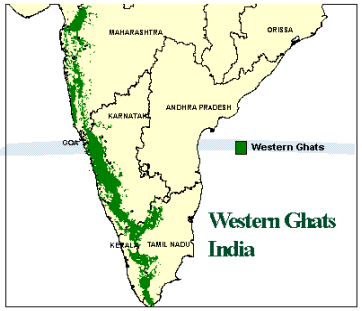
Revenues (Coffee quality, Timber and
Contribution to diet via fruits
Traditional medicine

Concluding remarks (2)

- Trees on coffee farms are important for:
  Adaptation (temp, rainfall pattern) to **climate change**
  Mitigation (carbon sequestration) of climate change



- Coffee AFS have an important role at the **landscape** level:
  i.e. buffer zone, corridor, water yield, eco-tourism…

- **Eco-certification** not strong enough of a driver on its own to promote AF
  Good impact in terms of social and environmental awareness,
  too "vague" regarding environmental criteria
  Not enough in terms of eco-incentives (premium 1-10%)

- **Combining rewards for eco-certification with PES**
  International =>carbon, local => water
  Farmers' organization for eco-certification => transaction costs (verification)
  Prioritization

Many thanks to the ASIC Organizing Committee for invitation