Designing cocoa shade canopies: trading-off productivity, biodiversity and carbon storage

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agroforestry systems with perennial crops

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Rationale: Shaded cocoa meet most recommendations for

- **resilience**
  - Cope with stresses, absorb shocks, retain structure and function
- **Vulnerability**
  - Low exposure, response to shocks, adaptive capacity
- **Mitigation**
  - Low emission, high carbon storage
- **Adaptation**
  - Range of ecological and social measures, including extensive use of organic matter, retaine high biodiversity, diversified production, improved livelihood capitals, etc.
- **There is room for improvements**

Cocoa farmers retain or plant trees in the shade canopy to:

1. Provide shade and shelter to cocoa
2. Produce goods (timber, fruit, firewood, etc.) for home consumption and sale
3. Reduce financial risk via product diversification


Erythrina poeppigiana

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Cocoa under coconuts in Jamaica – hurricanes

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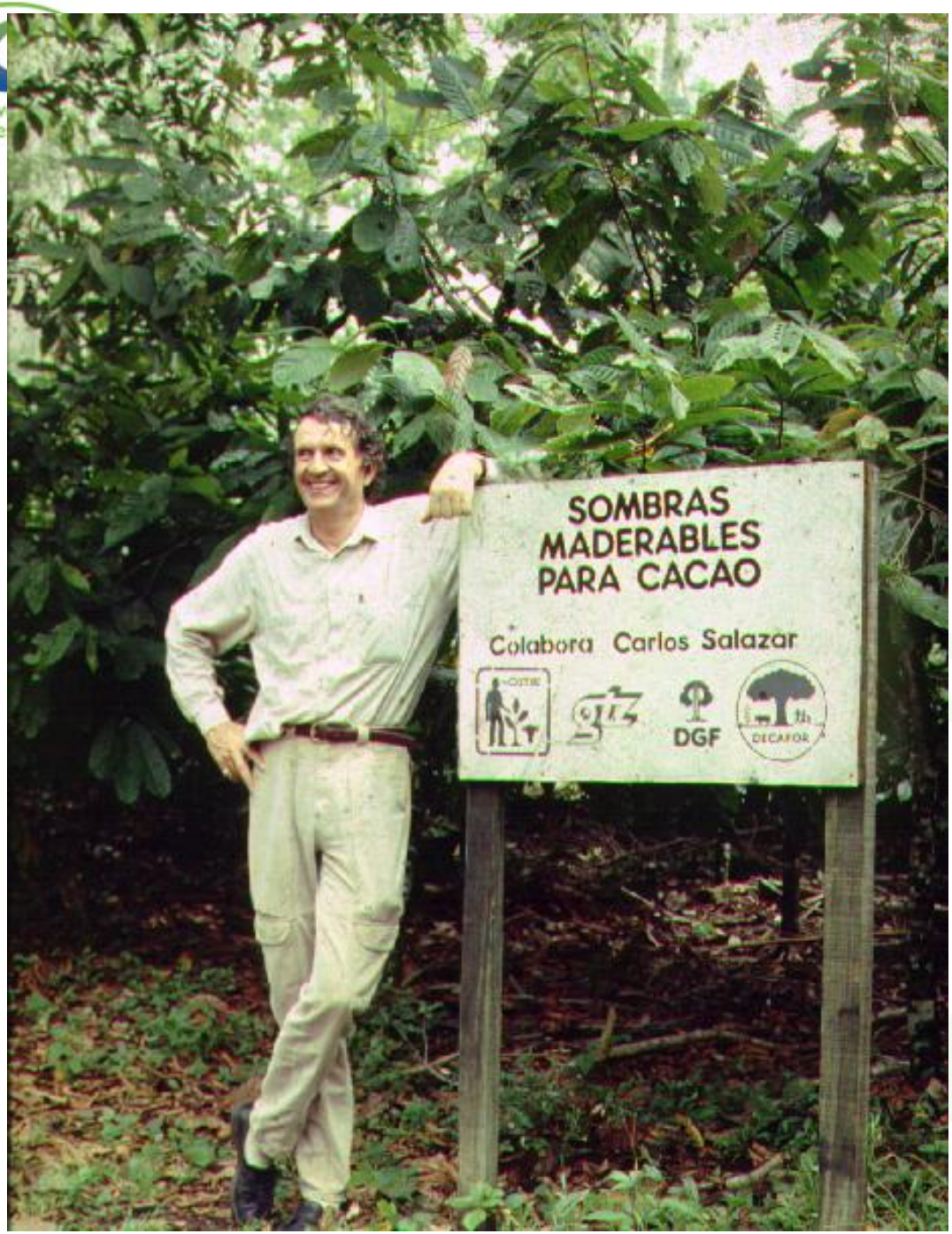
Cocoa and timber



Planted timber trees grow fast in cocoa plantations

CORALL= *Cordia alliodora*, TABROS= *Tabebuia rosea*, TERIVO= *Terminalia ivorensis*

1989 planting year

*After thinning

Somarriba & Beer 2011 Agroforestry Systems 81:109-121

	CORALL	TABROS	TERIVO
Year	V (m^3/ha)	V (m^3/ha)	V (m^3/ha)
1990	0	0	1
1991	6	5	7
1992	25	13	26
1993	49	24	54
1994	80	42	88
1995	81/77*	43/36*	101/89*
1996	96	54	107
1997	110	64	142
1998	121	75	155
1999	128	97	172

If properly managed same cocoa yields obtained under widely different shade species

Somarriba & Beer 2011 Agroforestry Systems 81:109-121

Site	Shade species	Bean yield	Yield losses (%)
CL	ERYPOE	802	43
CL	GLISEP	903	44
CL	INGEDU	829	43
	Mean	**845**	**43**
CT	CORALL	721	52
CT	INGEDU	767	53
CT	TABROS	727	56
CT	TERIVO	669	53
	Mean	**721**	**54**

ERYPOE = *Erythrina poeppigiana*; GLISEP = *Gliricidia sepium*; INGEDU = *Inga edulis*; CORALL = *Cordia alliodora*; TABROS = *Tabebuia rosea*; TERIVO = *Terminalia ivorensis*

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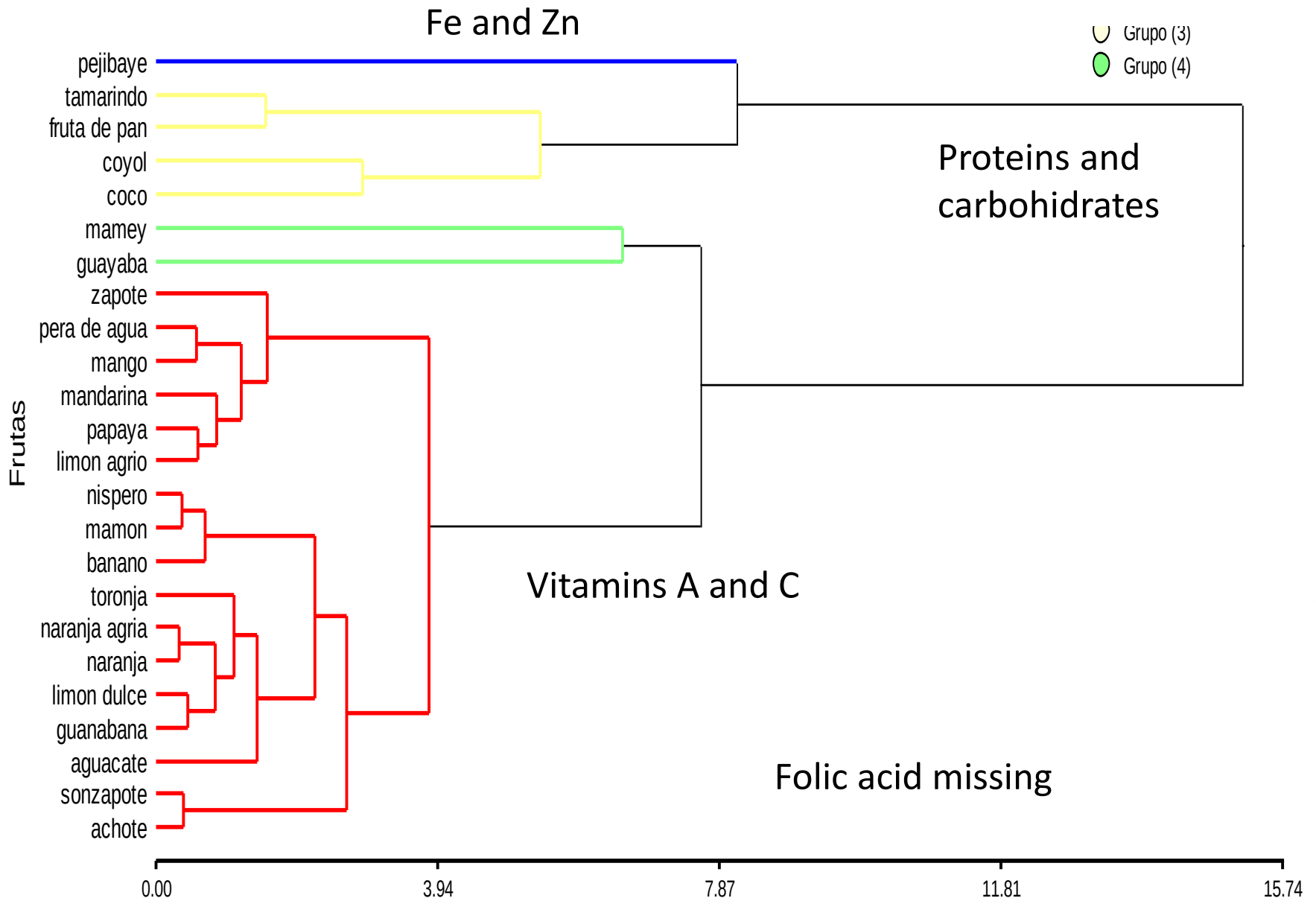
Fruit trees in Central American cocoa plantations

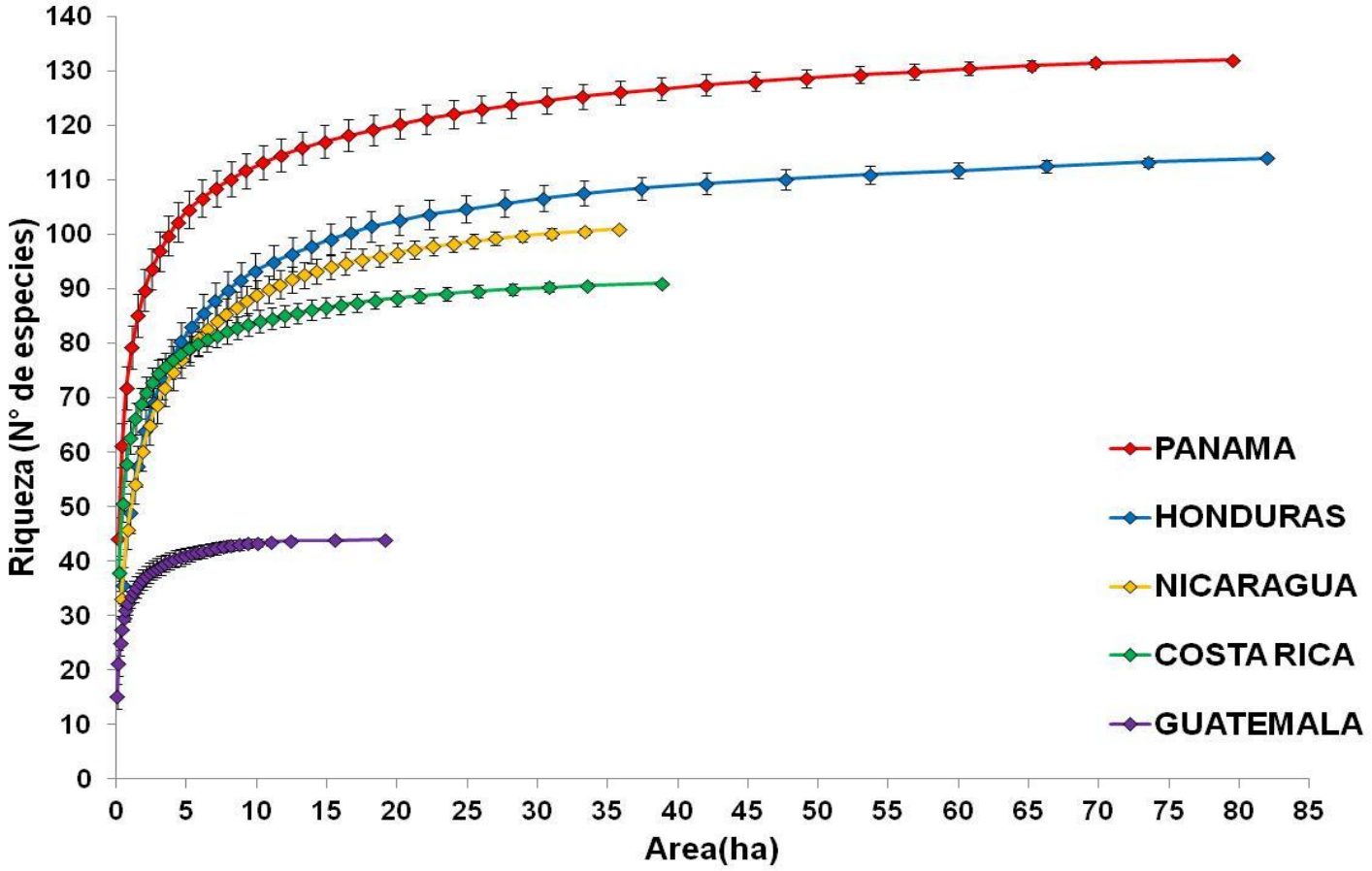
Food and nutritional security: nutrients from fruits in the shade canopy of cocoa



A new set of objectives to be met by cocoa farming

1. Provide ecosystem services
    1. Conservation of biodiversity (wild and agro-biodiversity
    2. Fix atmospheric carbon in woody biomass and mitigate climate change
    3. Regulate hydrological cycle
    4. Pollination, etc.

Rarefaction curves for shade canopy plant species in Central American cocoa plantations. However: 1) cocoa retain only 50% species in natural forests; 2) most species are generalists, secondary species of little conservation value. Climax species have limited regeneration under cocoa. NEED MORE RESEARCH.



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Species richness of various taxa in cocoa and other land uses

Variable	Forest	Cocoa	Banana	Plantain
	High	Intermediate	Intermediate	Low
 Oropéndula	High	High	High	Low
	Intermediate	High	High	Intermediate
 	High	Low	Intermediate	Low
	High	Intermediate	Intermediate	Low

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Cocoa plantations increase biological connectivity in the landscape, thus helping the conservation of wild biodiversity

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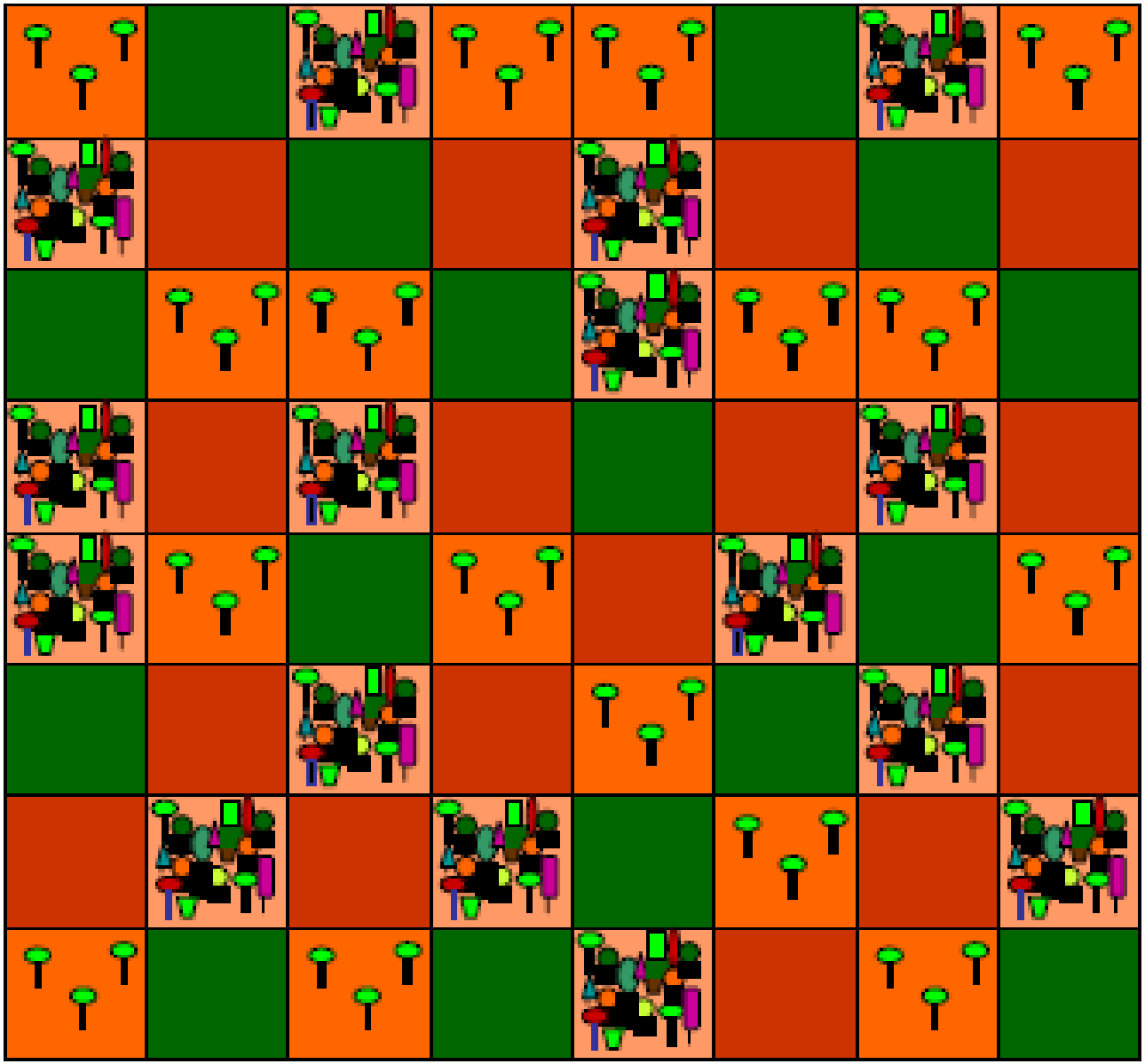
Cocoa landscapes for enhanced biological conservation

WE NEED MORE RESEARCH ON THIS ISSUE




Cocoa agroforestry systems in Central America store 50 Mg ha^{-1} of carbon in aboveground biomass

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Optimizing cocoa shade canopies for multiple objectives

Can we manage cocoa shade canopies to simultaneously conserve biodiversity, attain high cocoa yields and mitigate/adapt to climate change?

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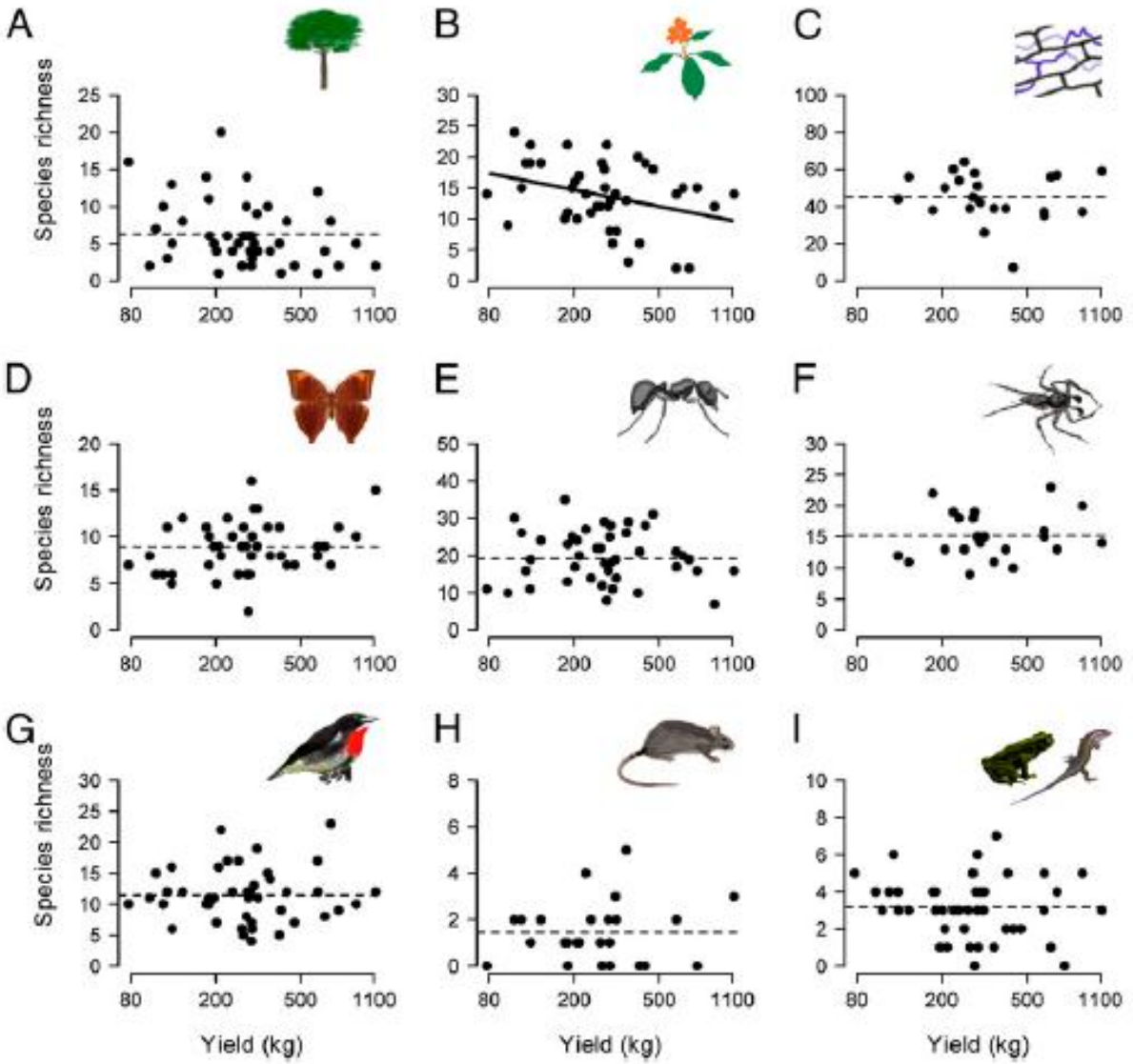
No relationship between biodiversity (various taxa) and cocoa yields. Clough et al. 2011. PNAS 108(20):8311-8316.



Forest carbon is lost when replacing natural forests with cocoa

- Climax forest vegetation in the ecological range where cocoa is cultivated, store an average 180 Mg C ha^{-1}, range 27 - 275 Mg C ha^{-1}
- Cocoa plantations store an average 50 Mg C ha^{-1} range 30 – 130 Mg C ha^{-1}
- Replacing natural forests with cocoa reduces C stored in the vegetation by 15 – 88%
- Cocoa production typologies determine amount of C retained


Open sun, clonal cocoa,
Ecuador


Specialized shade. *Gliricidia sepium*.


Productive shade. FHIA, Honduras


Cordia aliodora
Citrus aurantium
Bactris gasipaes
Theobroma cacao
Musa AAA
Mixed shade. Deheuvels, 2011

Rustic cocoa (Brazilian Cabruca). Sambuichi 2009


Amazonian
successional
cocoa agroforest

Key questions #1

1. Is it possible to minimice losses in forest C when converting forests into cocoa?
2. Are reductions in forest C similar over the entire ecological range where cocoa is cultivated?
3. WE NEED MORE RESEARCH ON THIS

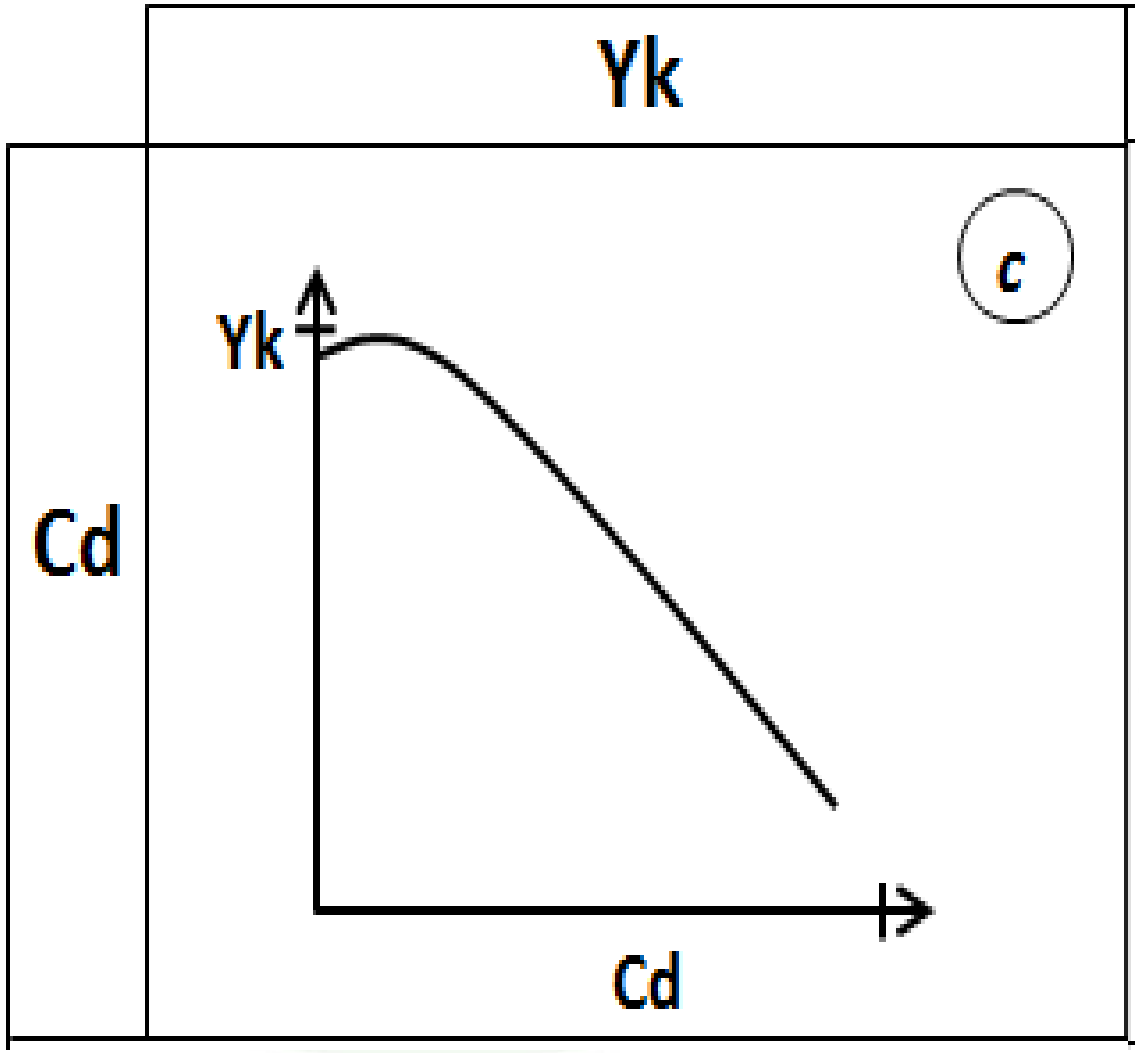
Key questions #2

- Can a high C cocoa plantation produce high cocoa yields?
- To answer this question we need to:
  1. Determine how C is distributed between cocoa and shade canopy in every cocoa typology. WE NEED MORE RESEARCH ON THIS TOPIC
  2. Evaluate 4 key interactions between carbon levels and yields for every cocoa typology

Cocoa yield (Yc) decreases (but not linearly) as carbon in canopy (Cd) increases

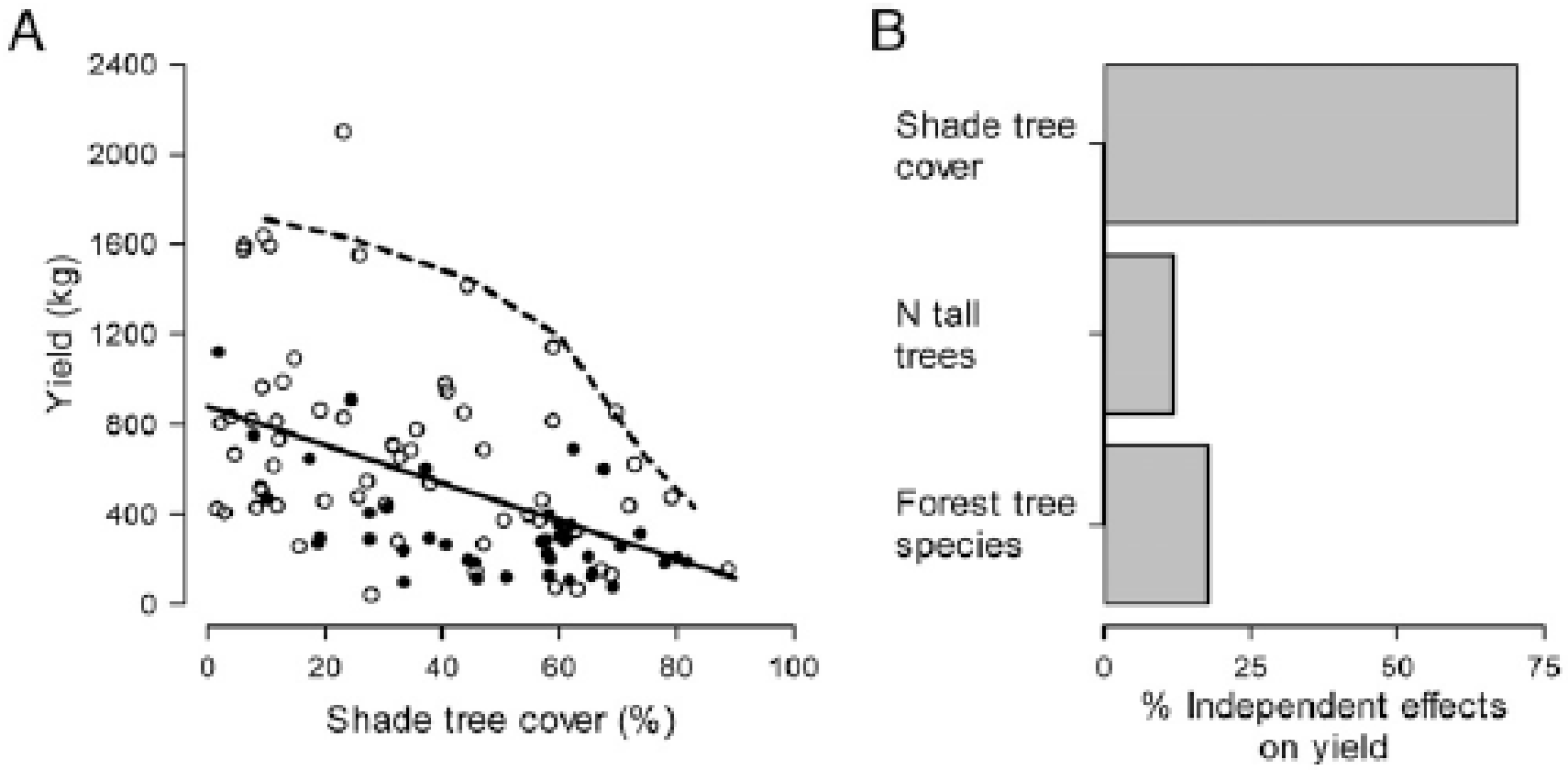
Various physiological models for cocoa support this proposition

…also field work

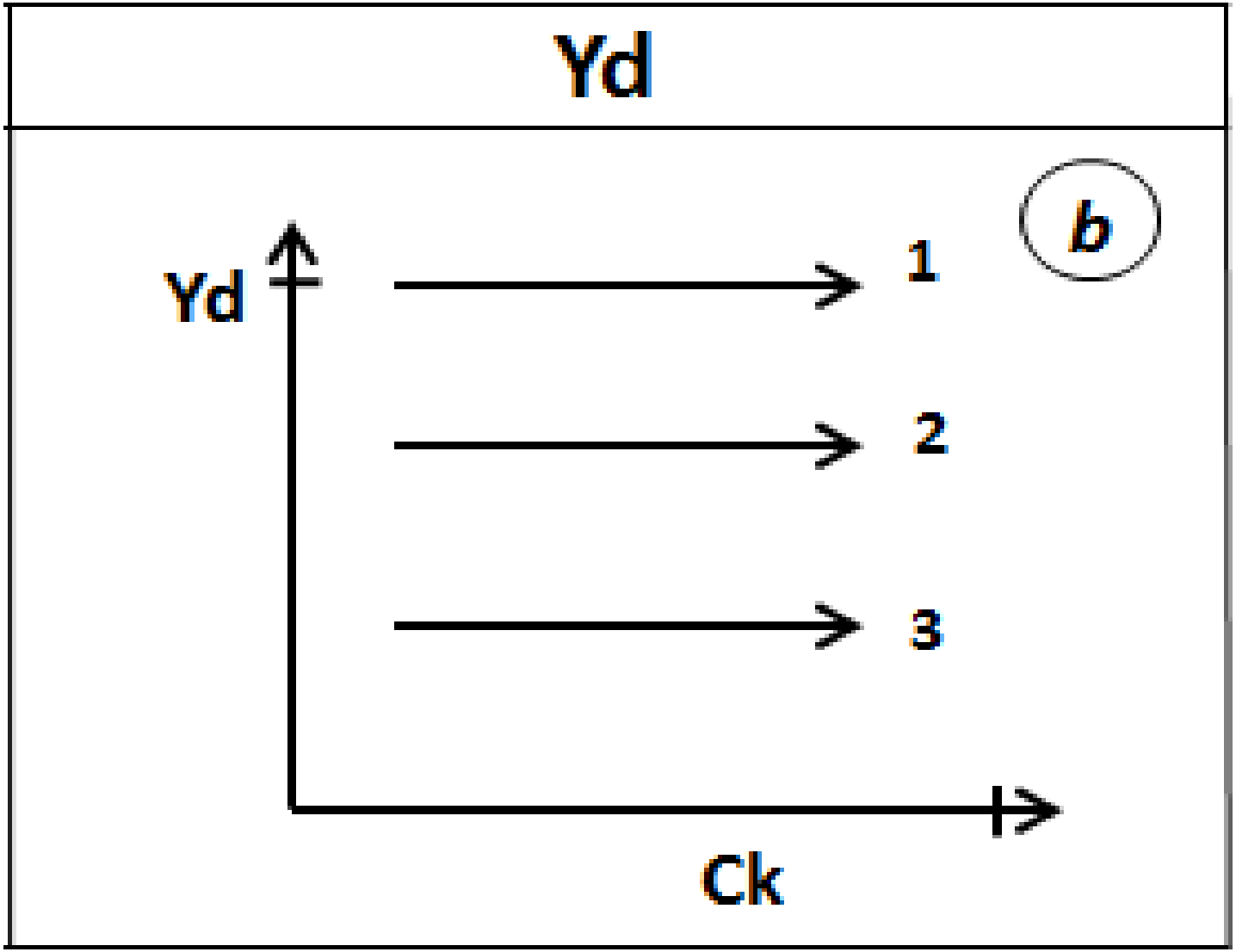


Tree cover affects cocoa yields negatively.

Clough et al. 2011. PNAS 108(20):8311-8316.

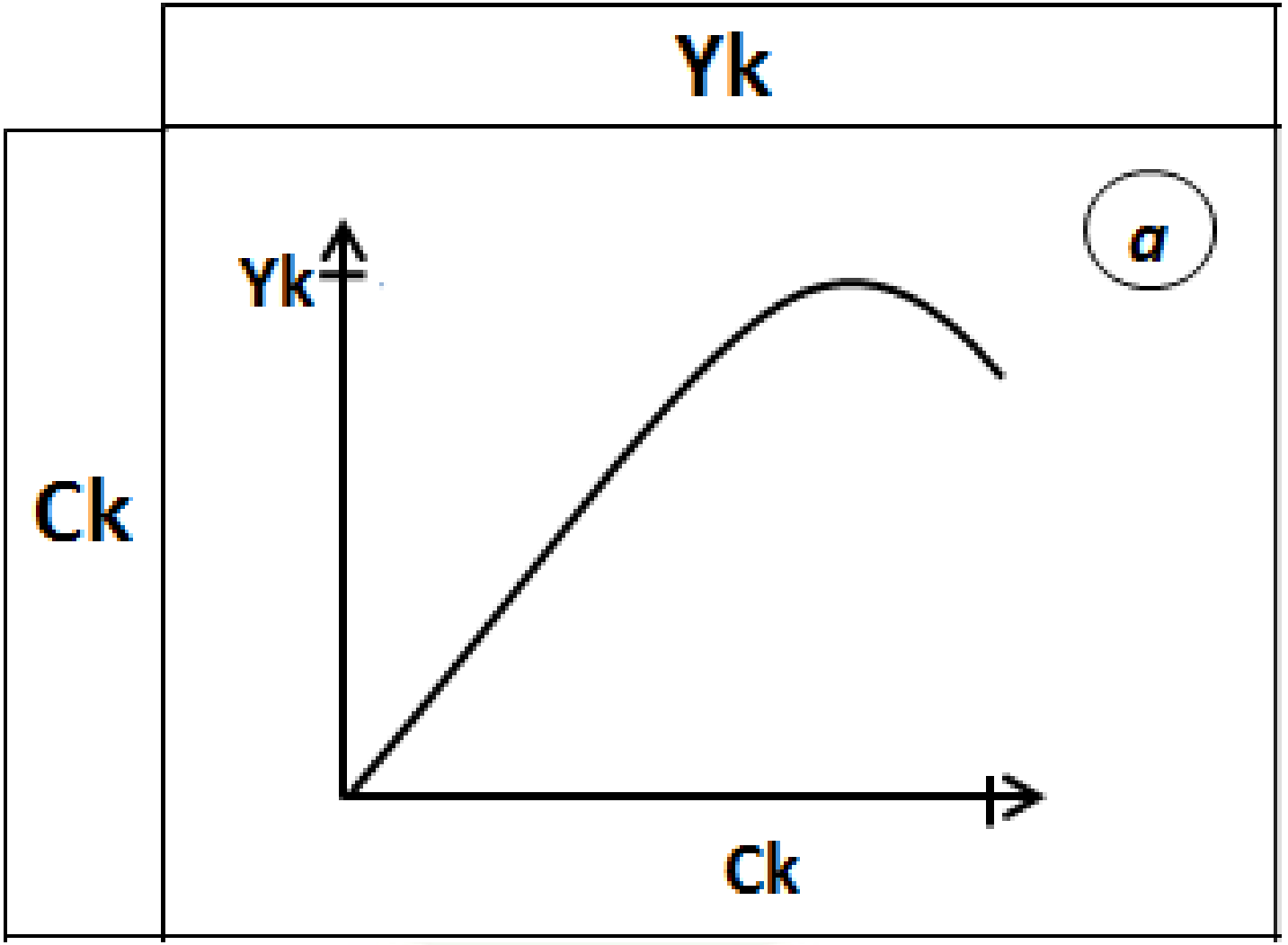


Canopy yield (Yd) is not affected by amount of carbon in cocoa trees (Ck)

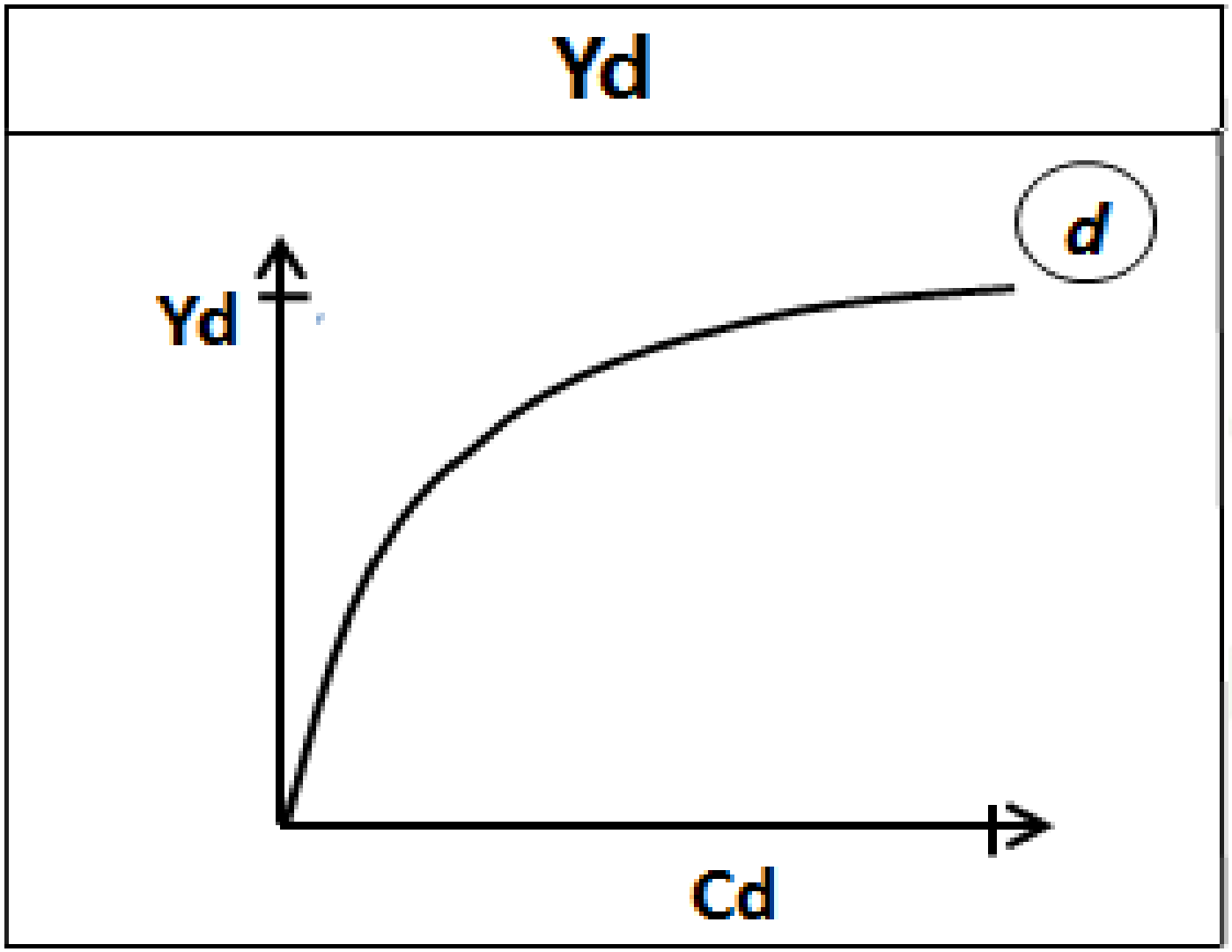


Cocoa yield (Yk) increases to a maximum with increases in cocoa carbon (Ck)…then Yk declines with increasing Ck

Agronomic research to determine optimal planting density for cocoa support this proposition



Canopy yield (Yd) increases as canopy carbon (Cd) increases



Designing high C, species-rich cocoa shade canopies

- C can be increased by using tall trees ("sequoia type")
  - Small crowned, sequoia type trees can allow for higher species richness
  - Tall trees cast "light shade" over cocoa
- Morphological and functional traits of tree species could be used to increase tree population without increasing shade levels
  - Small foliage (e.g. Mimosoideae) transmit more solar radiation on cocoa
  - Species with reversed phenology (e.g. shade leaves in rainy, cloudy months) may allow for better transmission of solar radiation
- MORE RESEARCH NEEDED ON THIS

It can be safely concluded that….

- There is plenty of room for designing improved shade canopies that simultaneously:
  1. Retain high biodiversity
  2. Produce acceptable yields (both from cocoa and canopy trees)
  3. Store significant amounts of carbon (in both cocoa and shade trees)

how to analyze and design improved shade canopies for cocoa?

- Optimal shade? There are no recipes. Each cocoa plantation is unique
- We need a methodology to guide shade canopy design at each location
- Methodology evaluates some 20 variables related to:
  - Plantation status
  - Site conditions
  - Functional and morphological traits of shade species

Methodology

1. Determine **farmers' objectives**
2. Evaluate **plantation status**
    1. Self-shading: age, spacing, variety, pruning
    2. Crop phenology
    3. Canopy cover spatial homogeneity
3. Evaluate **site conditions**
    1. Soil fertility and water availability
    2. Latitude, exposure, slopes
    3. Nearby vegetation – lateral shade
    4. Wind, clouds
4. Evaluate **tree species**
    1. Use
    2. Crown characteristics: diameter, density, phenology
    3. Tree height

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Self-shading reduce the need for (valuable) shade trees

Self-shading directly related to form and size of cocoa trees

- **Plantation age**…more self-shading in adult than in young cocoa trees
- **Planting density**…more shade in densely planted cocoa…planting arrangements also important
- **Cocoa variety**…hibrids >> grafted clones
- **Pruning** frequency…more pruning = less self-shading

Status of cocoa plantation

- **Crop phenology**
  - more light needed at cocoa flowering and fruit setting…monthly shade patterns
- **Spatial homogeneity of canopy cover**
  - avoid heavily shaded patches or patches with no shade in same plantation

More shade in sites with poor soils; less shade in fertile soils

Cocoa yield = shade x soil fertility interactions
1 = minimum; 4 = maximum yield

Shade	Soil fertility	
	High	Low
High	?	1
Low	4	?

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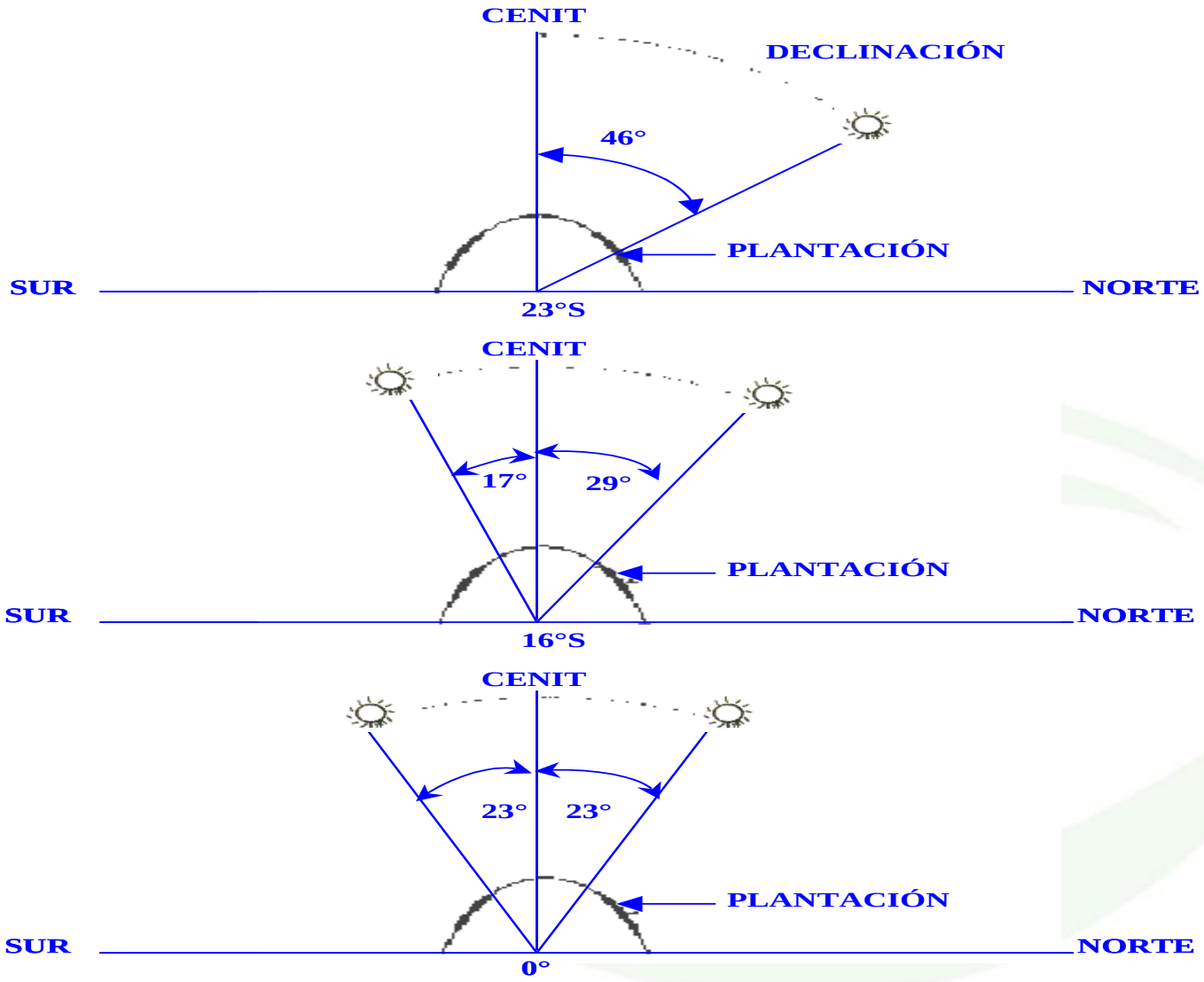
Topography and lateral shade

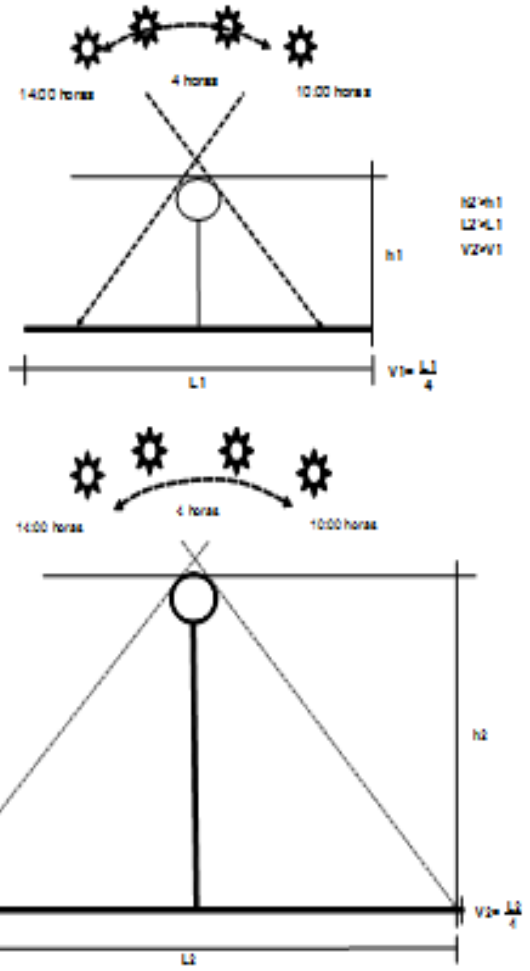
Latitude and exposure



Morphological and functional traits of shade species influence shade levels

Tall trees produce “light shade”…short trees produce “dense shade”

…use short trees with light crowns…and tall trees with dense crowns



One crucial task: educate farmers

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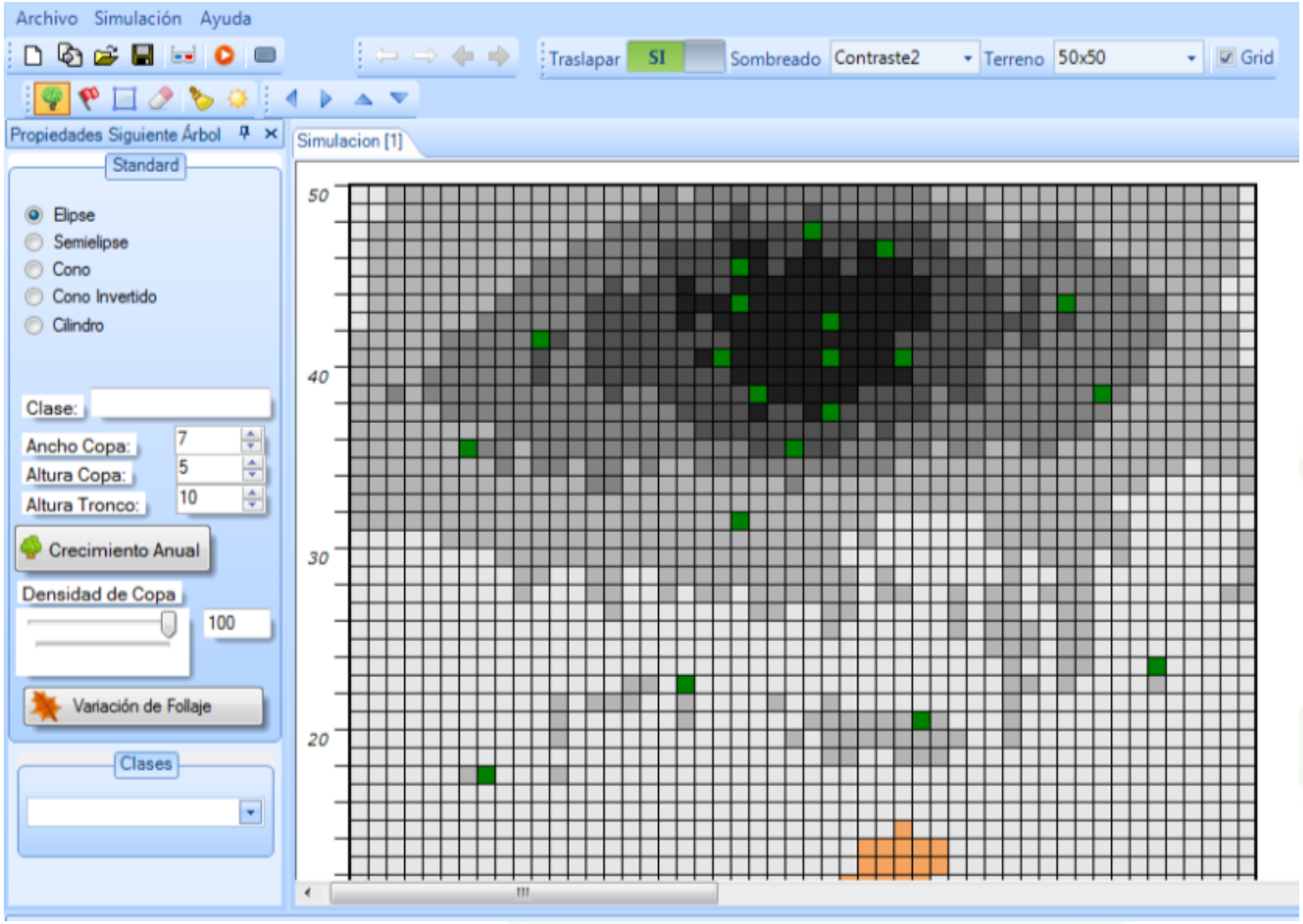
Research tools available for modelling shade patterns www.shademotion.com



http://biblioteca.catie.ac.cr/inaforesta information on cocoa agroforestry


Thank you