Detecting desertification in savanna systems

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What is desertification?

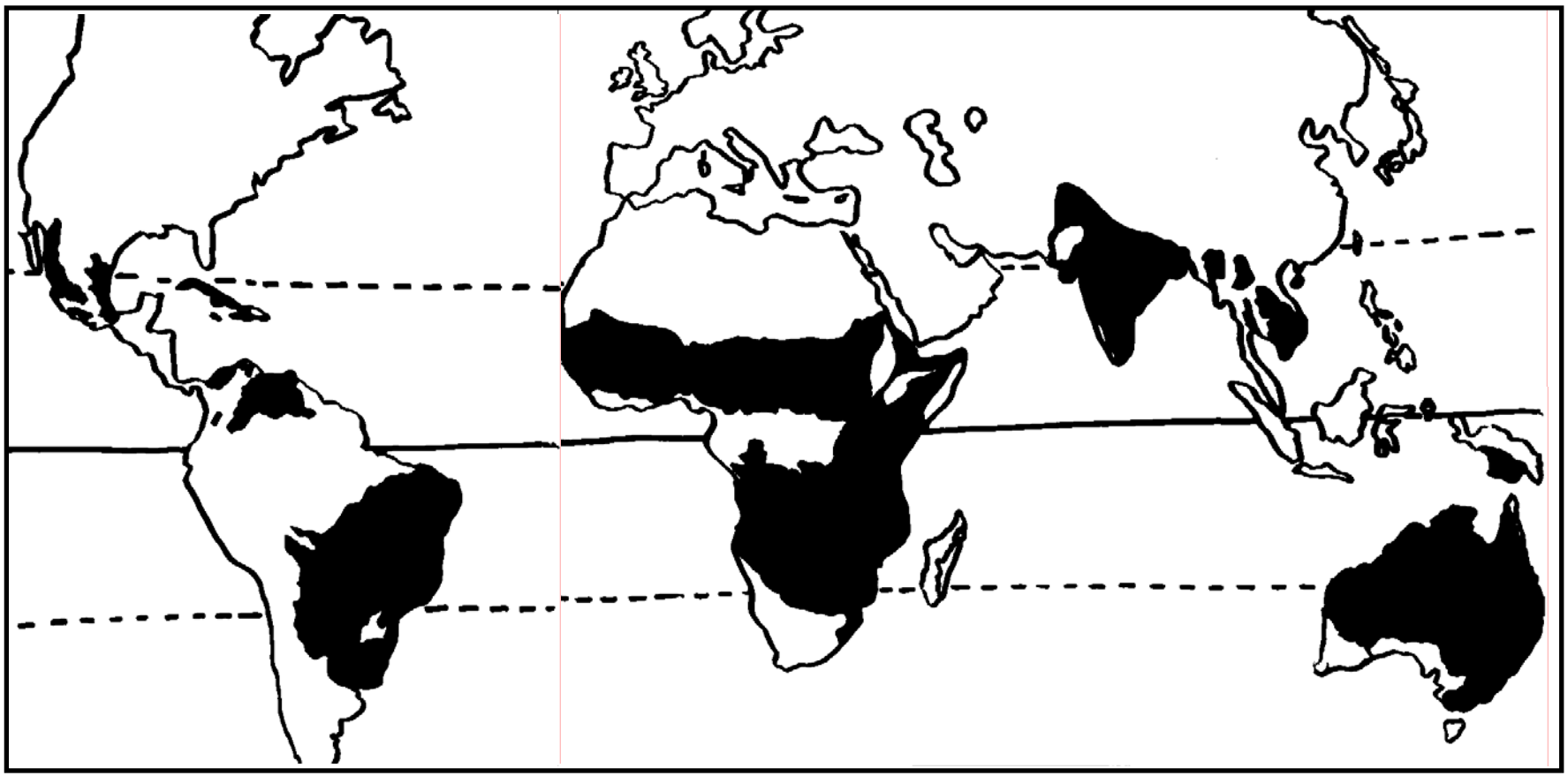
[Hyperarid]
Arid
Semiarid
Subhumid

Desertification is degradation in dry lands

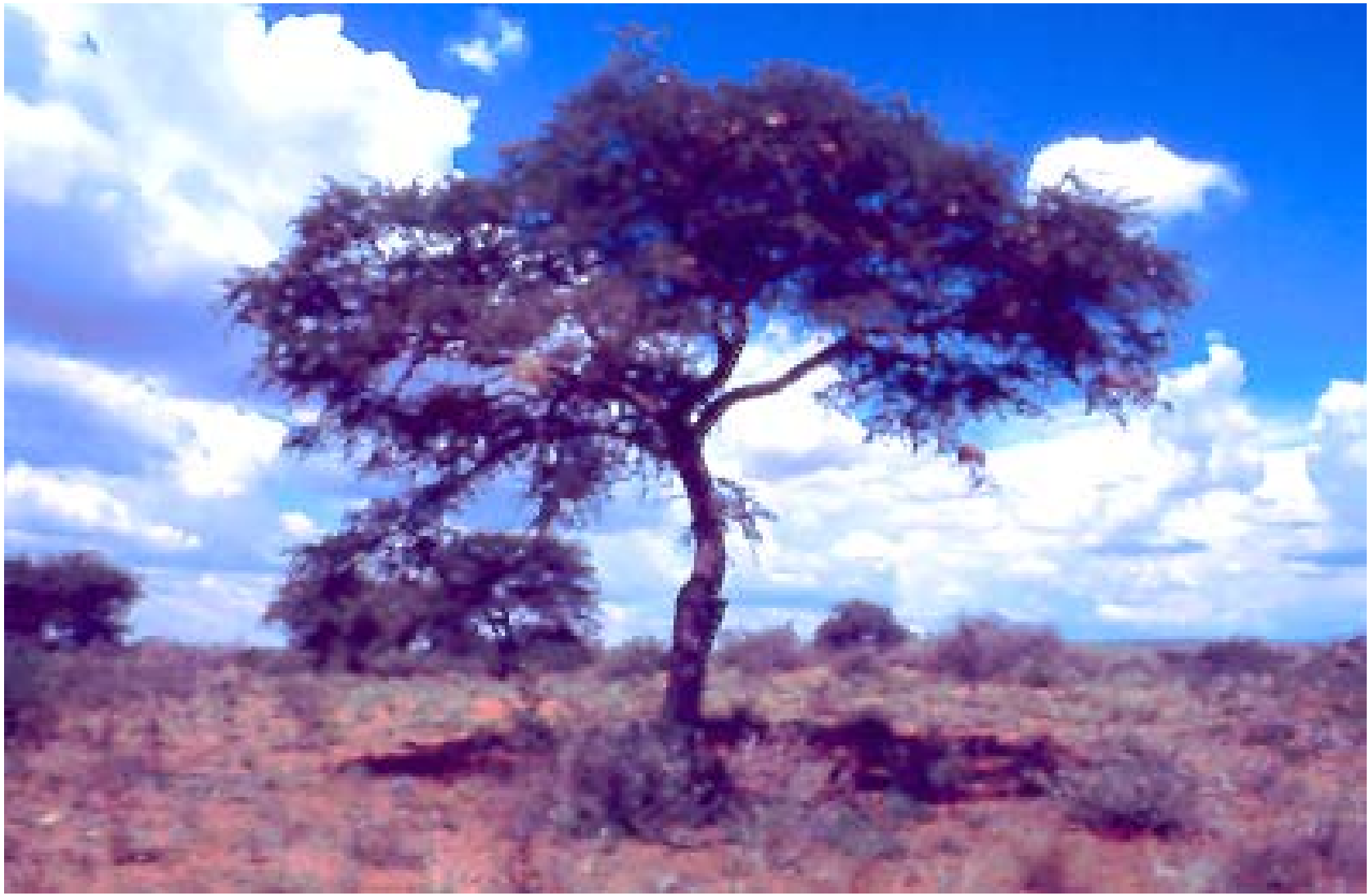
United Nations Convention on Combatting Desertification

Global distribution of savannas

(basically the same as the summer-rainfall drylands)



Savannas are mixed tree-grass systems



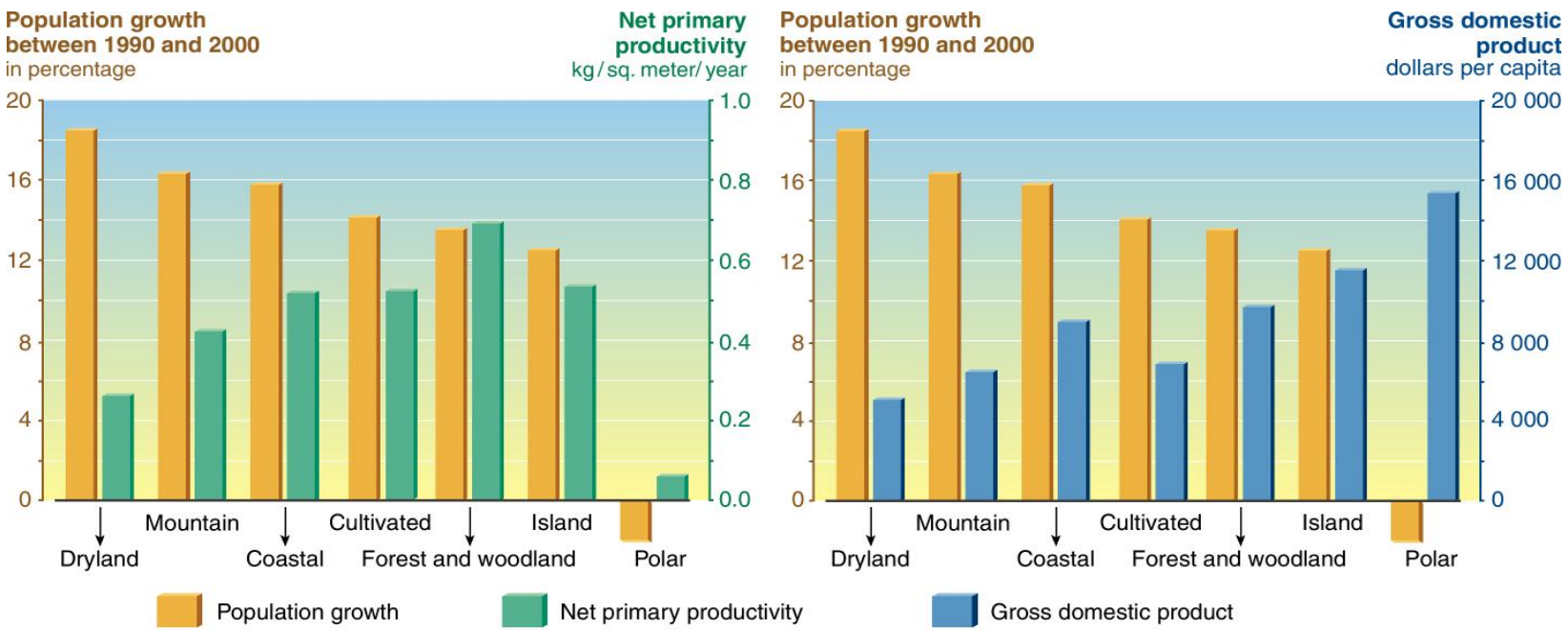
Some facts about savannas

- World's largest land biome (~12%)
- Second largest Net Primary Productivity and carbon store (16.8 x 10^{15} gC/y)
- Large 'natural' impact on atmosphere through fire, carbon cycle and dust
- Home to ~1 billion people; source of food and energy to most of them
- Centre of biodiversity (7000 species in Africa alone)

Desertification sucks!

The single environmental issue affecting the livelihoods of the largest number of people worldwide

41% of Earth's land surface
2 billion inhabitants
90% in developing countries



Sources: Millennium Ecosystem Assessment

What is degradation?

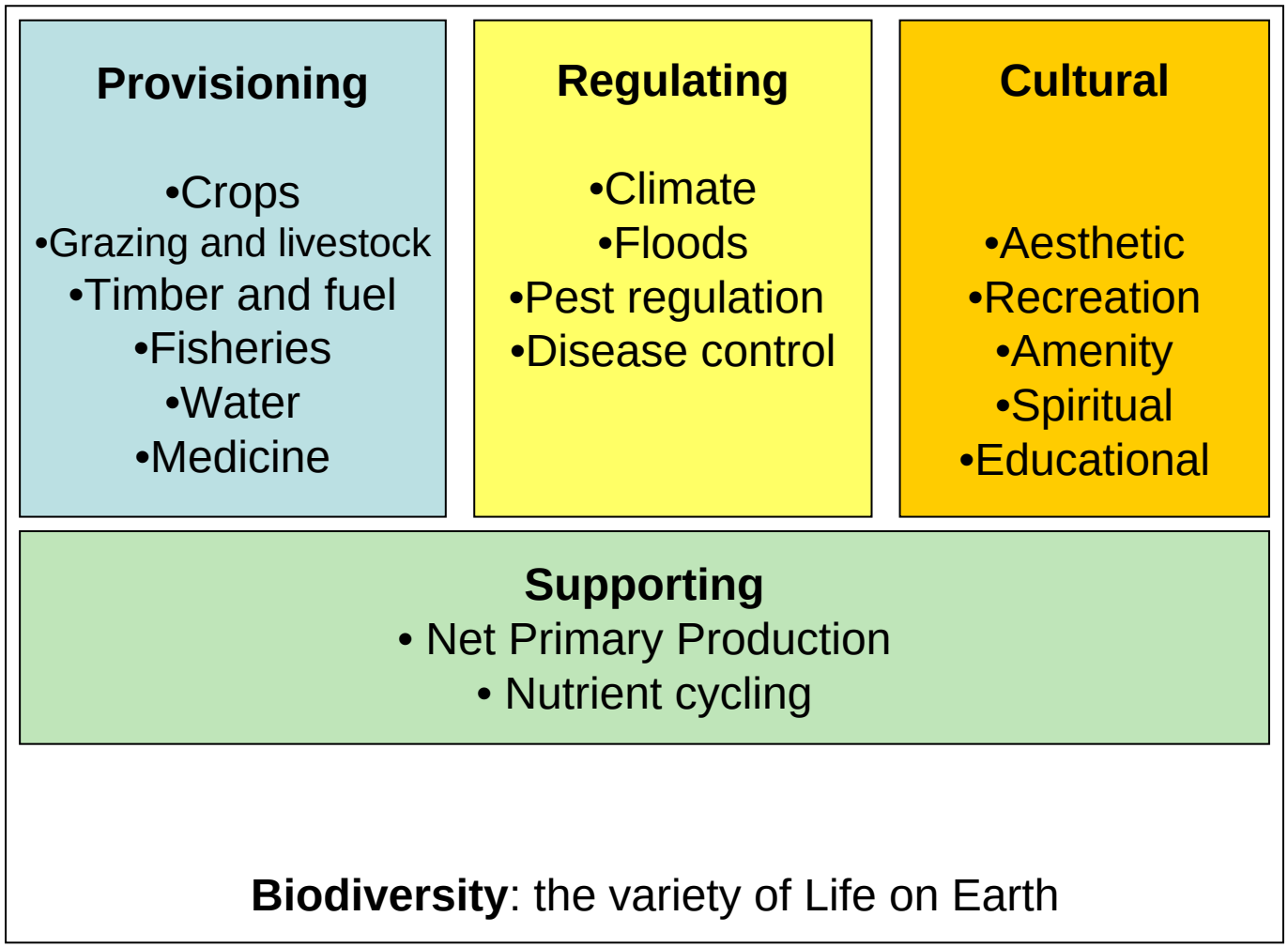
Does not spontaneously return to historical average within a *reasonable time* when you reduce the cause of change

Degradation is a *persistent decrease* in the capacity of an ecosystem to deliver *ecosystem services*

The benefits that people get from ecosystems
-Millennium Ecosystem Assessment

Ecosystem Services

Millennium Ecosystem Assessment Classification

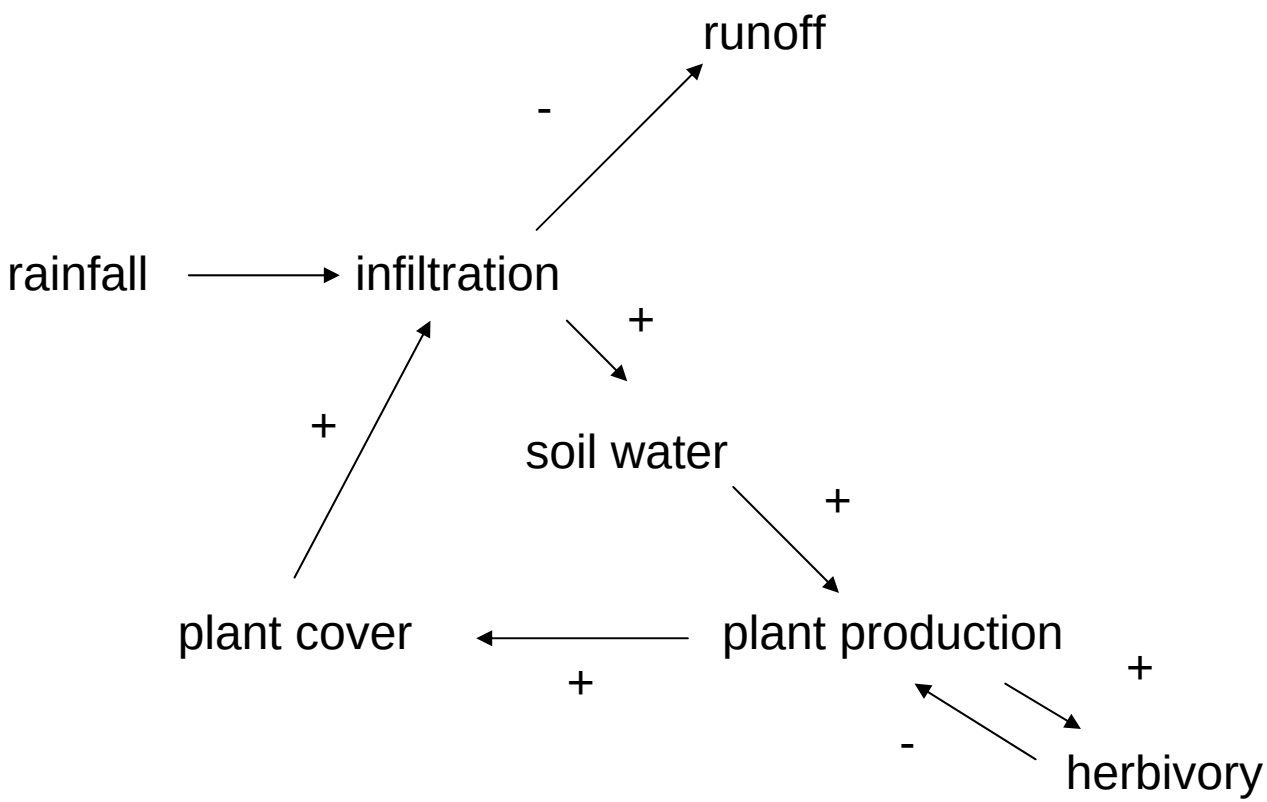


Summary so far…

To detect desertification, we are looking for a *change in state* in savanna ecosystems

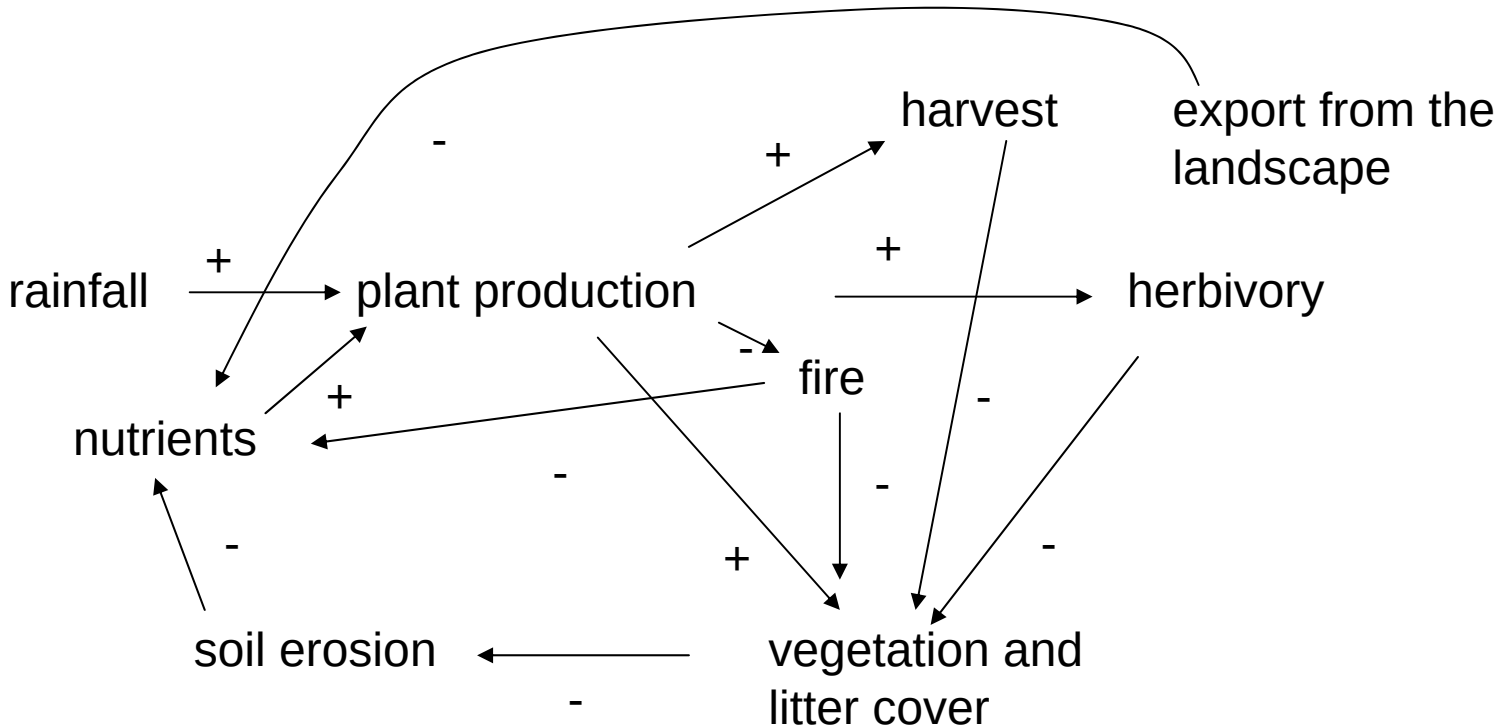
Ecohydrological state change

(typically on silty soils)

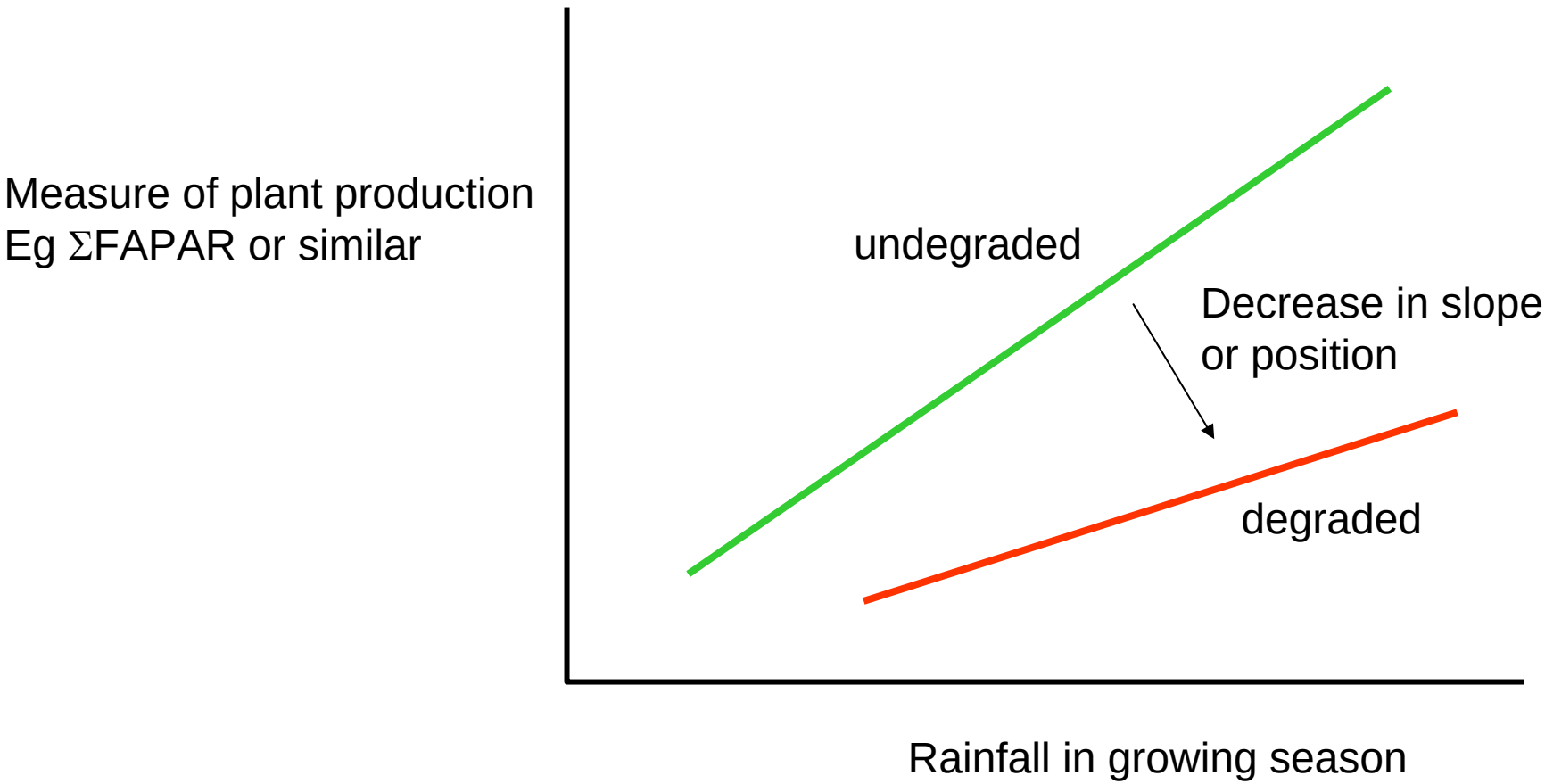


Nutrient state change

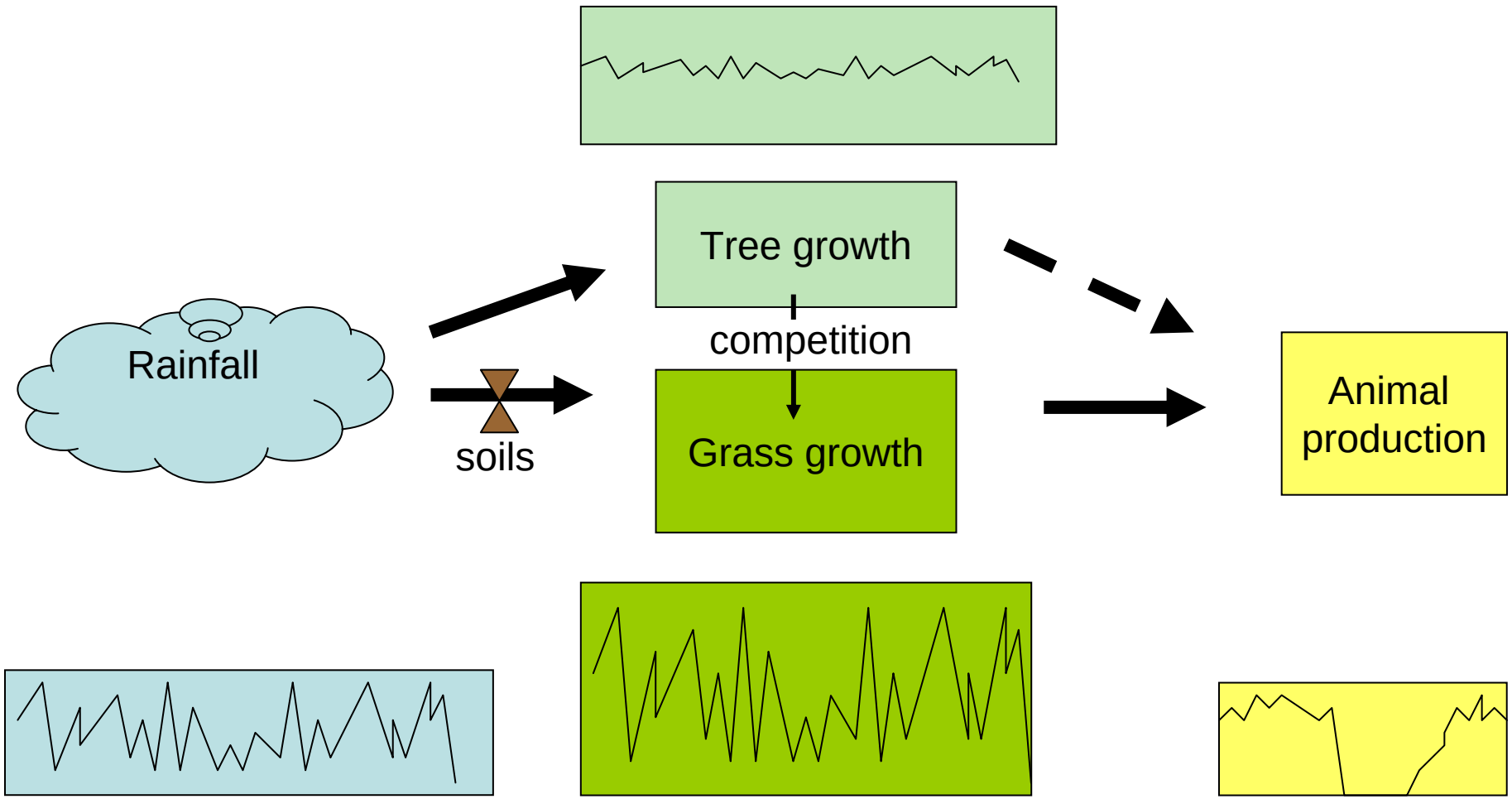
(typically on less-fertile, erodible soils eg sandy loams or loess)



Change in the rain use efficiency

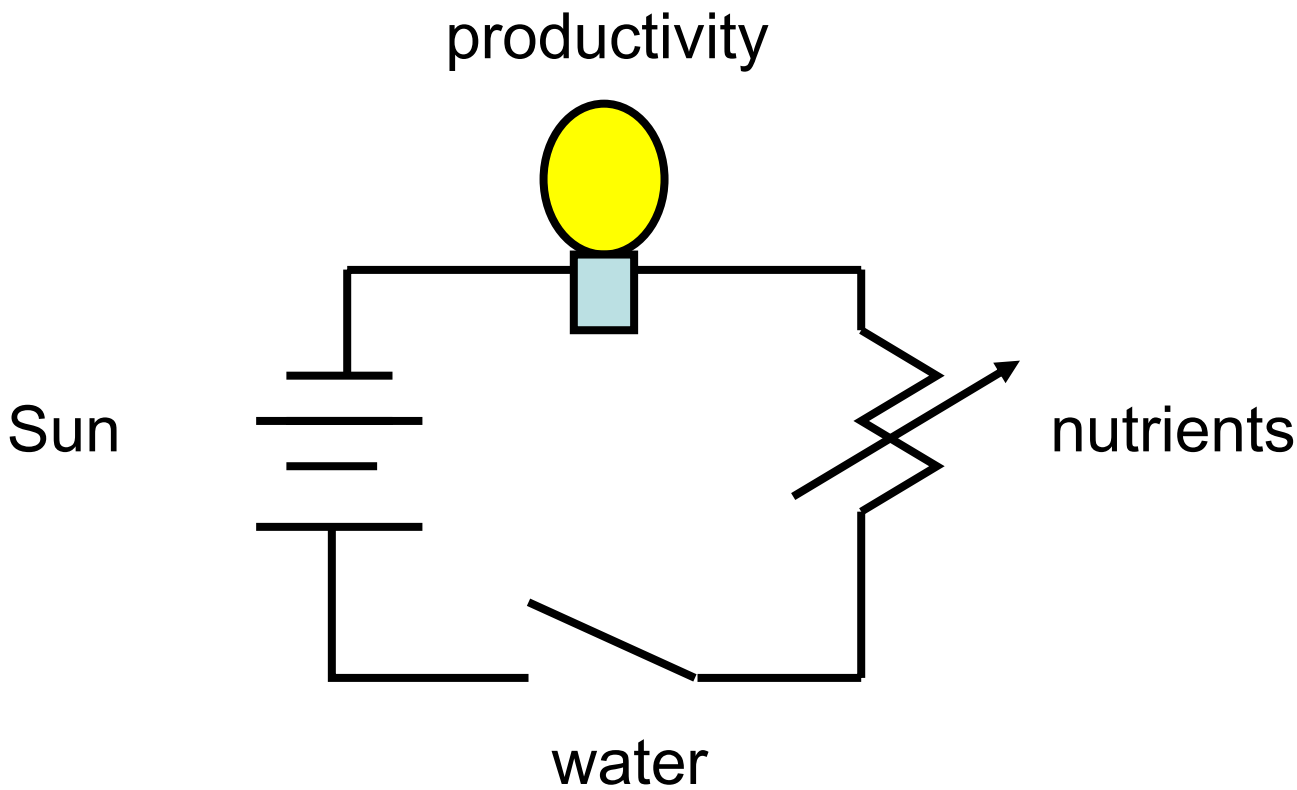


Production in water-limited pastoral systems

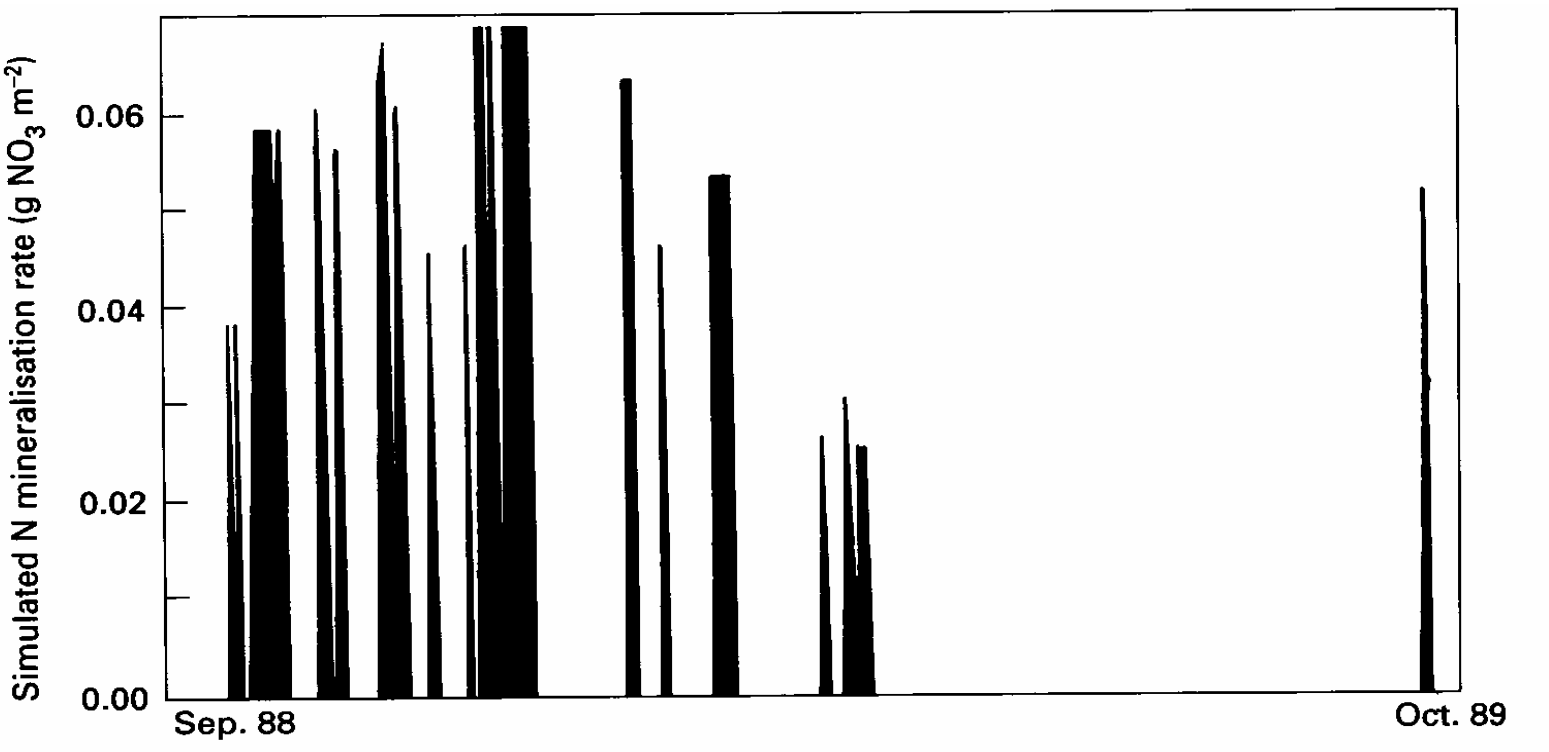


An electrical analog

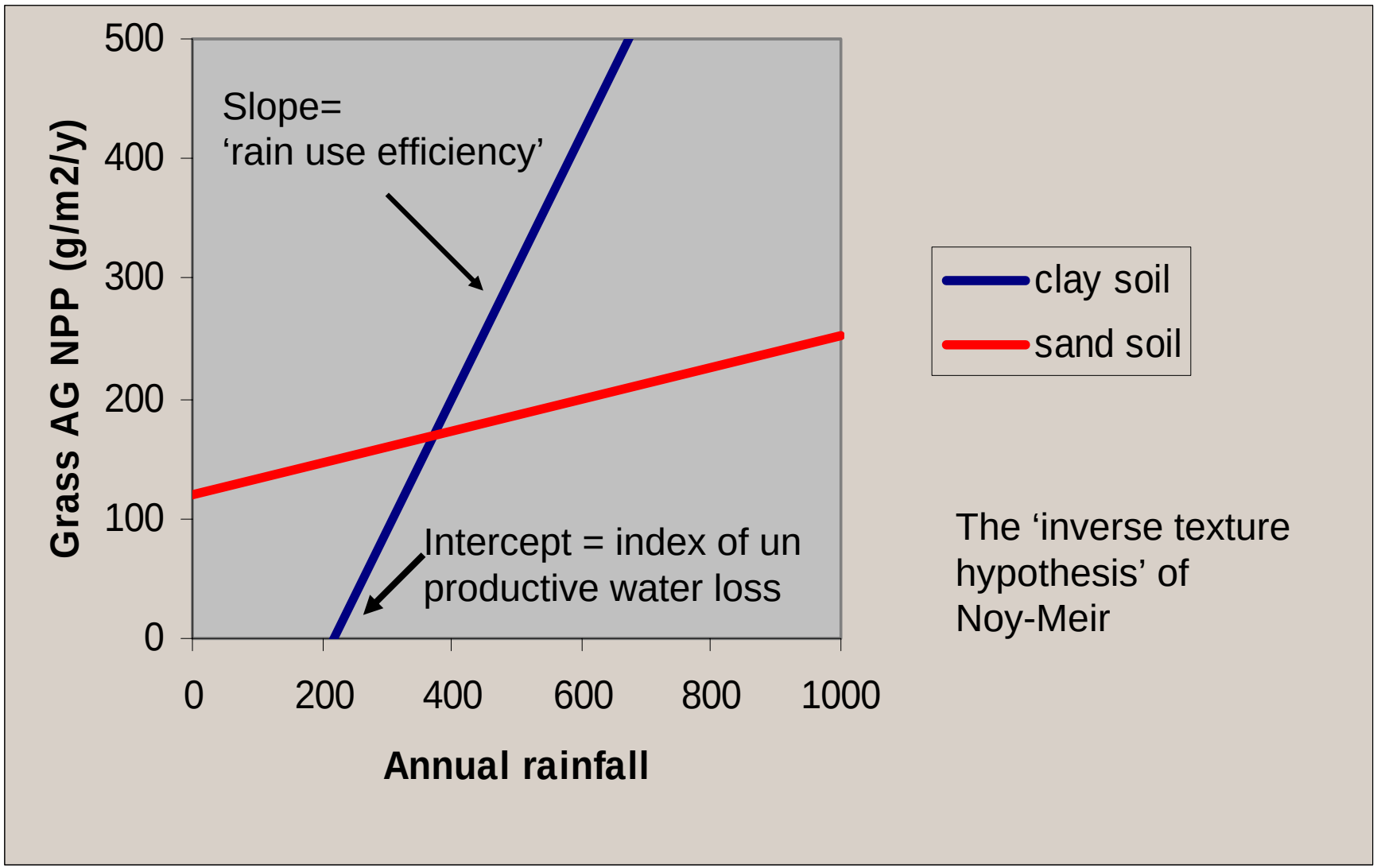
What controls the brightness of the lamp?



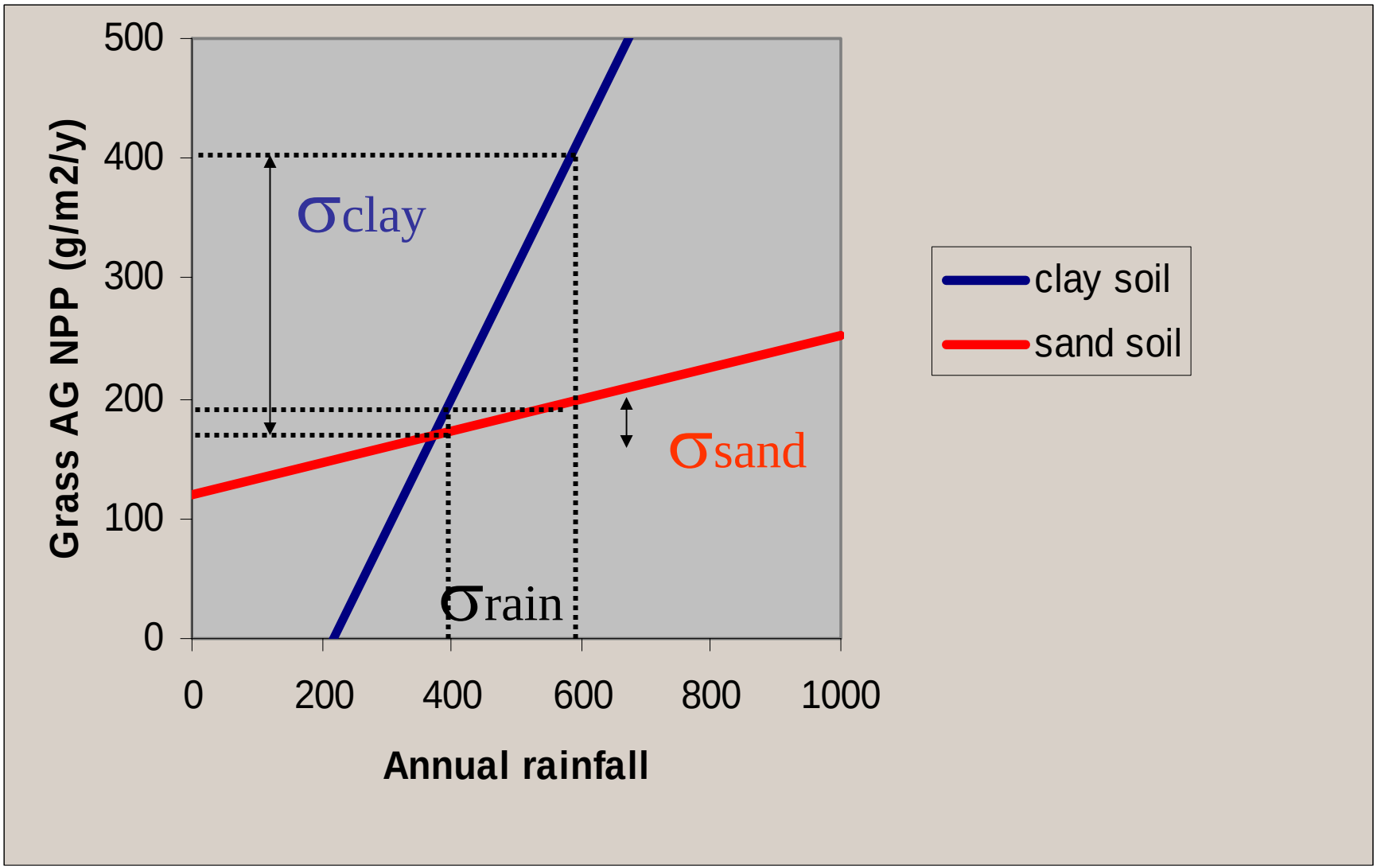
In pulsed systems, water availability controls the duration of growth opportunity



Linear relation between grass production and rainfall

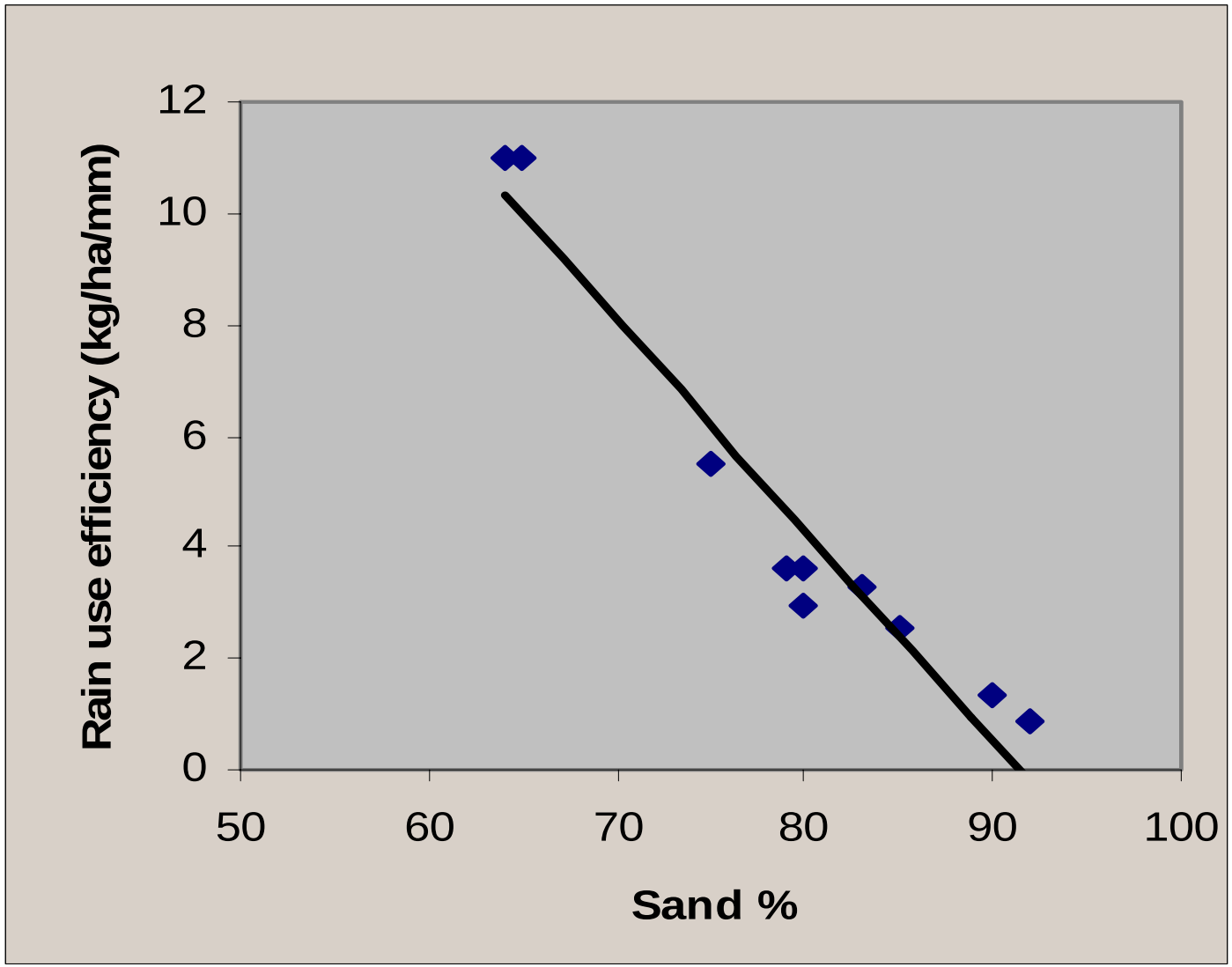


Interannual variability of grass production is higher on clays than sandy soils



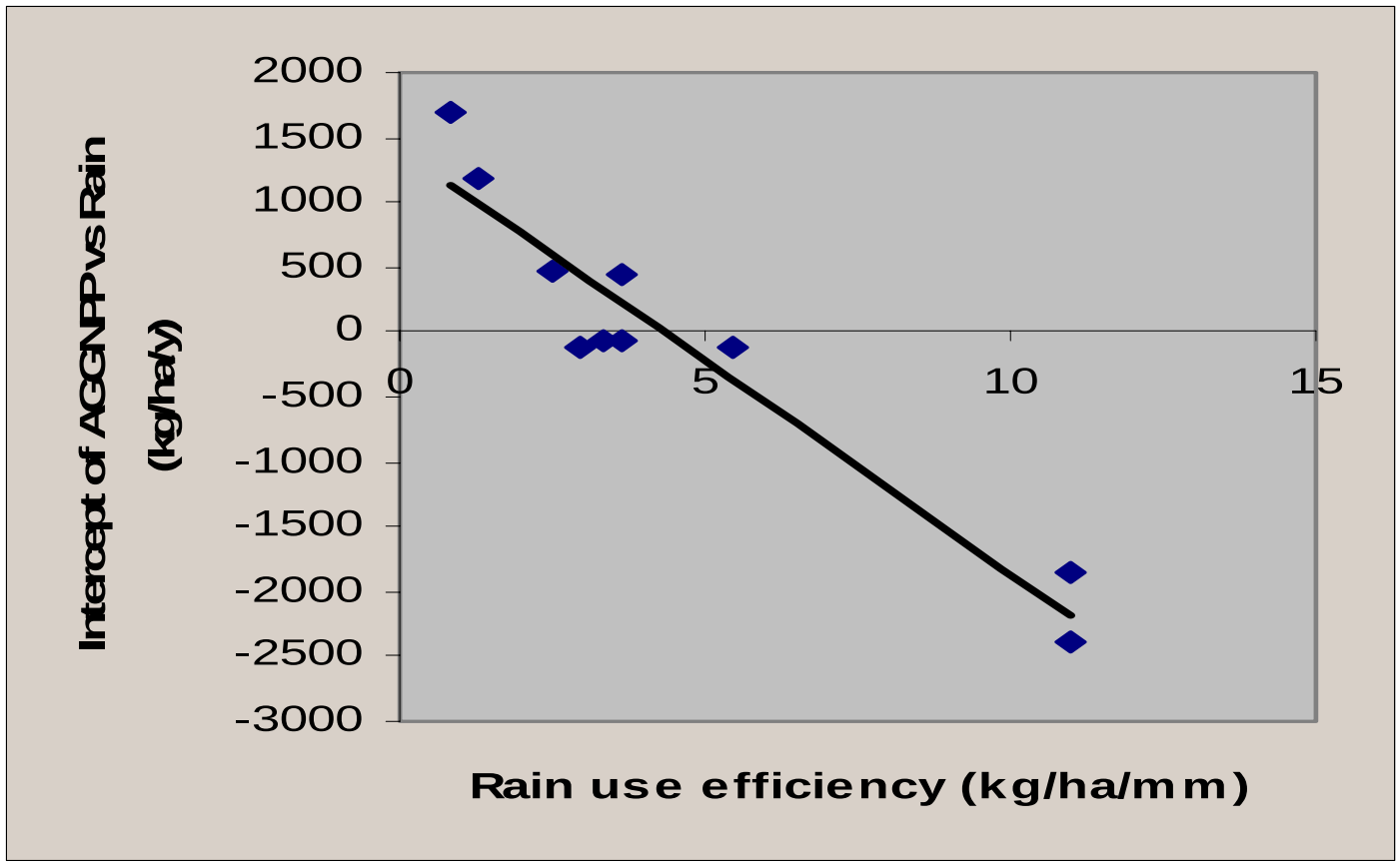
Rain Use Efficiency

(g/m^2/mm)



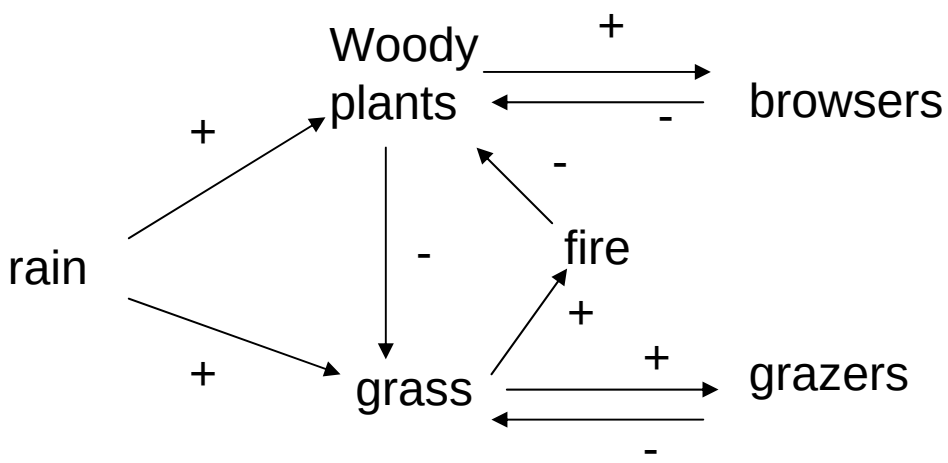
Intercept

dependent on soil water holding capacity

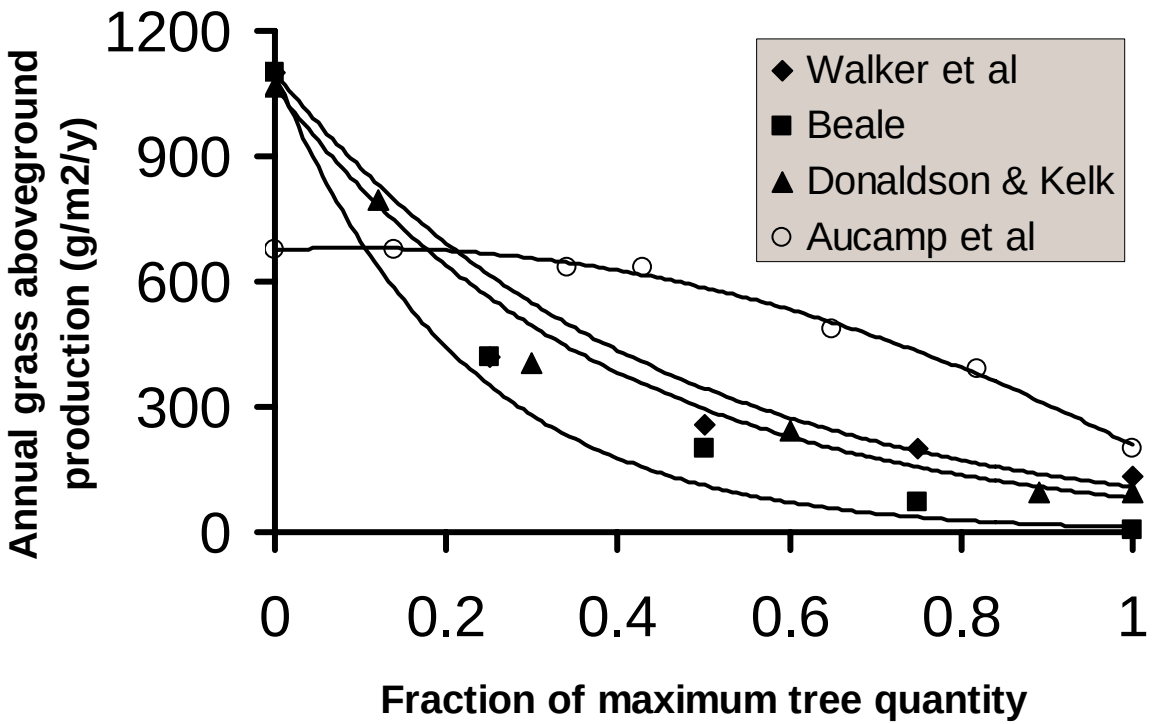


Changes in vegetation composition

(to species less productive or less useful)

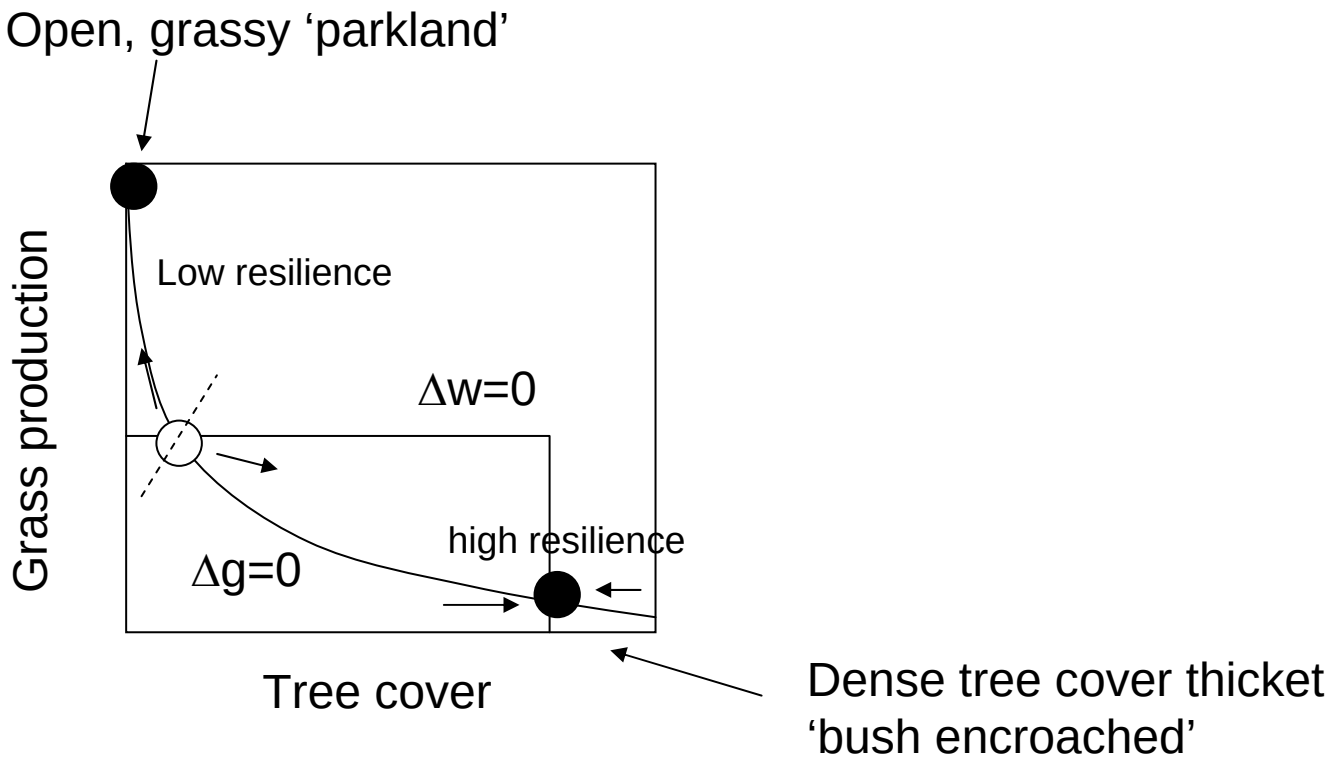


Tree mass has a non-linear inverse effect on grass production



Scholes RJ 2003 Convex relationships in ecosystems containing trees and grass. *Environment and Resource Economics* 26, 559-574

Graphical stability analysis



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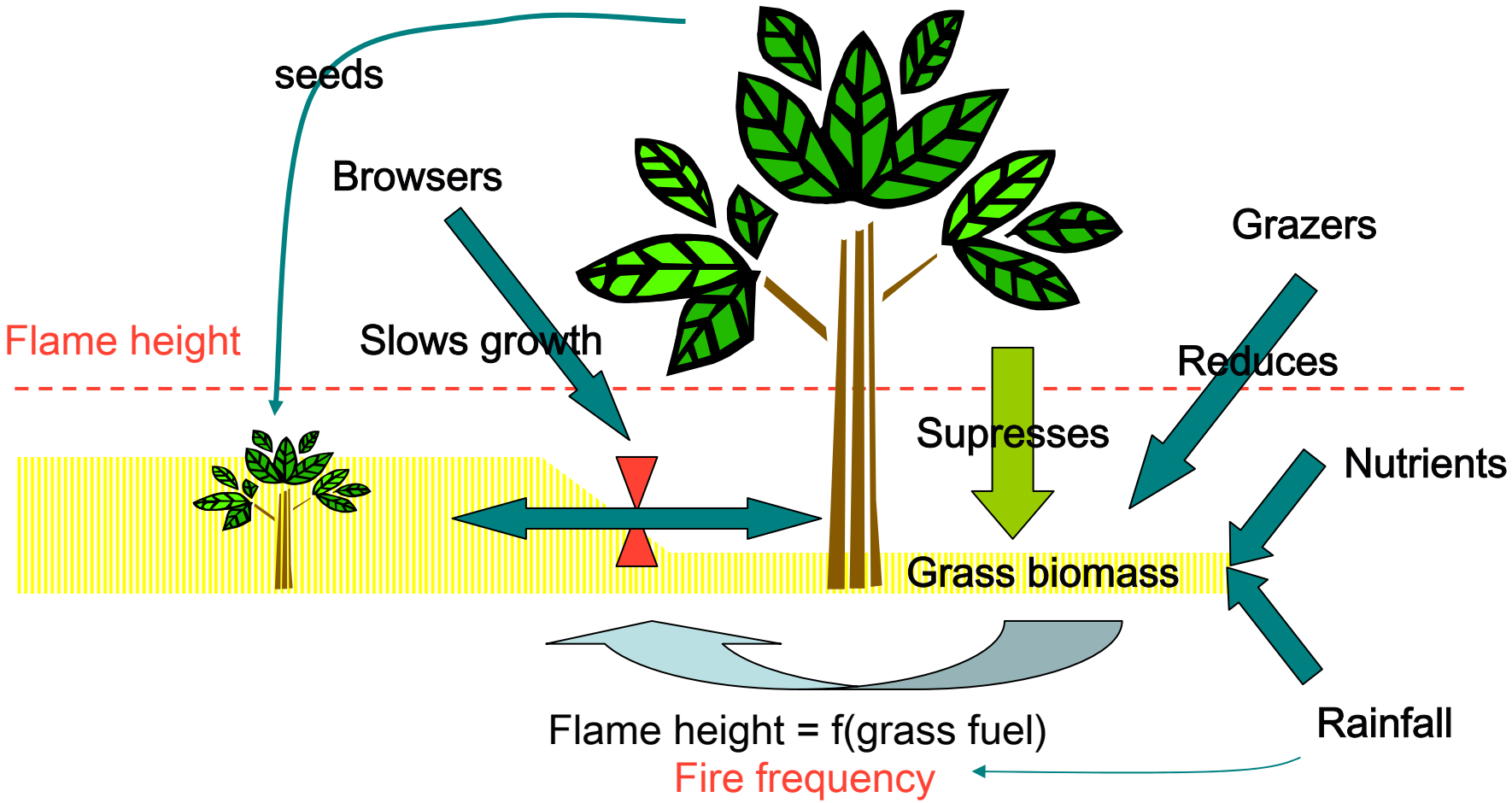
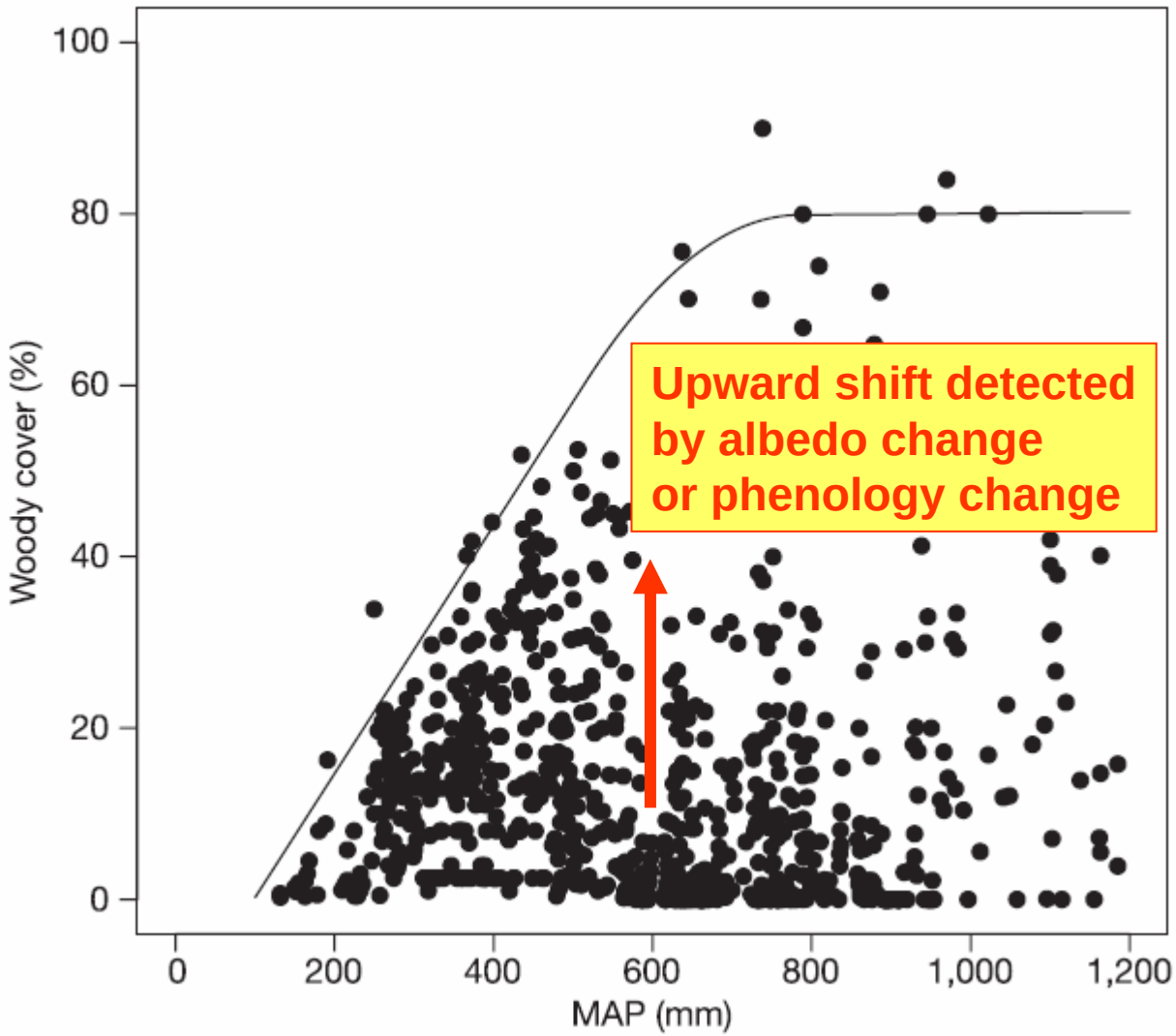
The actual tree-grass interaction is much more complex

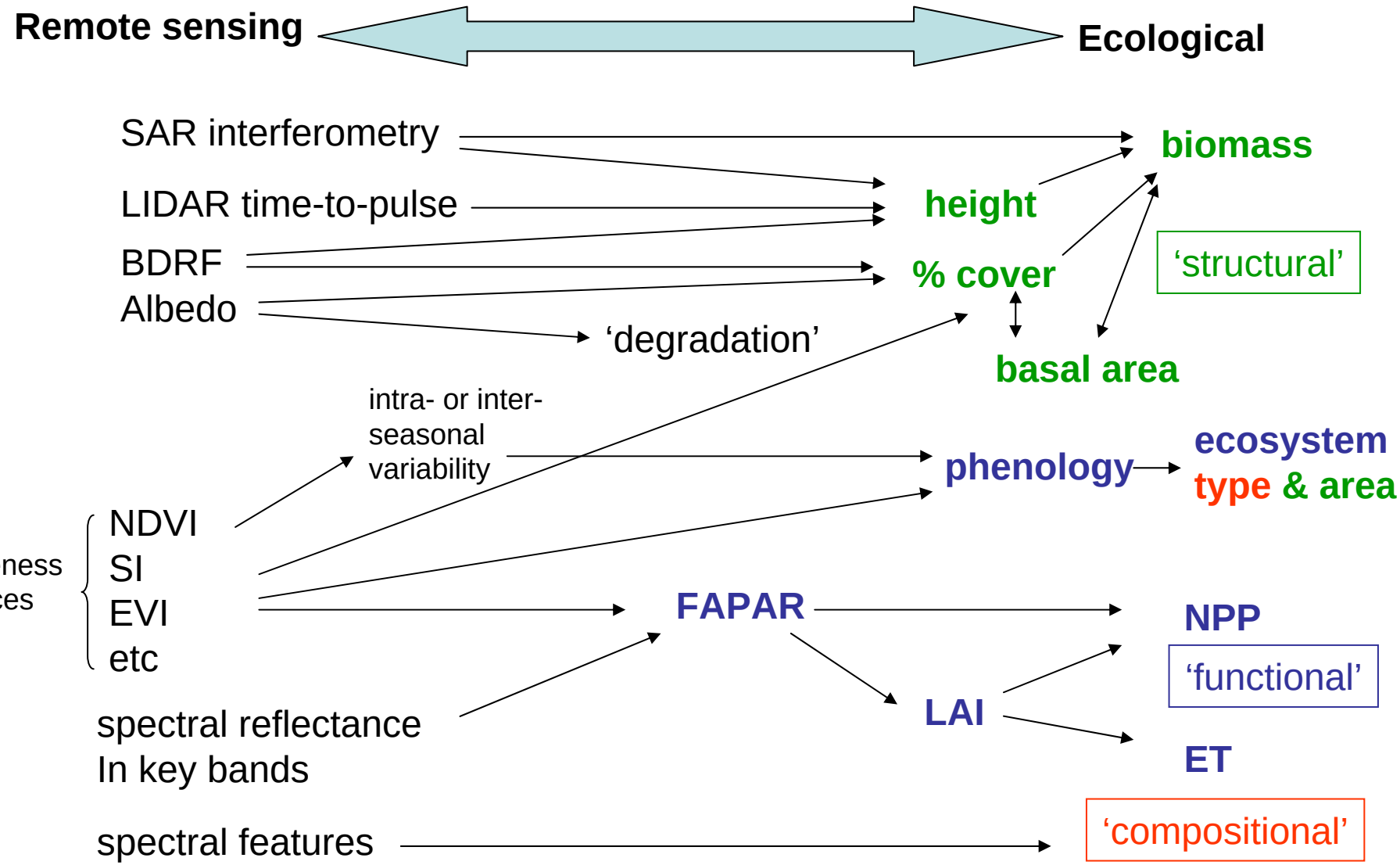


Relation between rainfall and quantity of trees in savannas

Sankaran et al 2005 Determinants of woody cover in African savannas *Nature* 438, 846-9



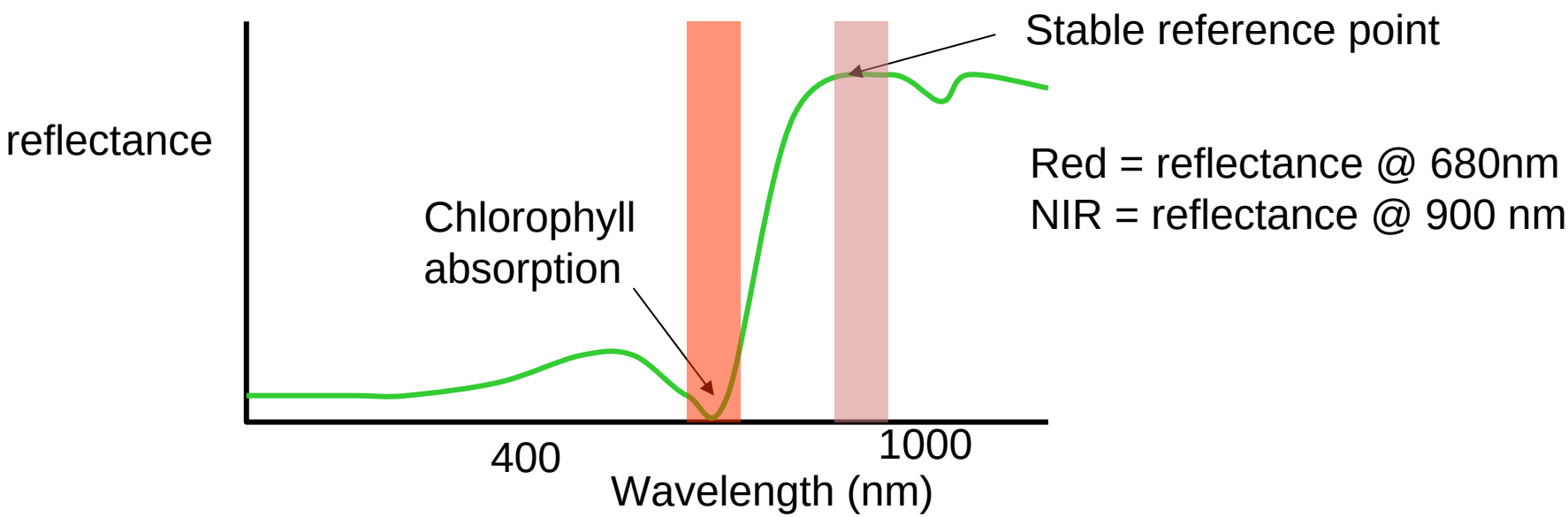
Vegetation metrics



‘Greeness’ Vegetation Indices

eg NDVI= (Red-NIR)/(Red+NIR)

and many others (SI,SAVI,EVI etc)



Leaf Area Index

- The one-sided leaf area per unit of ground area
- Can go down to near 0 in the dry season
- Theoretical limit about 6

$$I = I_0 e^{-K*LAI}$$ (Beer's Law)

therefore for LAI=6, k=0.5: I=5% of Io

- Hard to measure in forests due to saturation above ~ 3
- Seldom above 3 in drylands
  - Typically ~1 in savannas
- Useful for estimating evaporation and interception, but FPAR has fewer assumptions for modelling productivity

FAPAR

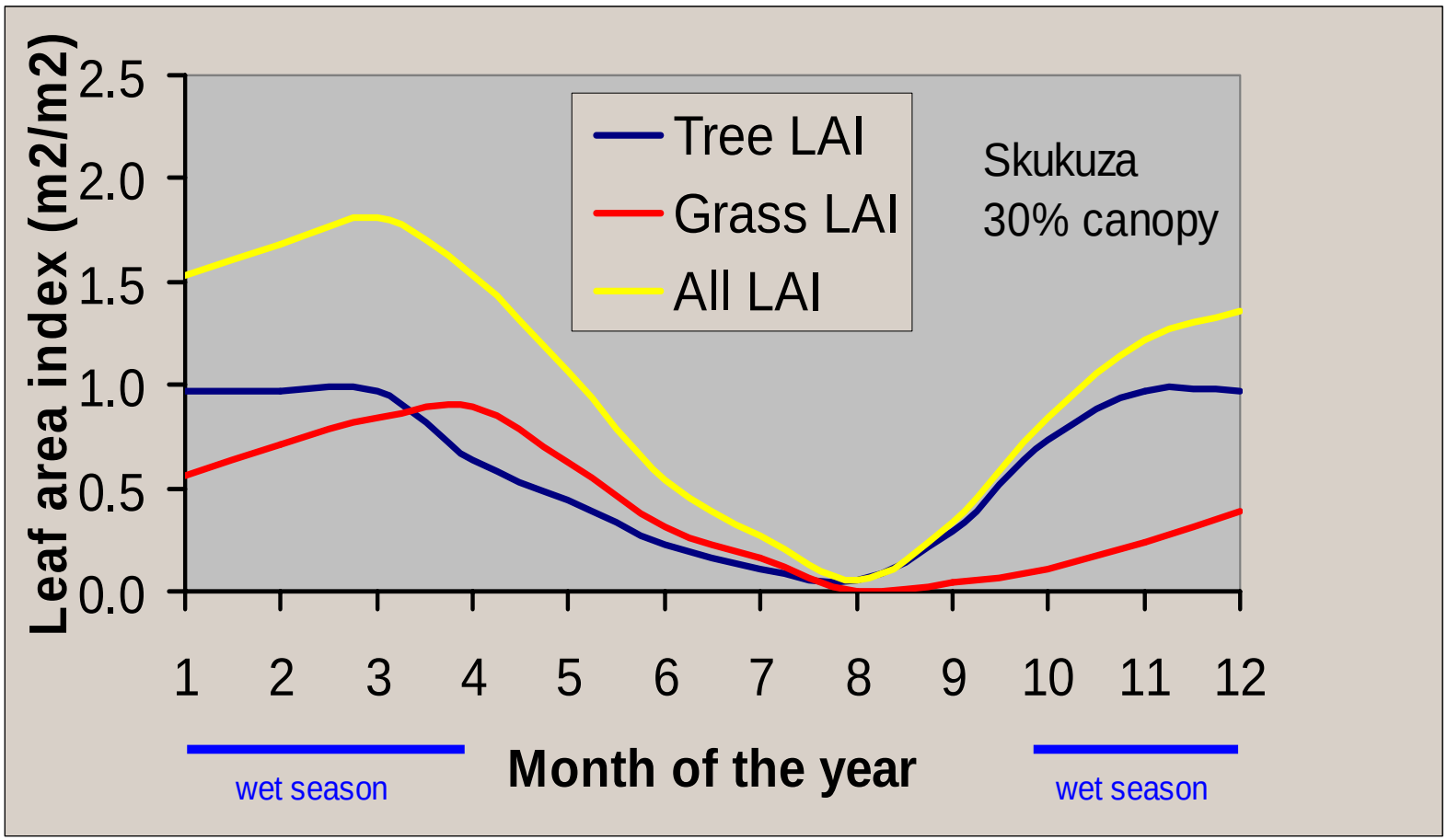
Fraction of Absorbed **P**hotosynthetically-**A**ctive **R**adiation intercepted by the vegetation canopy (range 0-1)

$$GPP = \varepsilon \sum(PAR * FPAR) * f(_{stress,nutrients})$$

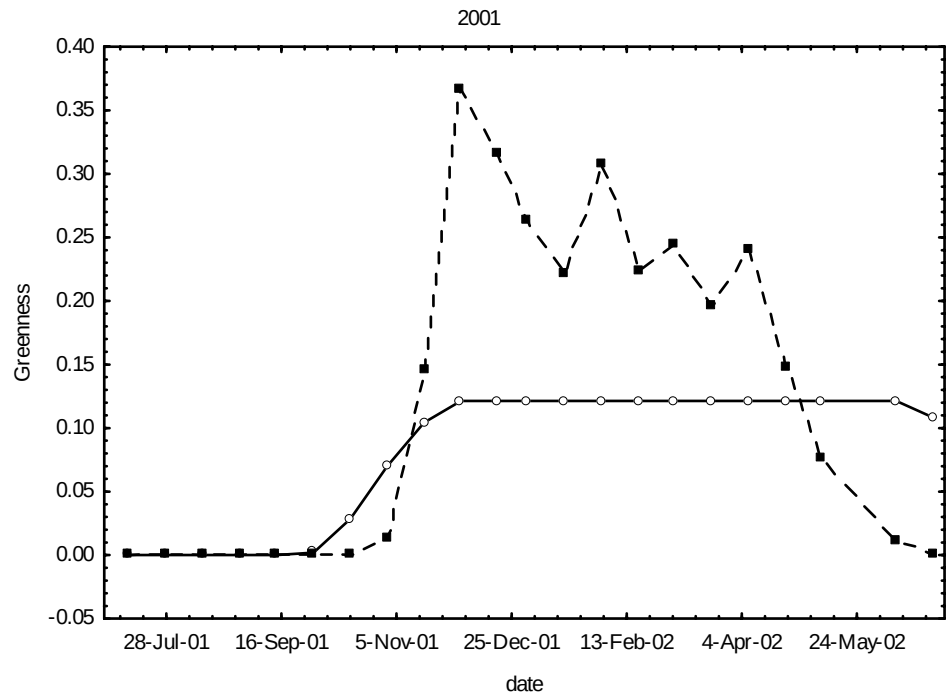
$$NPP = GPP - R_a$$

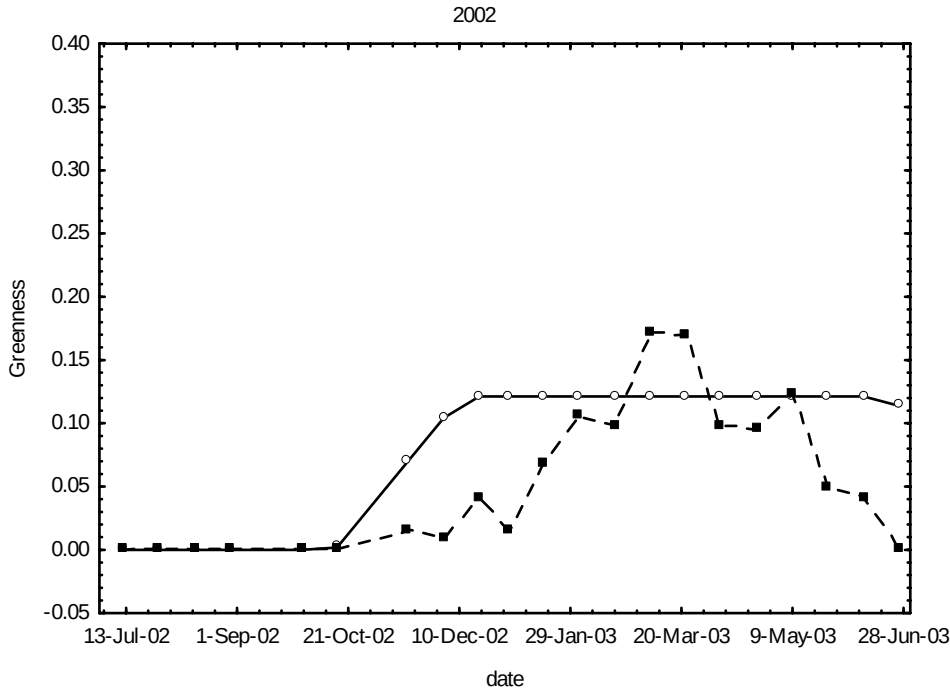
GPP = Gross Primary productivity (g/m^2) (dry matter = 42% C)
ε = Radiation use efficiency (gC/MJ),
species dependent (0.3-0.8 gC/MJ)
NPP = Net Primary Productivity (g/m2)
PAR = Photosynthetically-active radiation (400-700 nm) (W/m^2)
R_a = respiration by plants (~50% of GPP)

Seasonal pattern of LAI



Unscrambling the tree and grass signals





Conclusions

- It is possible to define desertification in a rigorous and operational way, via the concept of persistent loss of ecosystem services
- There are mechanisms by which state change in ecosystem service delivery can occur: desertification is a real and widespread phenomenon
- These should be detectable using remote sensing, but require additional non-remote sensing data (soil and rainfall), time series, and often the unmixing of the tree and grass signal