Looking beneath the surface

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Rooibos, a jack of all trades and example for ecological intensification in agricultural plant production via use of microbial root symbionts.

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Microbial services for an environmentally friendly & sustainable ***Rooibos Tea*** production by resource-poor farmers

EcoInt project: Ecological Intensification of organic Rooibos Tea cultivation in South Africa

PhD: MRes Josep Ramoneda Massagué PhD supervisor: Prof. Dr Emmanuel Frossard
PI: Dr Hannes A. Gamper
Co-PI: Prof. Dr Johannes J. Le Roux
Co-PI: Msc Noel Oettle
Collaborator: Dr Cecilia Bester, Agricultural Research Council, ZA

Aspalathus linearis *(Burm. F) Dahlg.* (Crotolarieae, Fabaceae)

= a unique South African produce of an endemic legume shrub

http://www.equalexchange.co.uk/wp-content/uploads/2016/08/Equal-Exchange-Rooibos.jpg

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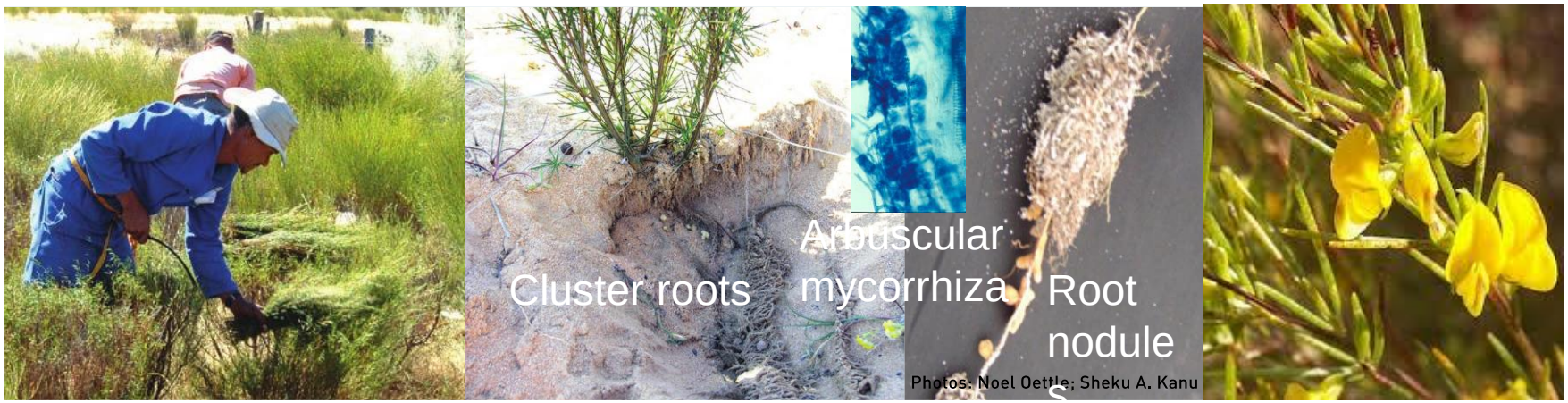
Ecological intensification of rooibos cultivation (EcoInt)*



Aspalathus linearis (Crotolarieae, Fabaceae)

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* ***'The smart use of biodiversity-mediated ecosystem functions to support agricultural production.'***

Tittonell *et al.* 2016

= **Optimal utilization of functional diversity**

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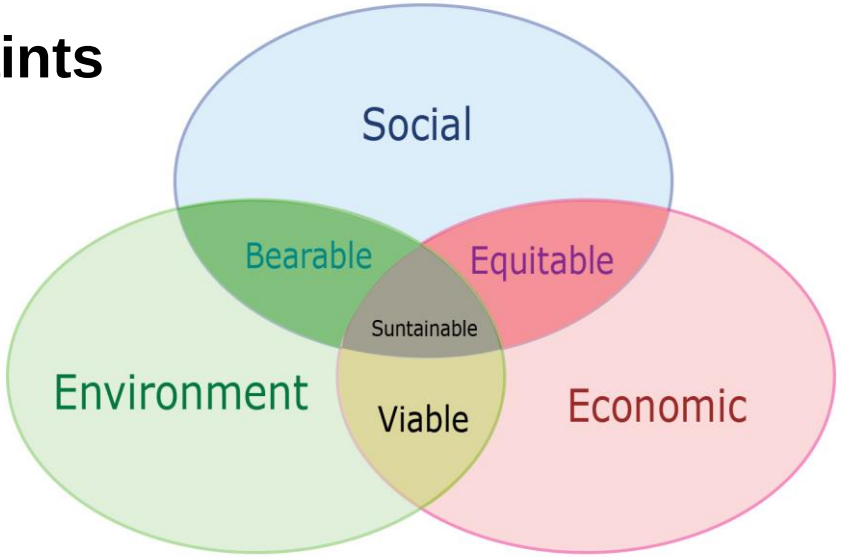
Context:

Agricultural productivity has to increase or be sustained, despite **increasing constraints on production by restrictions due to dwindling water, fossil fertilizer, and energy availability.**

(cf. nitrogen (N) and phosphorus (P) fertilizers)

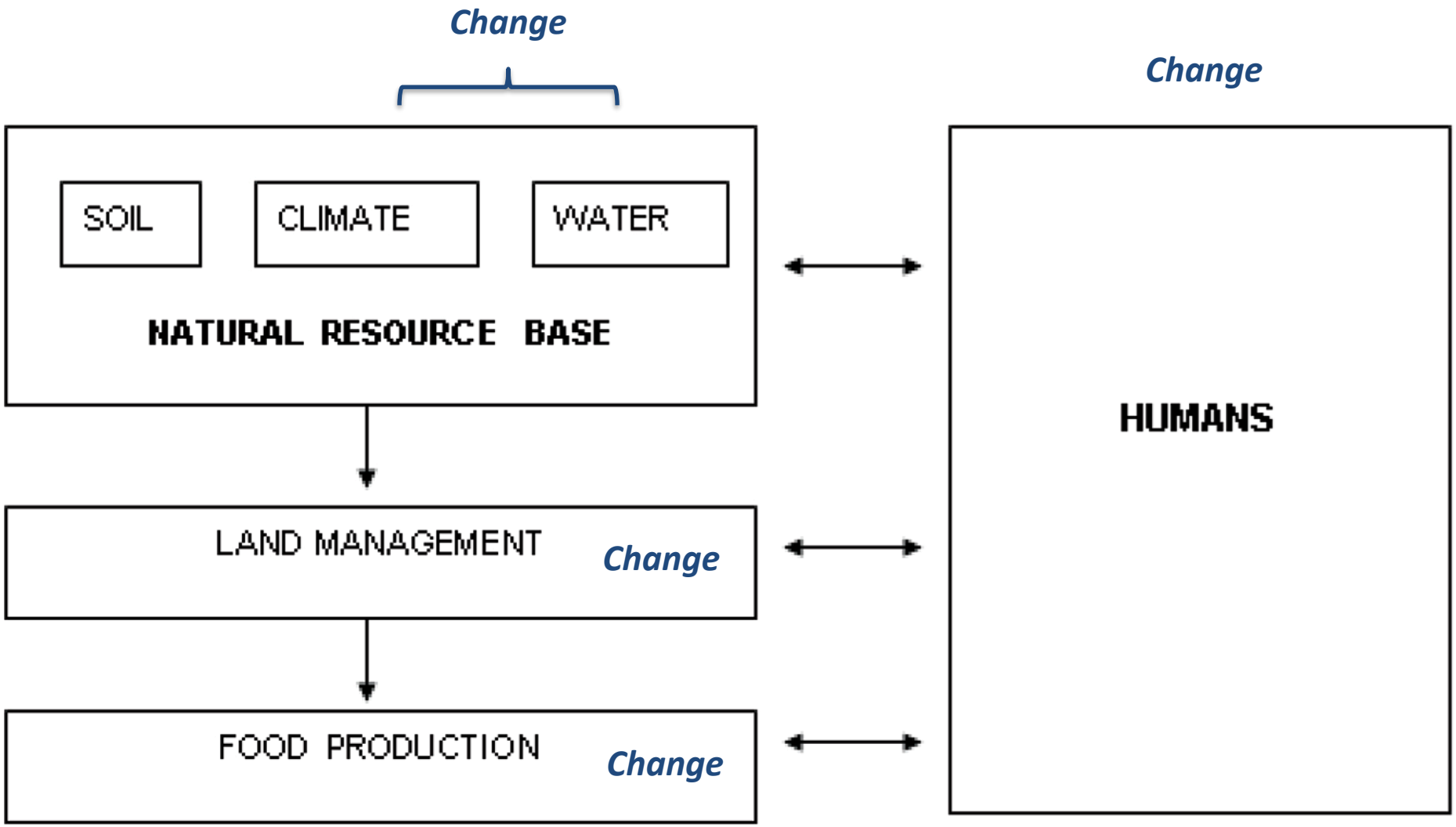


. . . while this has to happen in a manner that is:

- ***socially fair***
- ***environmentally safe*** and
- ***economically viable*** to meet overall sustainability goals***.***

➡ Organic rooibos cultivation, harvesting & marketing is an example, that demonstrates that this ***seems*** be possible.

Agricultural production systems under change



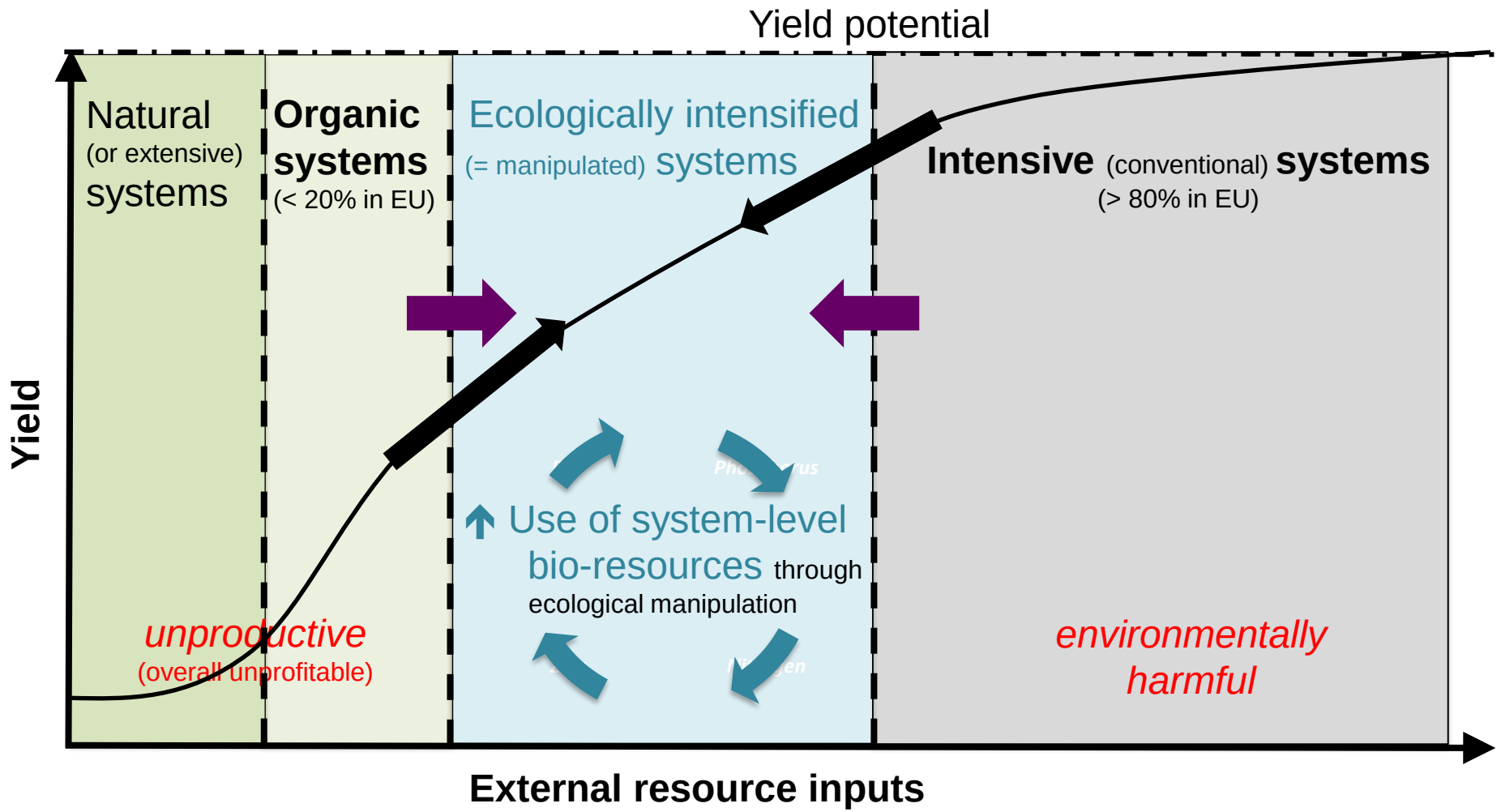
http://www.ee.co.za/article/impact-geo-spatial-planning-agricultural-sector.html

Ecological intensification ≈ Integration of organic & conventional farming

Unsustainable for people !

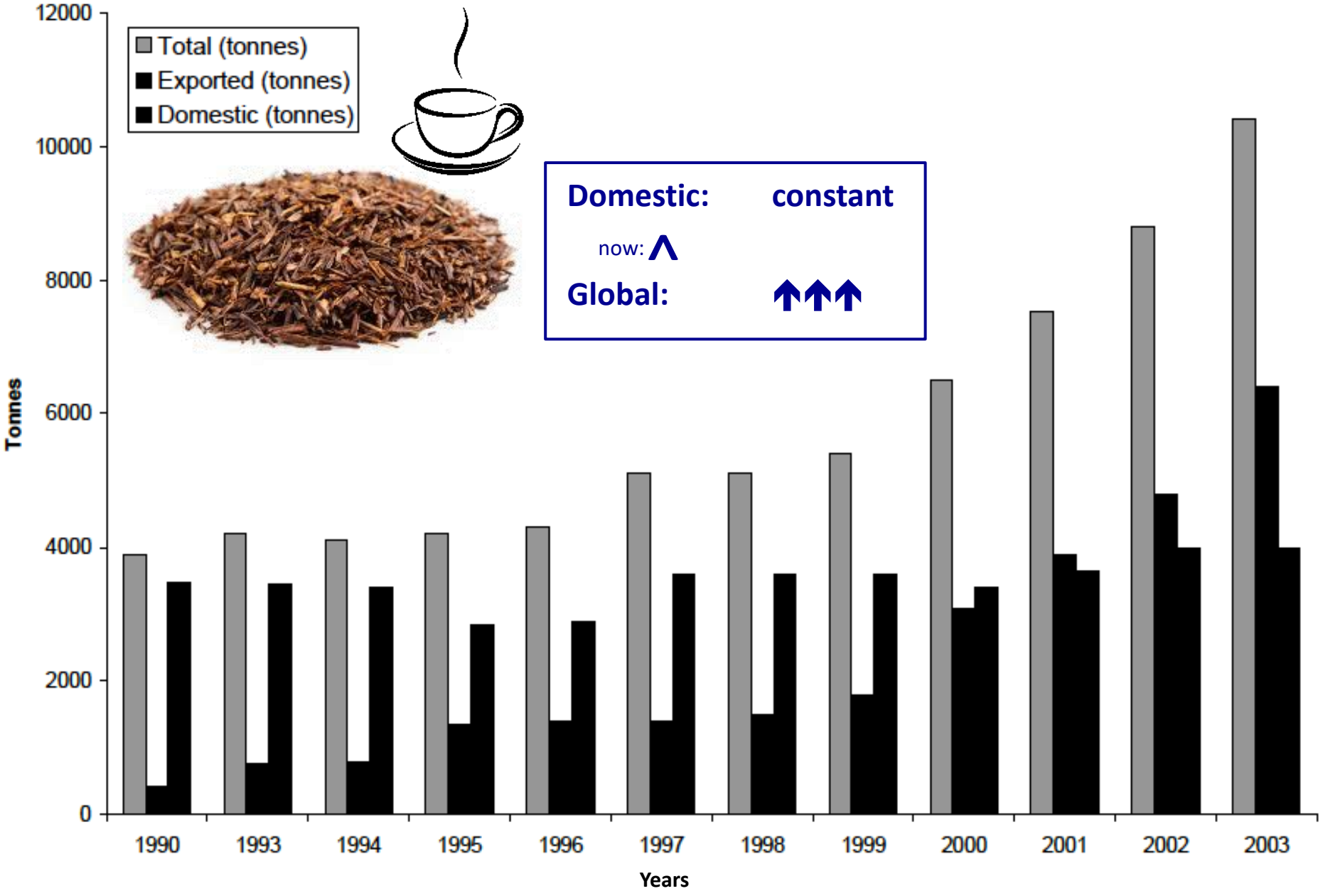
Sustainable for all ?

Unsustainable for the environment !



(≈ substitution of biological by chemical processes)

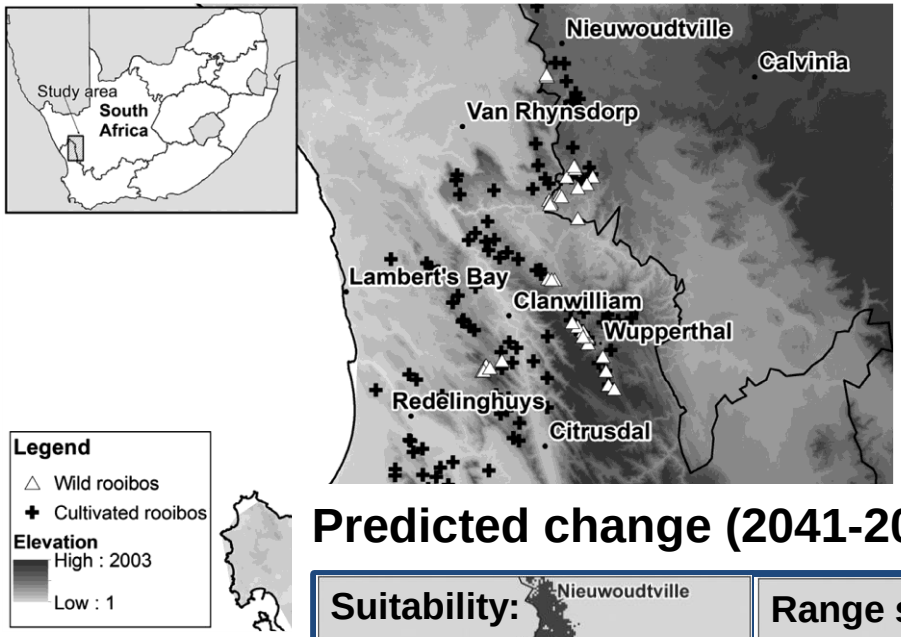
Development of the domestic & global Rooibos Tea market



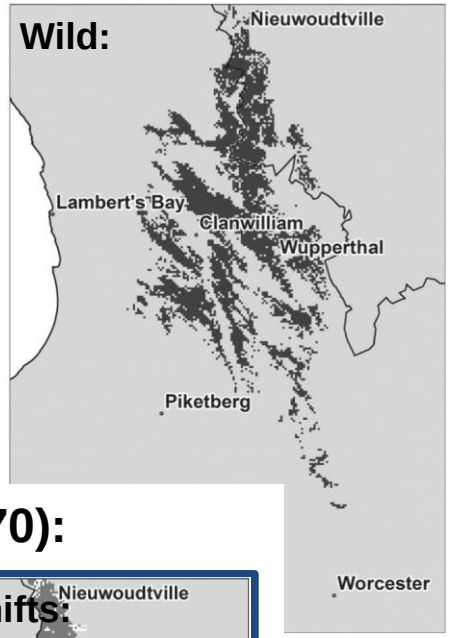
Willem Engelbrecht, Department of Trade and Industry Rooibos Sector Report, 2004.

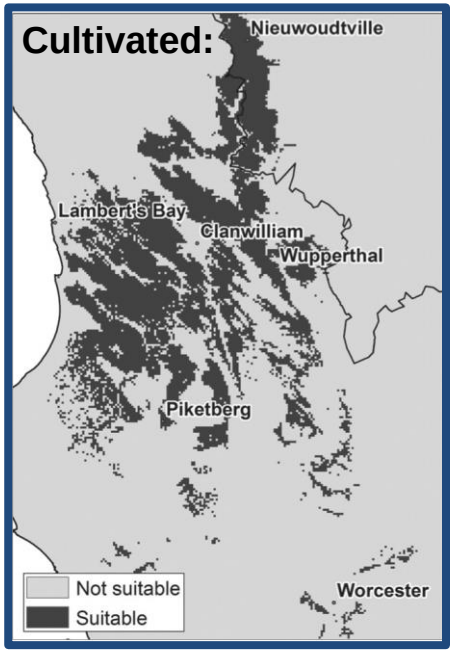
Rooibos's current & possible future distribution:

Actual distribution:

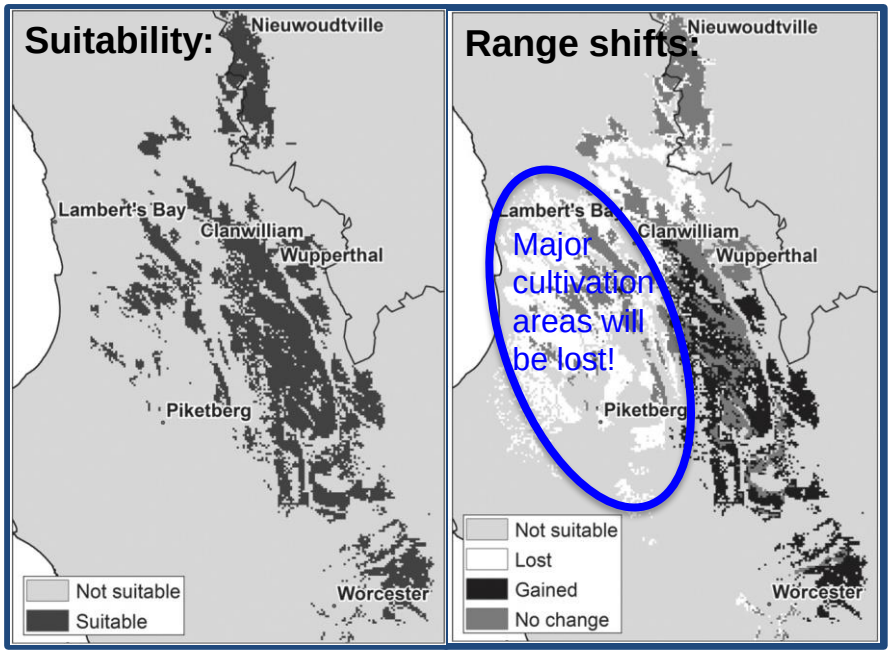


Potential distribution (climate suitability):





Predicted change (2041-2070):



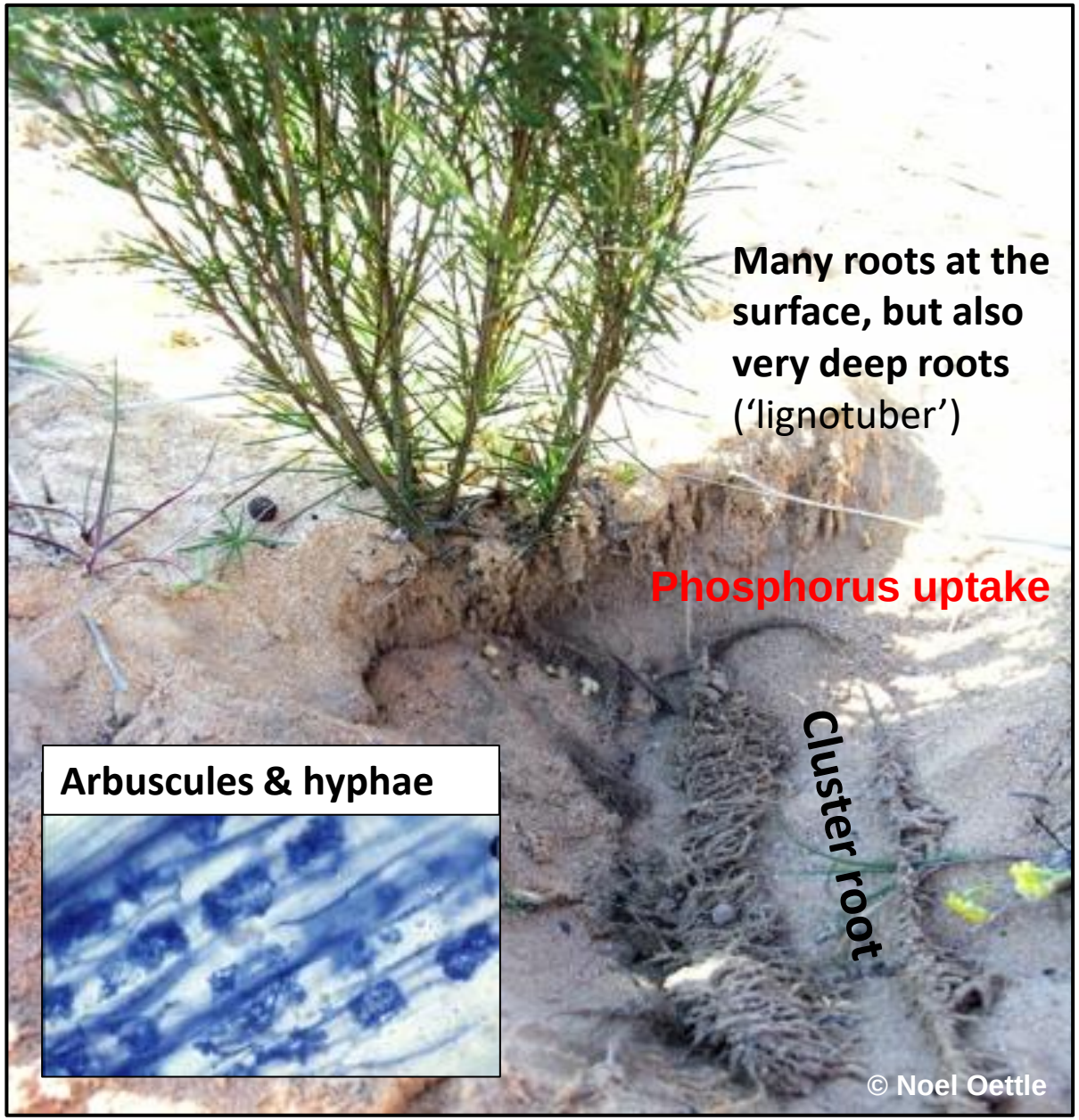
Adaptation needed!

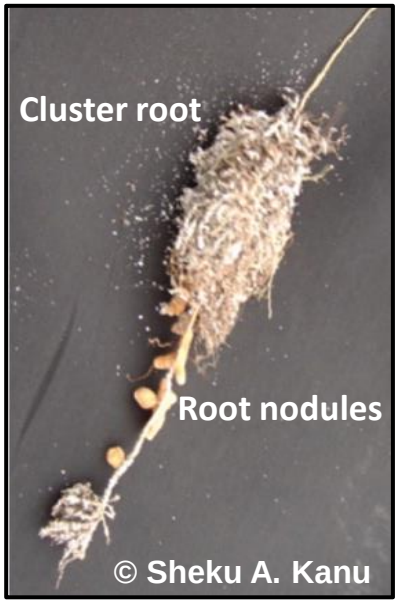
- Cultivar choice ('*ecotype*')
- Cultivation measures

? Soil microbes & soil nutrient & organic matter content ?

Lötter & Le Maitre 2014, *Ecol. & Evol.* **4**: 1209-1221

Rooibos (*Aspalathus linearis*) – A jack of all trades





Nitrogen uptake

Large indeterminate nodules formed close to thick lateral roots

Root-associated microbes:

- ‘Surprisingly little is known about the rhizobia nodulating *A. linearis*, although it is known to be able to fix well over 100 kg N ha^{-1} annually (Muofhe and Dakora, 1999). ‘

  Sprent *et al.* 2009, J. Exp. Botany 61: 1257-1265

- Members of both the α-Proteobacteria and β-Proteobacteria were shown to form effective root nodule symbioses. *Mesorhizobium* spp., *Rhizobium* spp., *Bradyrhizobium* spp., *Agrobacterium* spp., *Rhodosprillum* spp., *Burkholderia* spp., *Herbasprillum* spp., were recovered from **indeterminate nodules**.

  Hassen et al. 2012, *Biol. Fert. Soils* 48: 295-303
  Mavengere et al. 2014, *Int. J. Syst: & Evol. Microb.* 64: 1906-1912

- Arbuscular mycorrhizal fungi (AMF, phylum: Glomeromycota) colonize the roots of seedlings & improve their P uptake.

  Allsopp & Stock 1992*, Oecologia* 91: 281-287

- Oomycota, such as *Phythophtora* spp., *Pythium* spp. are potent pathogens.

  Bahramisharif *et al.* 2013, *Mycologia* 105: 1174-1189
  Bahramisharif *et al.* 2013, *Plant Disease* 98: 223-232
  Bahramisharif *et al.*2013, *Plant Disease* 97: 1605-1610

Pressing problems:

- Cultivated (fast-growing & re-seeding) *Nortier* ecotype of rooibos is drought & pest sensitive and depends on more nutrient-rich soils.

- Intensive cultivation in monoculture leads to land degradation due to:
  - soil organic matter depletion
  - excessive fertilization or nutrient depletion
  - mineral nutrient imbalances
  - pathogen accumulation
  - declines in beneficial microbial populations (?)

- Destruction of pristine, exceptionally biodiverse Fynbos vegetation for new plantations

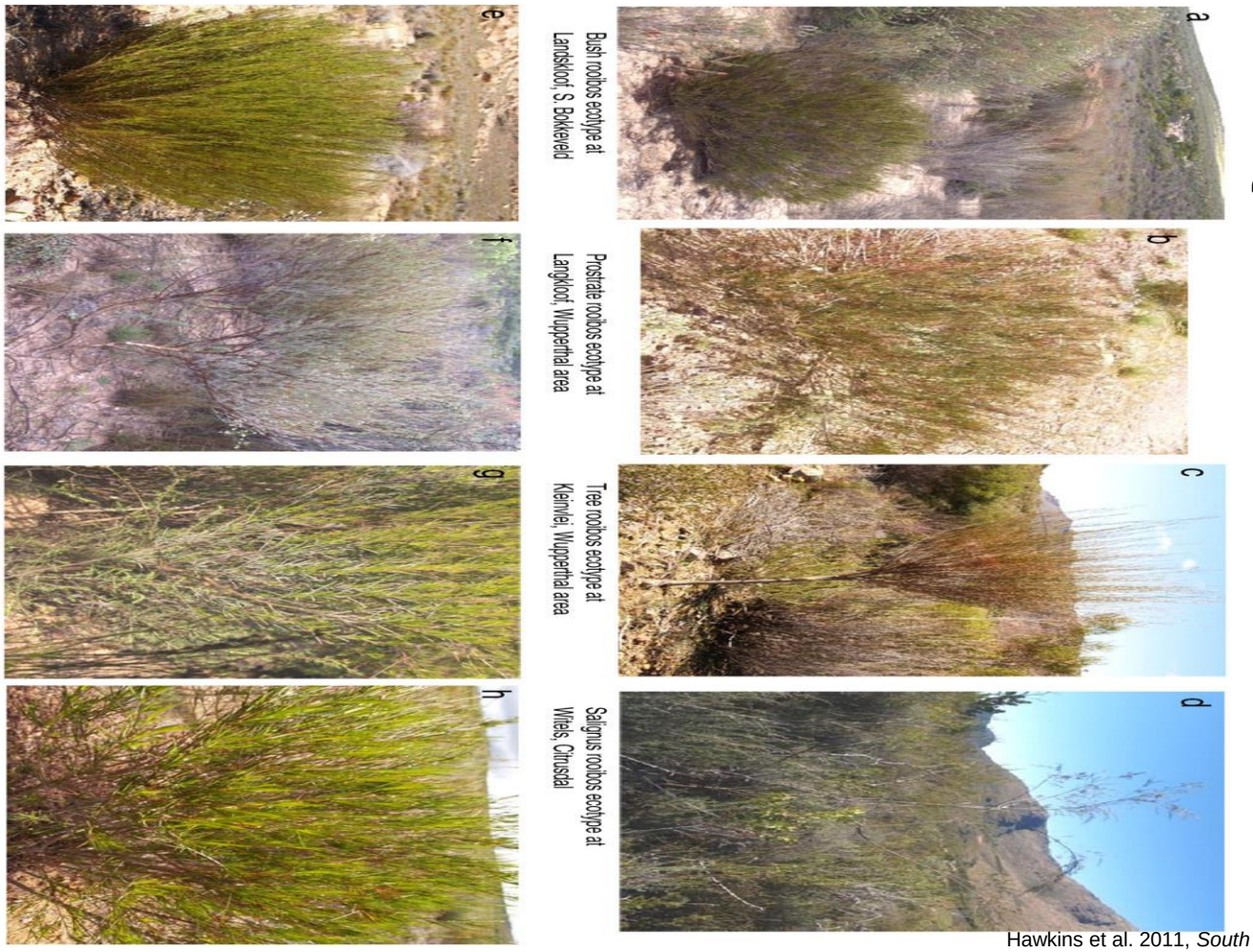
- Over-exploitation of wild populations

Possible problem amelioration measures:

- Cultivation of locally adapted rooibos (slower-growing & re-sprouting) ecotype of rooibos.
- Cultivation in diversified fields (wild vegetation strips, intercropping ?)
- Incorporation of plant residues from wild vegetation strips, instead of burning.

Available ecotypes (species ?)**:**

Rooibos is '*exceptionally polymorphic*' (Heerden *et al.*, 2003)



'Resprouters'

'Reseeders'

Hawkins et al. 2011, *South African J. Botany* 77: 360-370

Cultivation measures:

- Wild vegetation strips for biodiversity conservation & erosion protection

- Oat intercropping for protection against wind erosion & abrasion

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At the nursery stage:

?

- Propagation in soil from neighboring healthy wild populations to ***associated*** ***(= 'inoculate')*** ***seedlings with competitively balanced microbial communities***, *using priority effects*.
- ***Kick start seedling growth with slow-release fertilizer***,
  e.g. locally available sheep dung (keeps soil moisture & has an adequate N:P ratio).

Hypotheses / predictions:

1) Soils from wild populations of rooibos harbor more balanced ('diverse') communities of microbes than those from plantations.

2) Rooibos plants select beneficial root symbionts depending on need & availability.

3) Beneficial root microbial symbionts assist rooibos in N & P acquisition and confer resistance (or tolerance) against pathogens & drought.

4) Continuous Rooibos Tea production without re-supplying soils with mineral nutrients & organic matter leads to nutrient & water deficiencies and accumulation of pathogens & declines in the population sizes of mutualists.

5) Local, indigenous traditional farmer knowledge & practices combined with ecological system understanding opens opportunities for agro-ecological innovation.

- ***Addition of soil from wild populations and of manure to nurseries can sustainably increase rooibos growth even after transplantation.***

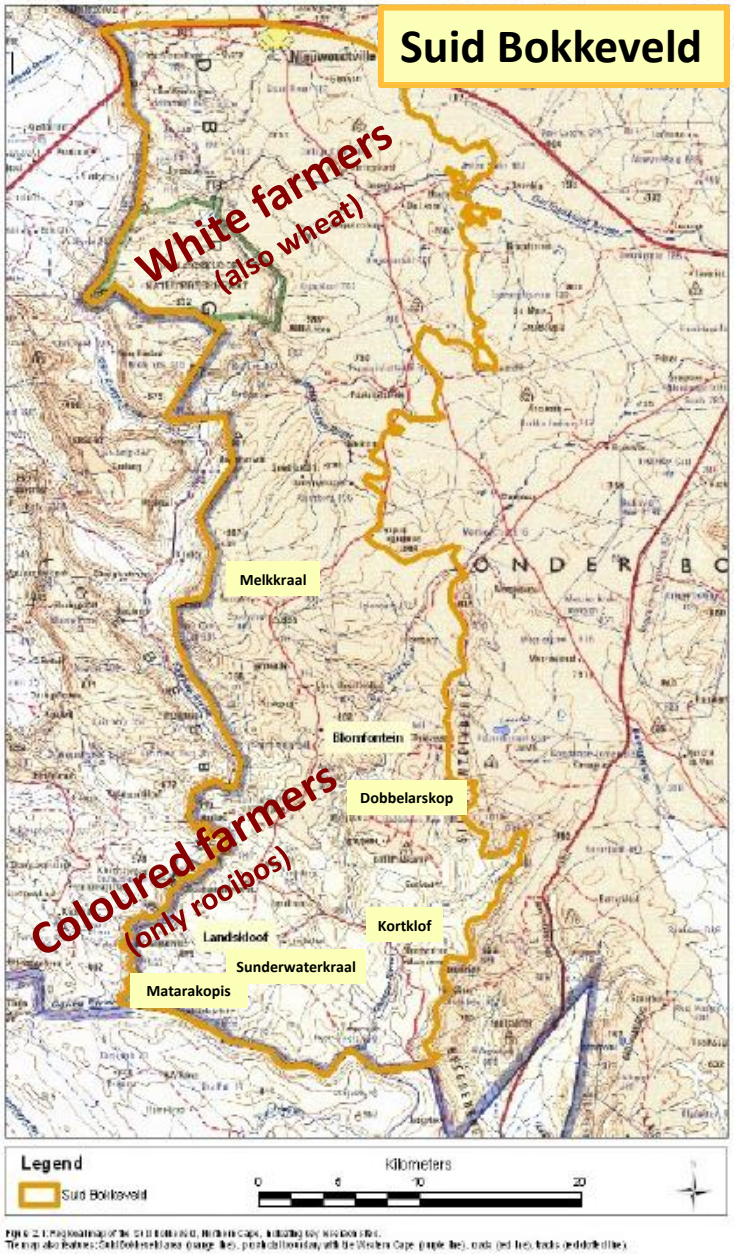
Project parts / approaches:

1) **Observational field survey** in pairs of plantations & wild populations of rooibos across a precipitation gradient, based on molecular ecological & ecophysiological analyses.

2) **Manipulative pot experiments** on seedling performance depending on soil origin and in response to sheep dung addition & reduced irrigation in the form of outdoor & indoor common garden experiments.

3) **Survey on farmer's perception** of possible ecological intensification measures **& compilation of local agro-ecological knowledge** among contrasting groups of Rooibos Tea producers.

Field survey:



Heiveld farmer's cooperative

'High' (approx. 300 mm)

Rainfall gradients

'High' **'Low'**

'Low' (approx. 220 mm)

Root, cluster root, root nodules & leaves sampled from:

7 areas

15 plantations & adjacent wild populations

Soils collected from:

5 areas for pot experiments

Nursery-type pot experiments ('common gardens'):

Experimental factors:

- Different soils
- Mixing of soils from plantations & wild populations of the same site
- Sheep dung addition
- Reduced irrigation

① 

Outdoor experiment on farm

Replication:

10 times

Questions:
What is most limiting,
the availability of
- Water
- Mineral nutrient, or
- Beneficial microbes ?

How do these factors interact?

② 

Indoor experiment at research station

Cross-factorial design:

Soil:	**Fertilization:**	**Drought:**	**Replicates**
from wild populations (5)	- sheep dung	yes	10
from plantations (5)	+ sheep dung	no	
Mixture (5)			

➔ 60 treatments, 600 pots

Analytical approaches:

1) Community PCR amplicon sequencing:
   - Rhizobia
   - Arbuscular mycorrhizal fungi
   - Oomycota

   ➔ ***Selectivity of root-symbionts & root health***

2) Nutrient analyses:
   - N, Mn, Mo, P, Zn

   ➔ ***Plant nutrition***

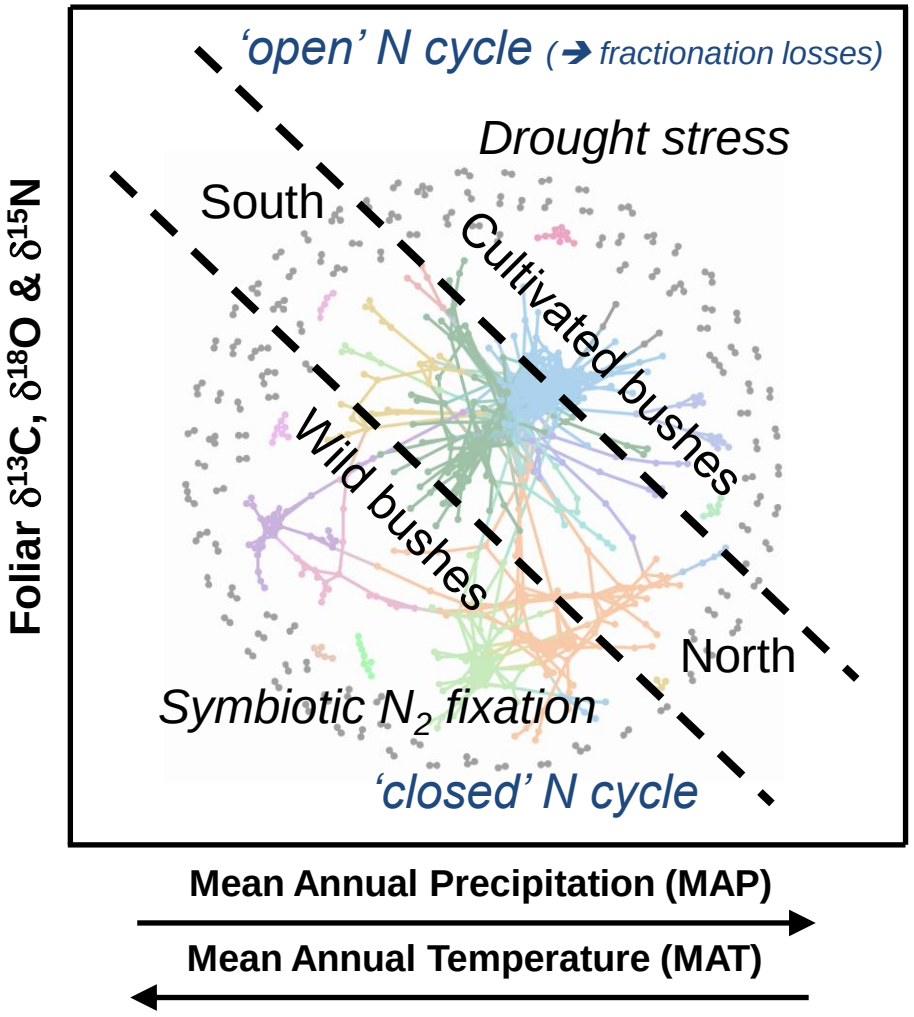
3) Isotopic signature analyses:
   - $\delta^{13}C$, $\delta^{18}O$

   ➔ ***Drought tolerance***

   - $\delta^{15}N$

   ➔ ***Microbial N acquisition***

Conceptual analytical framework:



Interviews on farmer's perception & suggestions for ecological intensification

- To learn from local, indigenous traditional knowledge.
- To foster acceptance & implementation of novel ecological intensification measures.
- To broaden the impact and scope of the project. – Comparison of small- & large scale farmers/plantation managers.

Exchange with farmers

Conclusions:

- A ***science-based understanding*** of whole ecosystem functioning together with ***local indigenous traditional knowledge & practices*** may open opportunities for agro-ecological innovation.

- Raising rooibos seedlings in soil amended with soil from wild populations and locally produced sheep dung may ***improve soil-microbe-plant system functioning*** also in plantations.

➢ **Successful ecological intensification of Rooibos Tea production via improvements to the functioning of root-microbe symbioses could serve as an example for other crops.**

Acknowledgements:

- Prof. Dr Emmanuel Frossard (ETH Zurich)
- Dr Cecilia Bester (ARC-Infruitec)
- Prof. Dr Johannes J Le Roux (SU)
- Farmer community & workers

Project funding:

Stiftung Mercator Schweiz

World Food System Center

TANK YOU FOR YOUR ATTENTION !

"It is so important to sustain the soils and the vegetation so that we can always depend on them to sustain us"

Hendrik Hesselman (Rooibos farmer)

Involved organizations:

ETH zürich

UNIVERSITEIT STELLENBOSCH UNIVERSITY

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Excellence in Research and Development

EMG Environmental Monitoring Group

HEIVELD
WORLD'S FINEST ROOIBOS TEA