NITROGEN CYCLE AND PROTEIN CROPS

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Workshop on « Plant Proteins-Agronomic practices and environmental benefits »

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UR ASTER-Mirecourt
FRANCE
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N cycle in the biosphere and human needs

N cycle and agriculture : from scarcity to surabondance

Traditional agriculture : A set of practices allowing the exportation of proteins from an ecosystem while ensuring soil N restitution in a close cycle

Inert atmospheric Nitrogen : 78 % air N_2

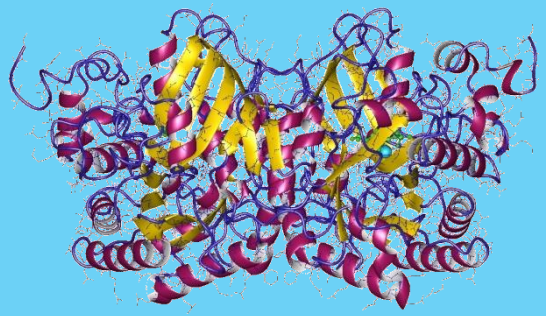
- **Nitrogen reactive forms :**

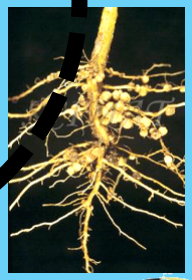
NH_3 , NH_4^+, NO_2^- , NO_3^- , N_2O, NO_2…

Redox processes : Nitrfication / Denetrification

- **All living beings are made of organic**

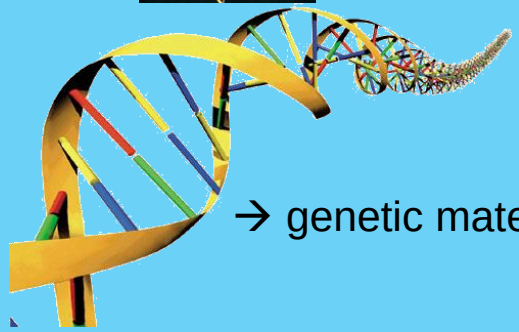
proteins → enzymes





N fixation by bacteria

Nucleic acids



→ genetic material

The surabondance of reactive N in the environment is recent

Human needs in proteins

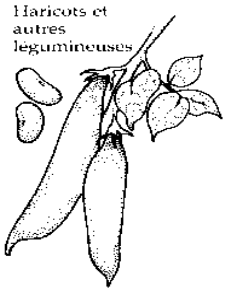
Vital minimum :
2200 kcal / cap/ day
with 60 g proteins / cap/ day (= 10 gN/ cap/day jour = 3.6 kgN/cap/yr)
200 kg equiv cereals/ cap /year

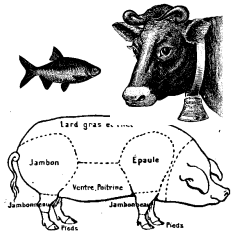
9 essential amino acids

building proteins

brought by the diet

Methionine
Tryptophane
Thréonine
Phénylalanine
Valine
Leucine
Isoleucine
Lysine





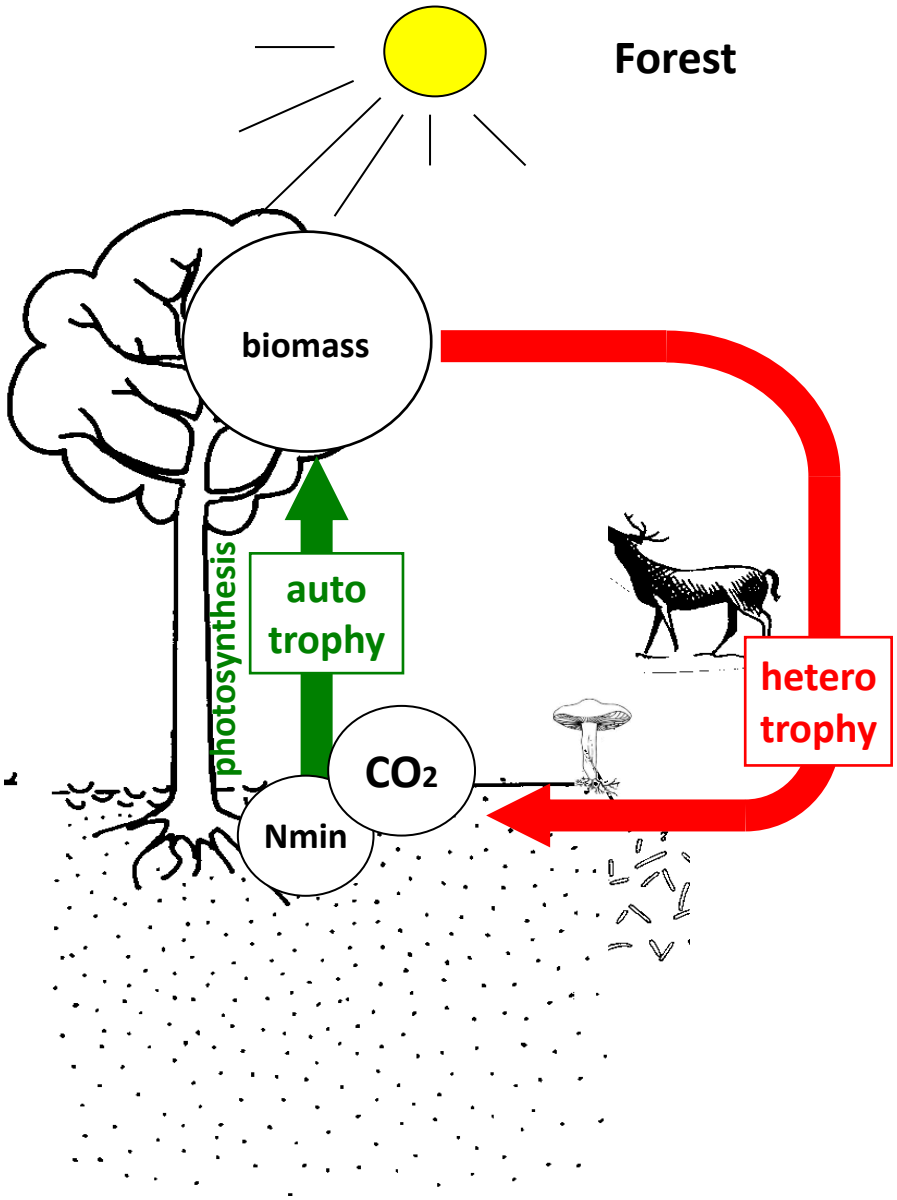
Traditional diets associate :

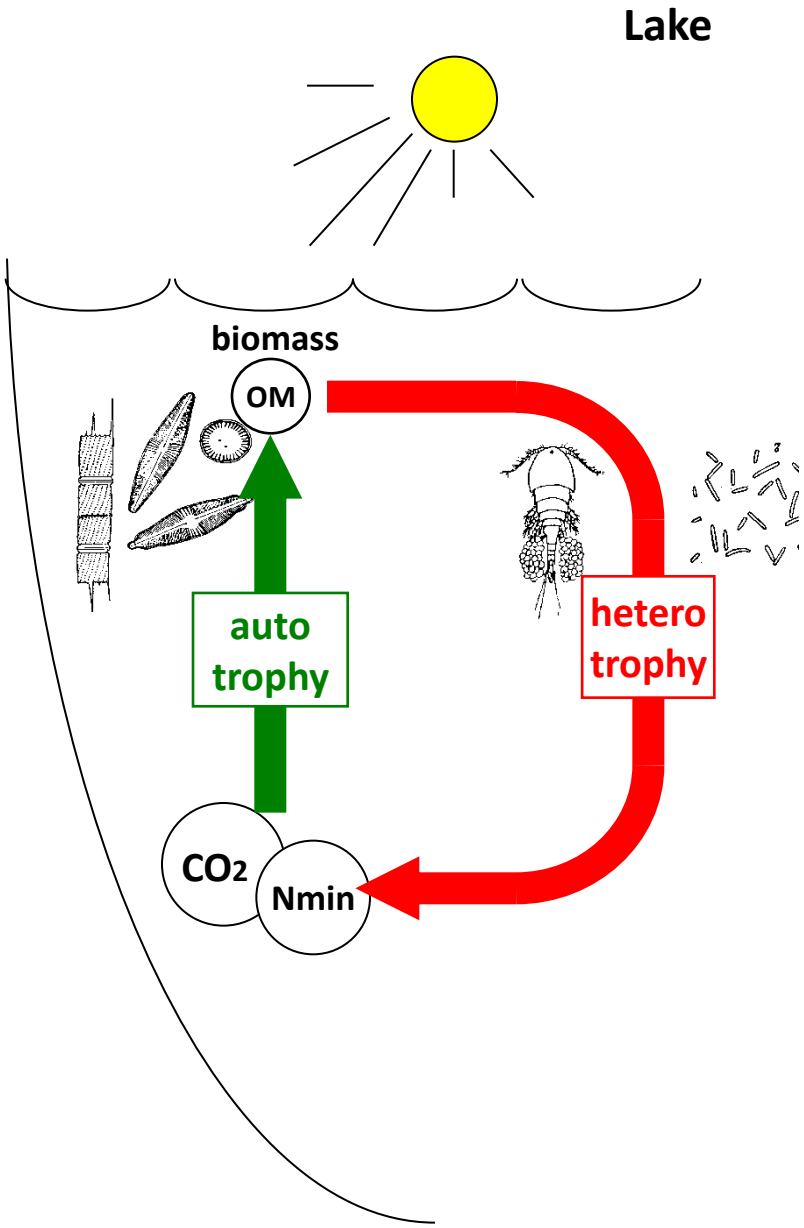
Cereals + legume crops

Cereals + animal products

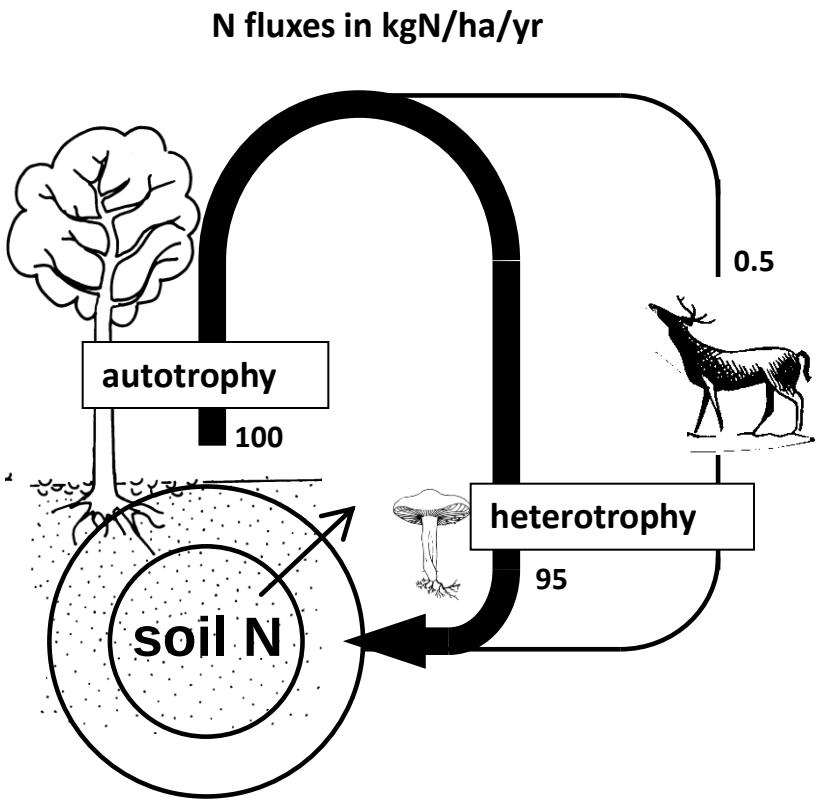
Legume crops + animal products

Schematic terrestrial and aquatic ecosystems functioning



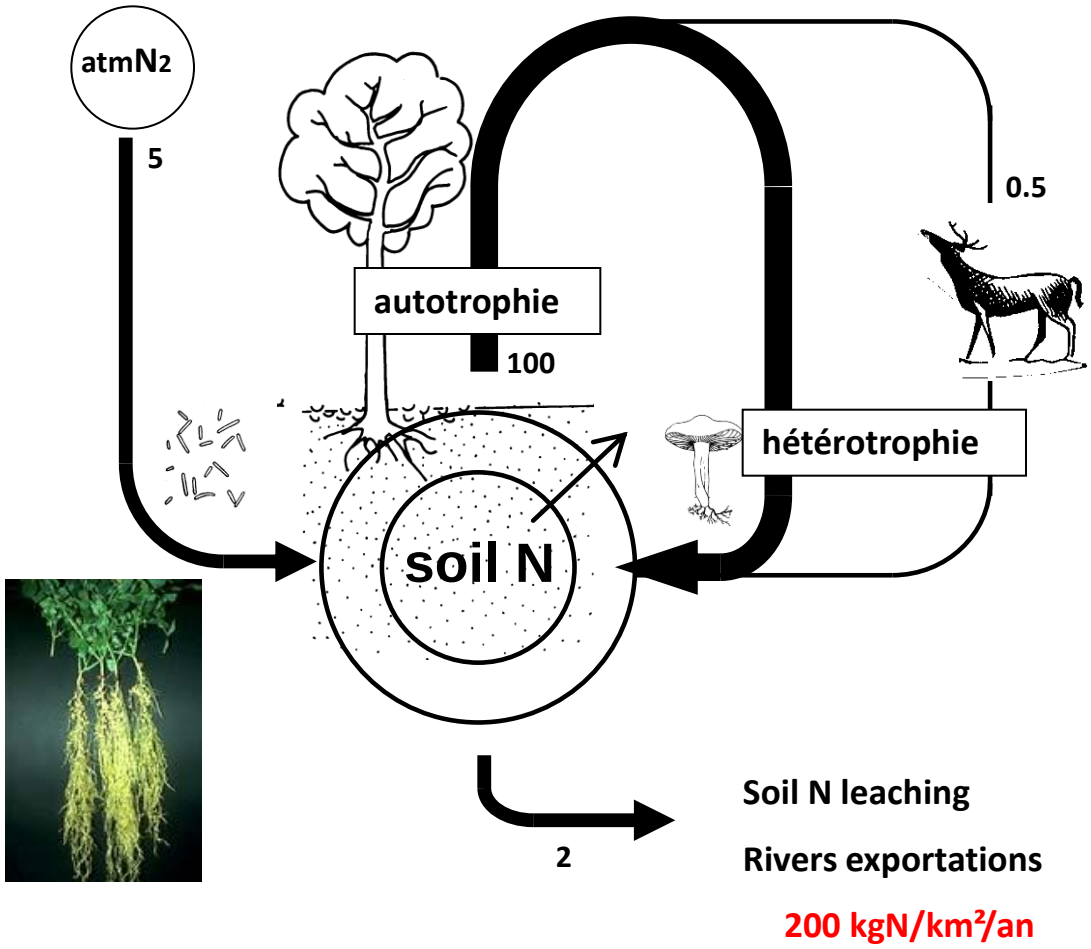


Pristine N cycle : the example of forest functioning



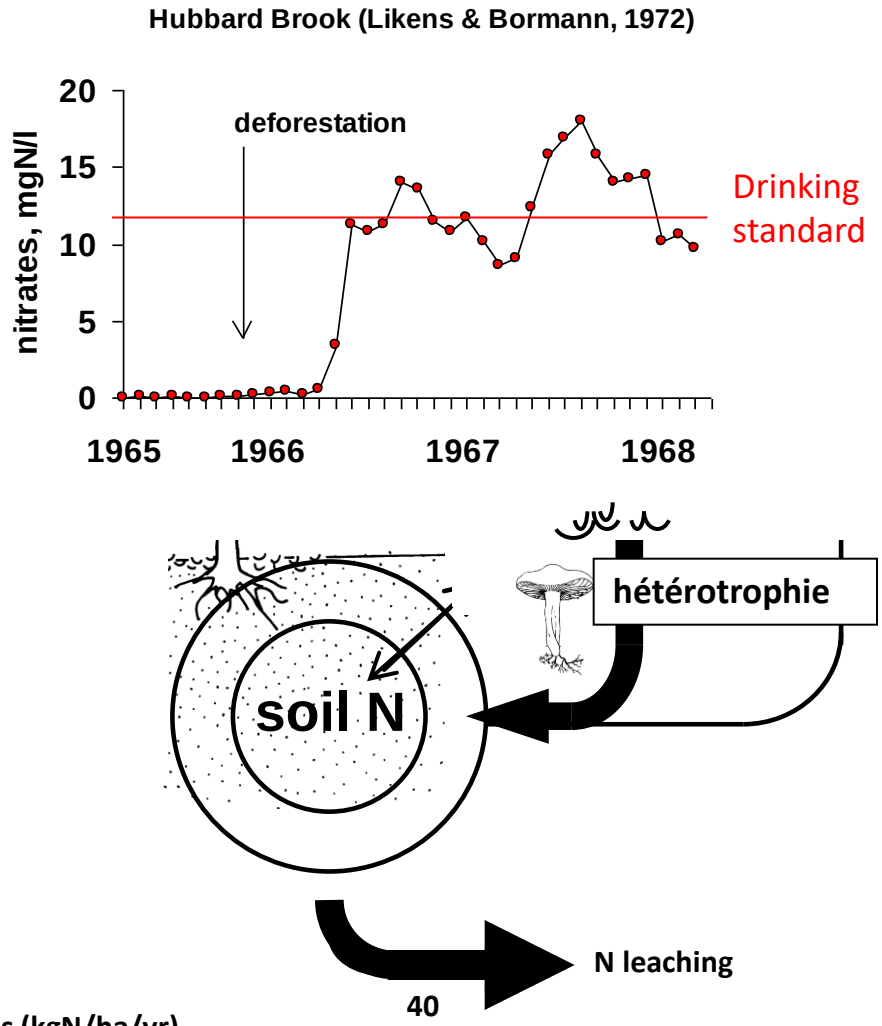
Pristine N cycle : the example of forest functioning

- **Terrestrial biomass maintains a very low nitrate concentration in soils**



- **Biological N fixation largely compensate local Nr losses through N leaching**

Anthropic perturbation of N cycle : deforestation



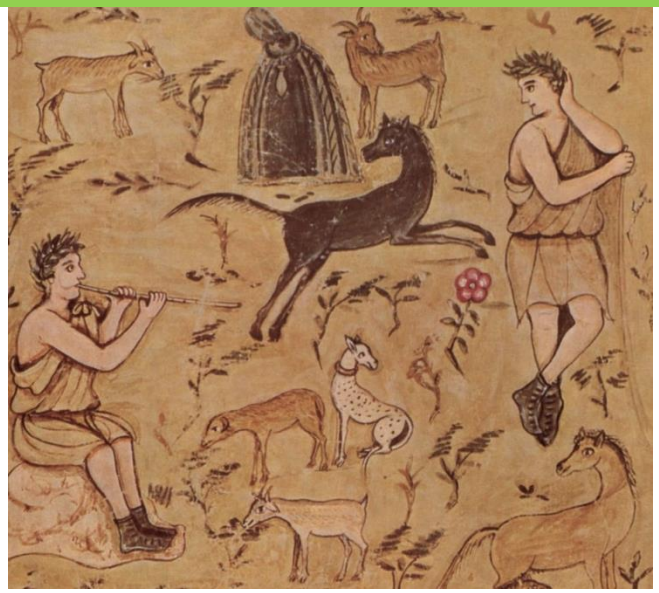
4000 kgN/km²/an

Nitrate is a highly mobile molecule (very soluble)

A brief history of occidental agricultural systems
The crucial role of legumes for productivity and soil fertiliy

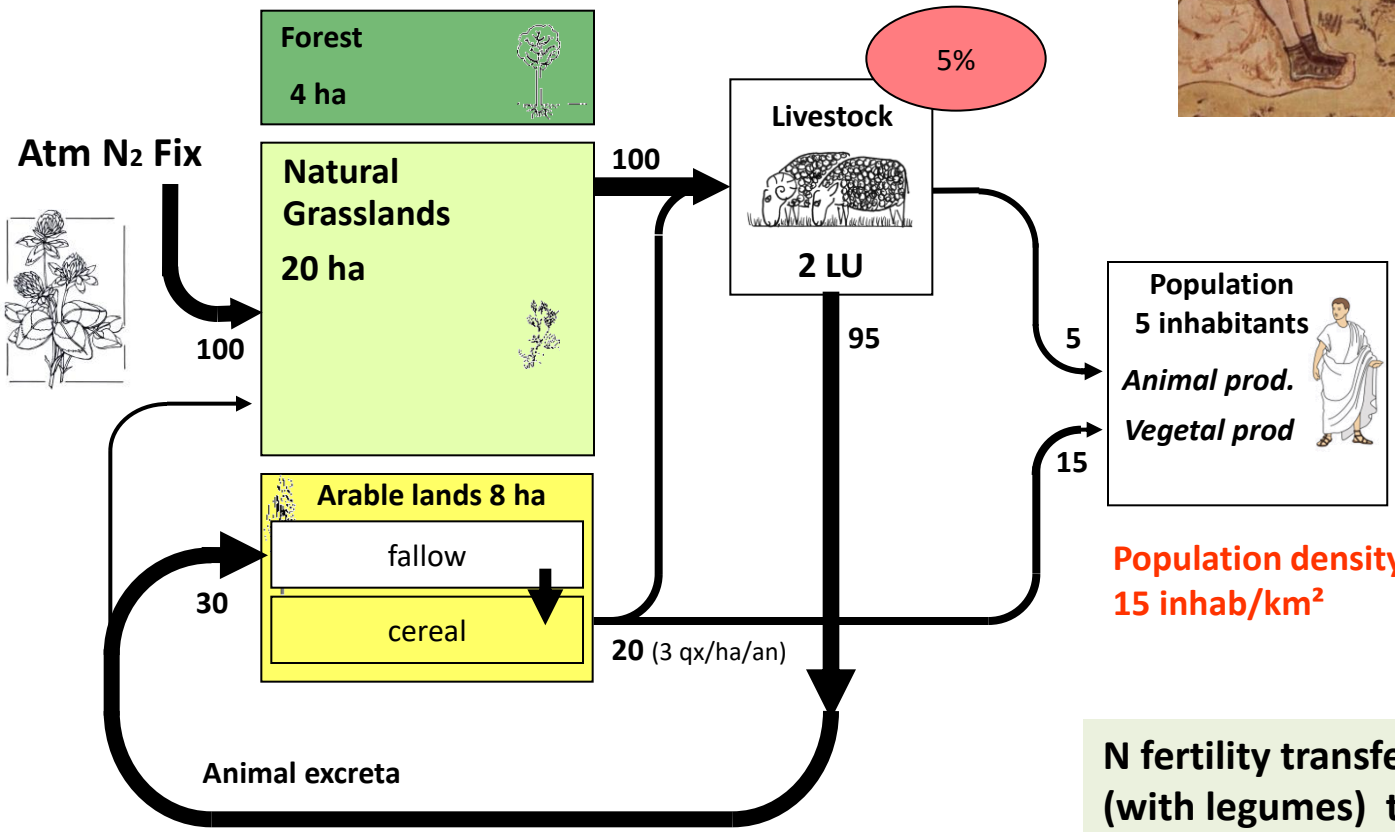
A brief history of occidental agricultural systems (1)

Antiquity of occidental world



Mixed crop and livestock
Biennal rotation with fallow
Forest and pastures: collective goods
Arable lands: private property

kgN/yr 32 ha of territory



Population density :
15 inhab/km²

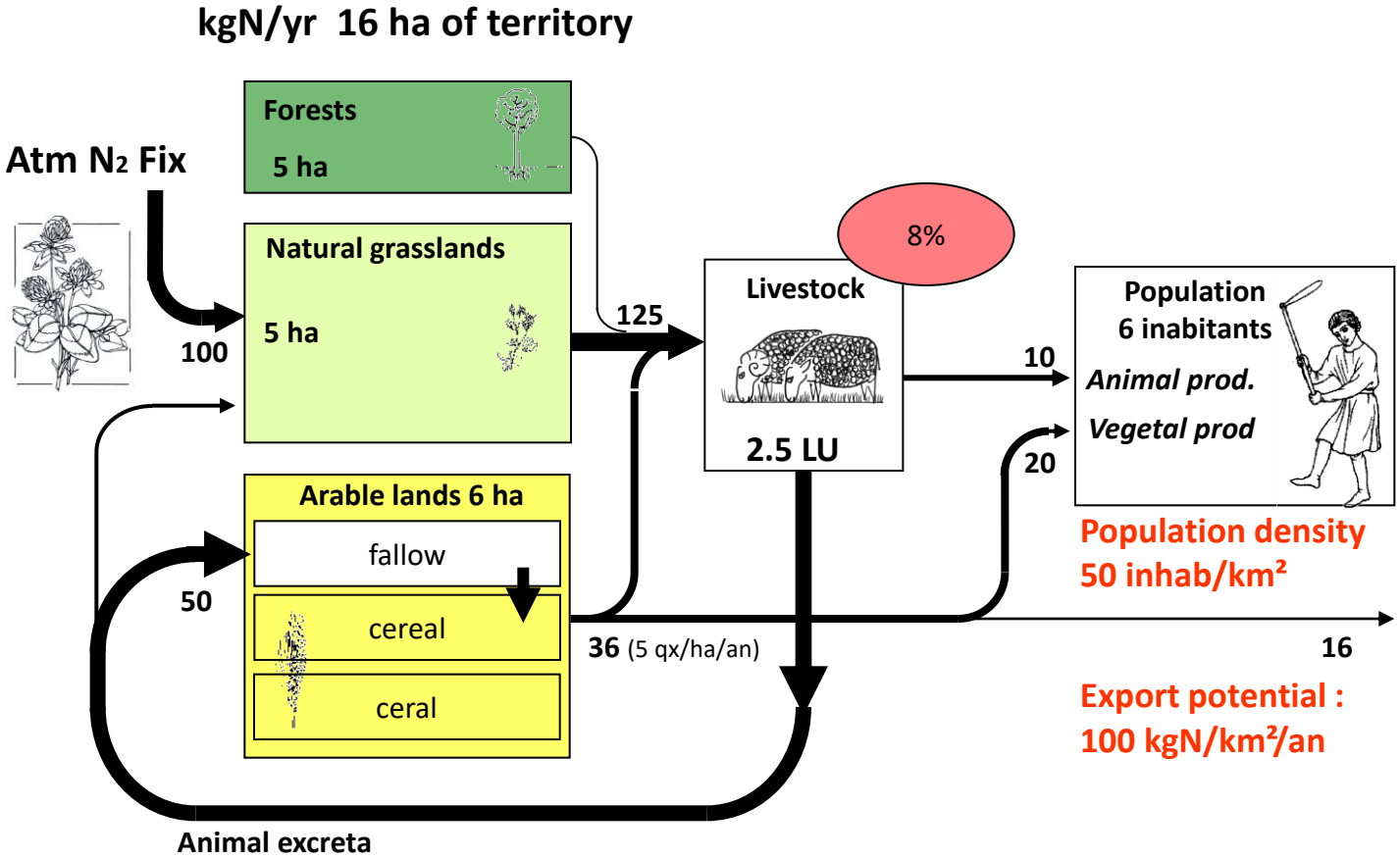
N fertility transfer from natural grasslands (with legumes) to arable lands

A brief history of occidental agricultural systems (2)

Medieval world

Mixed crop and livestock
Triennal rotation with fallow

Increase in livestock density :
best fodder and herd excreta management

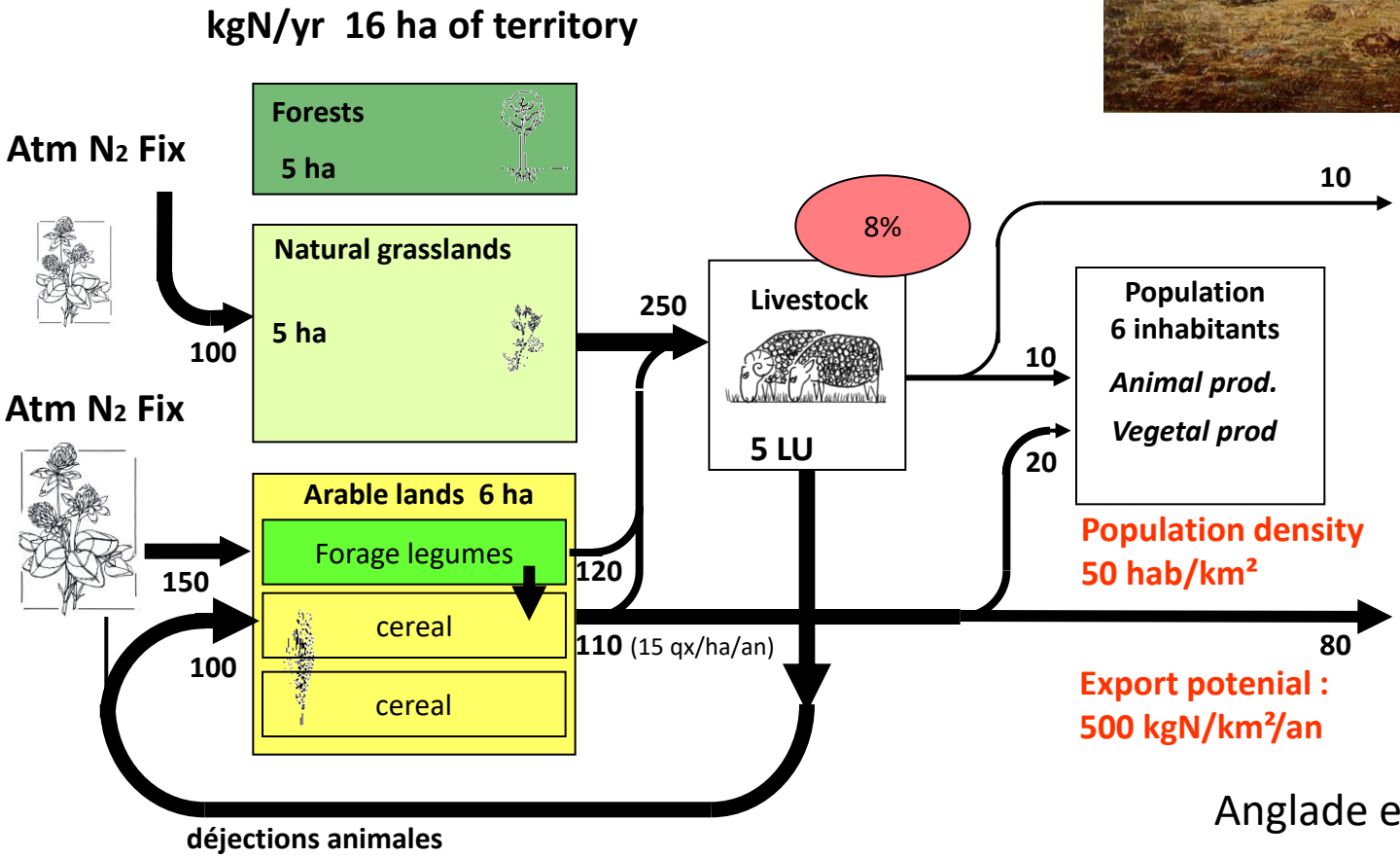


A brief history of occidental agricultural systems (3)

XIXth century – the revolution of legume forage

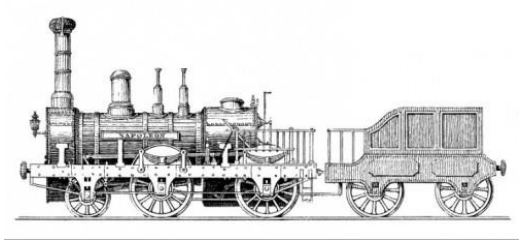
Mixed crop and livestock
Triennal rotation without fallow replaced by a sole of legume forage (alfalfa or clover)

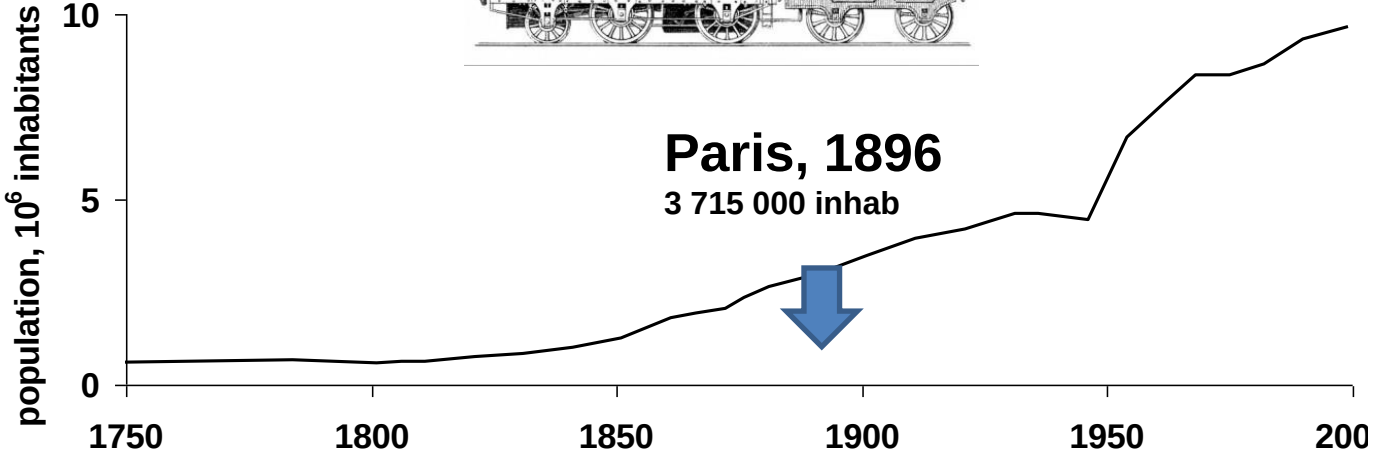
Increase in livestock density
Increase in crop yields

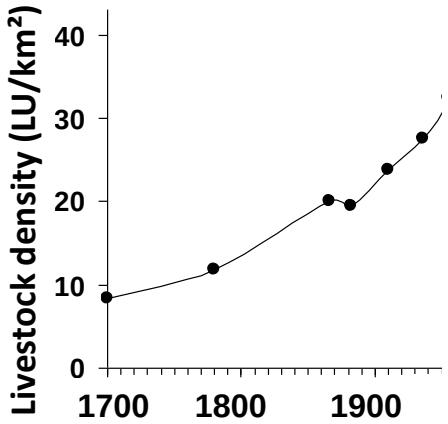


Anglade et al. 2015, VertigO

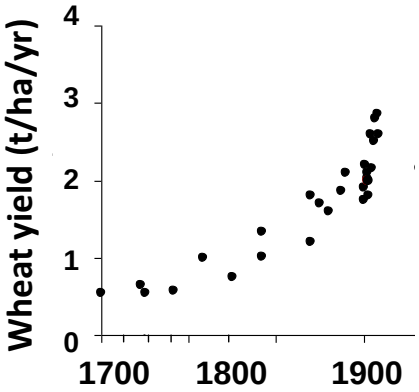
Feed the city : agricultural and industrial revolutions





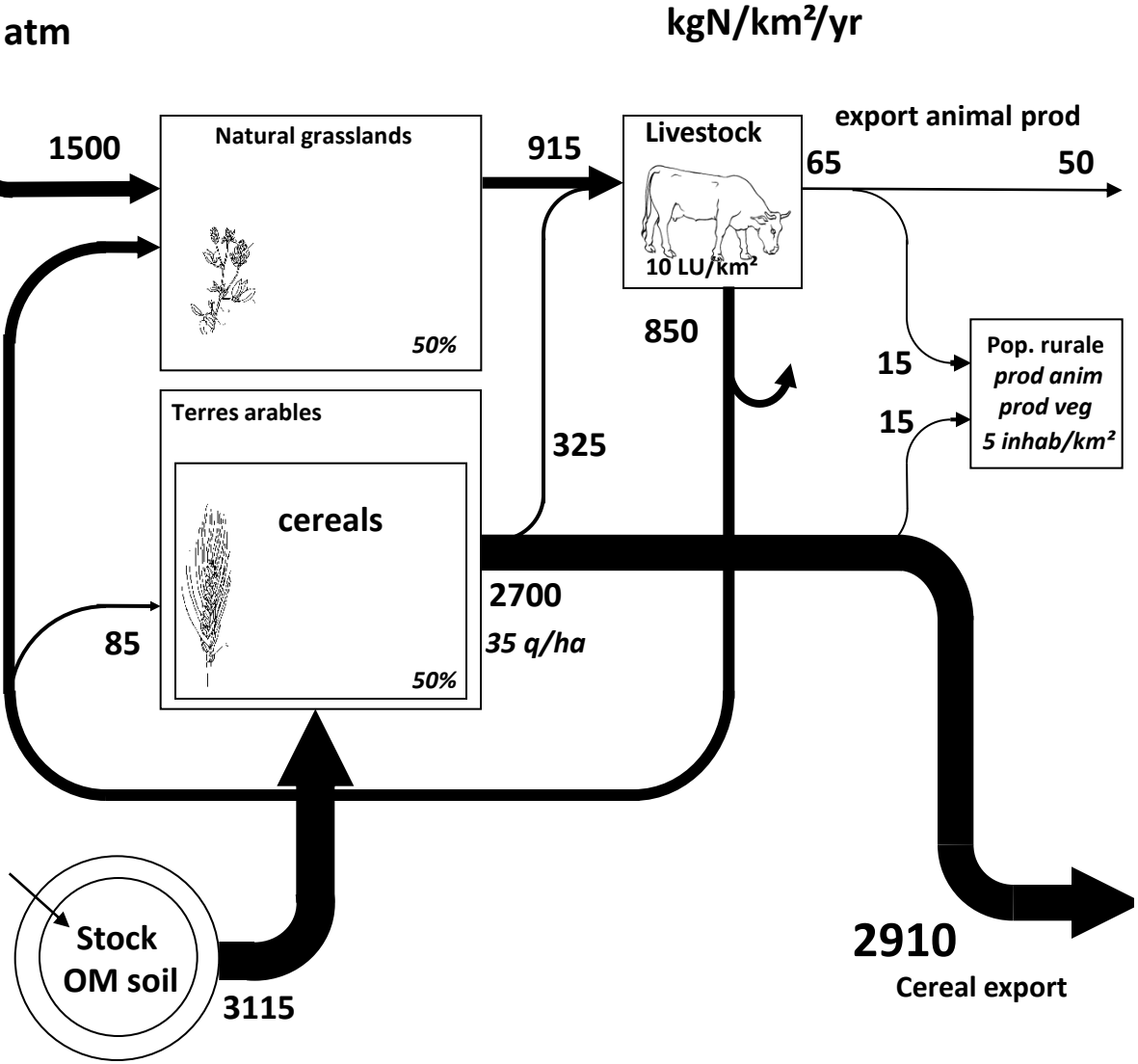


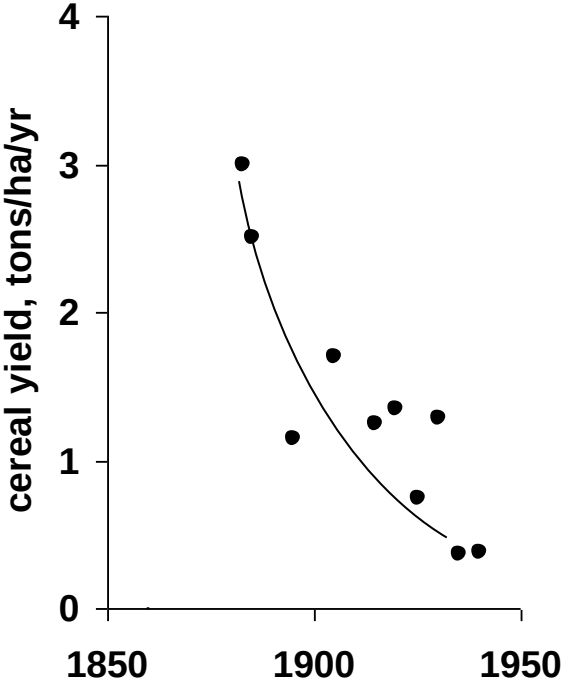
- Increase in cereal yields : more cultivated lands + increase N inputs to soil through legumes N fixation
- Rural exodus: individual property, suppression of common pastures
- Cheap wheat price : more important offer + free exchange with the USA



« Mining agriculture » of the American Middle West

Kansas Family farm at the end of the XIXth : 120 ha



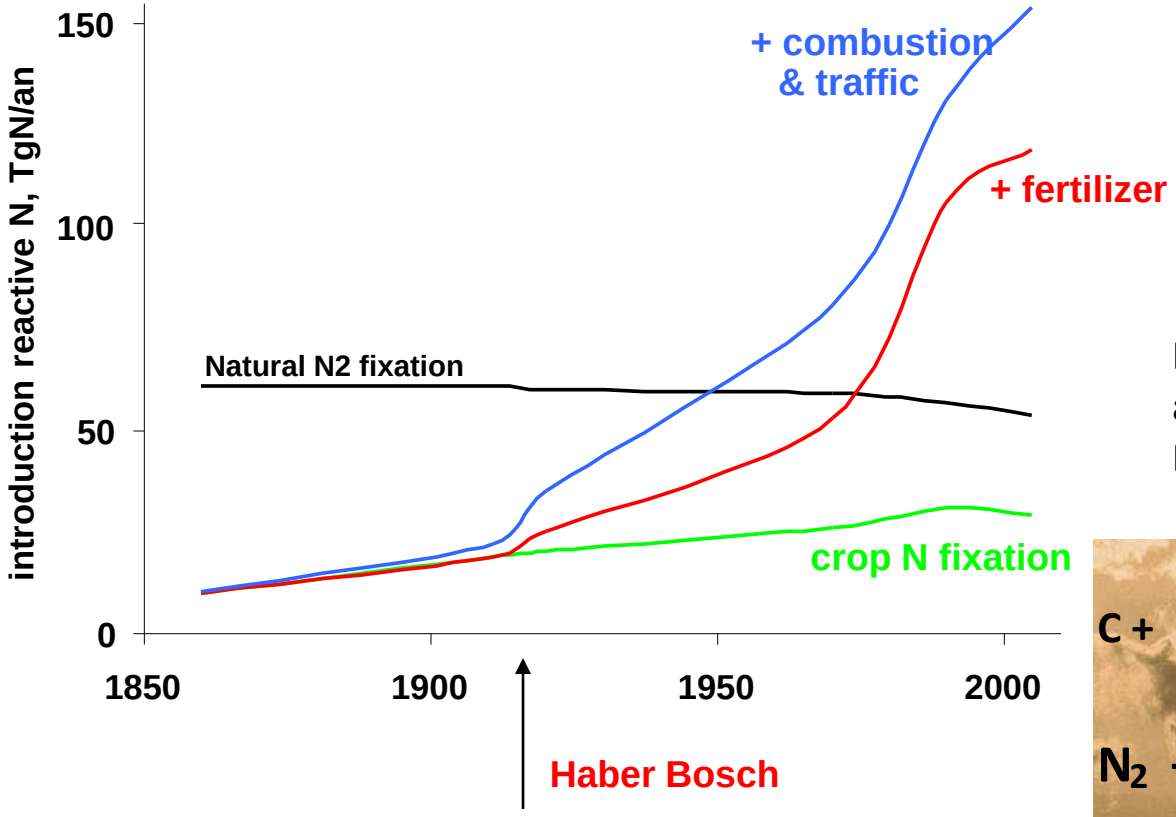


Cunfer et al, 2010

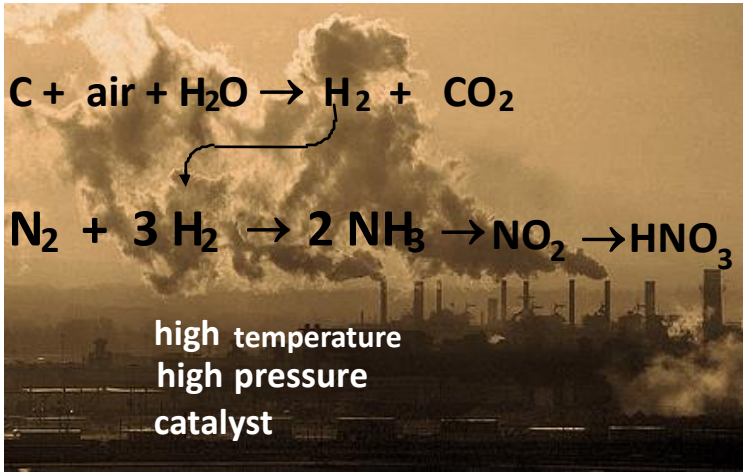
Golden Door (Nuovomundo) Crialese, 2007

Sources of reactive nitrogen at the global scale

From 1950's Nr introduction into the biosphere through human action exceeds that by natural processes …

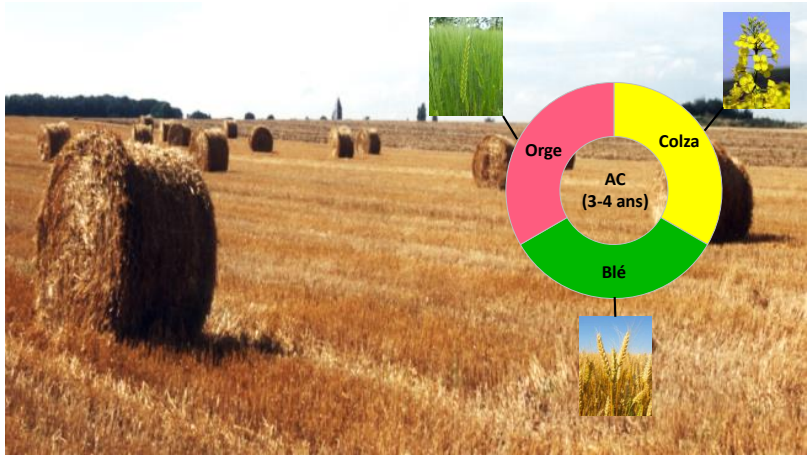


Industry is able to tap into the atmospheric inert N stock to inject Nr into the biosphere cycle

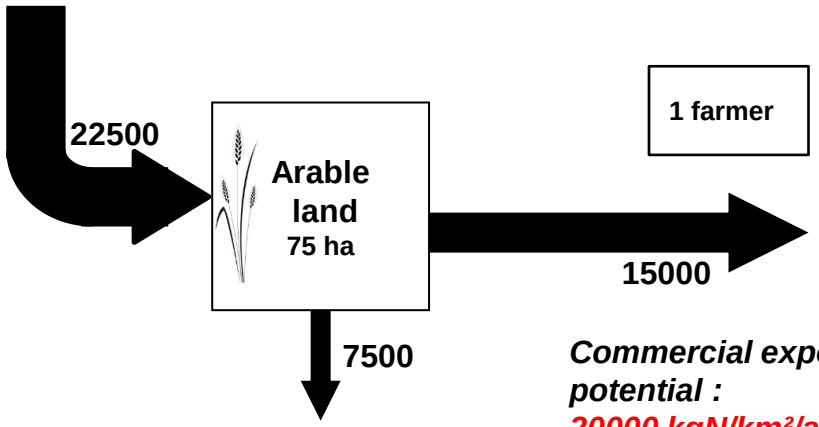


Industrial agriculture (2nd half of XXth century)

The use of synthetic fertilizers allows agricultural simplification (2-3 yrs crop rotation without legumes) and specialisation and increases by 10-20 the commercial export potential of 1920

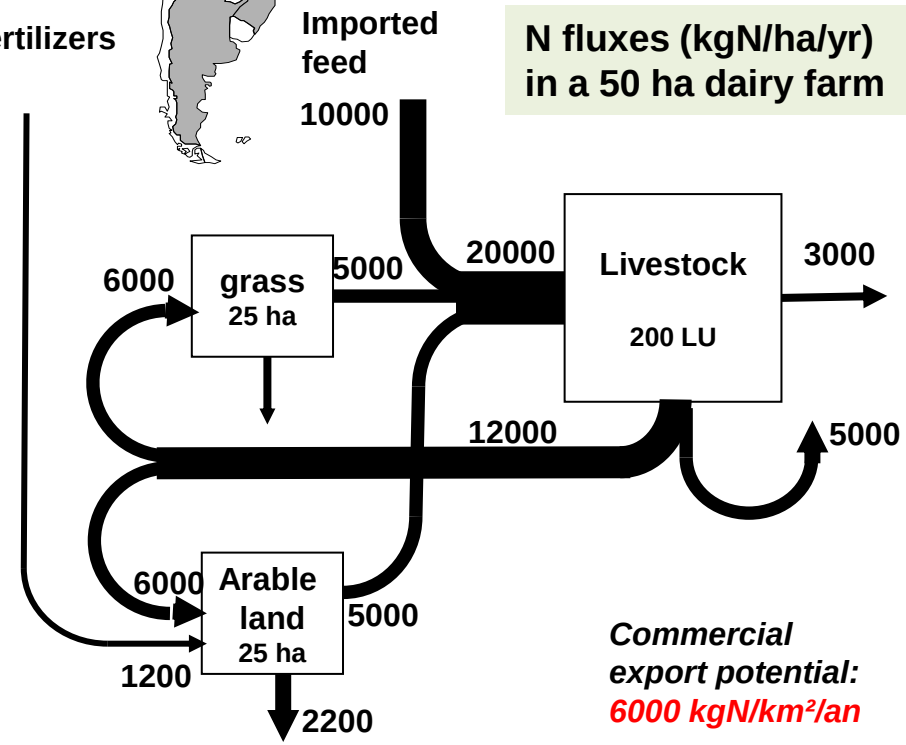


N fluxes (kgN/an) in a 75 ha cash crop farm



Commercial export potential : 20000 kgN/km²/an

N fluxes (kgN/ha/yr) in a 50 ha dairy farm

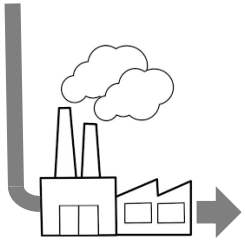


Commercial export potential: 6000 kgN/km²/an

The N cascade in environment

Billen et al. 2013, Cahiers de l'Agriculture

Atmospheric contamination



Haber-Bosch

N_2O

NH_3

Nr

N_2O

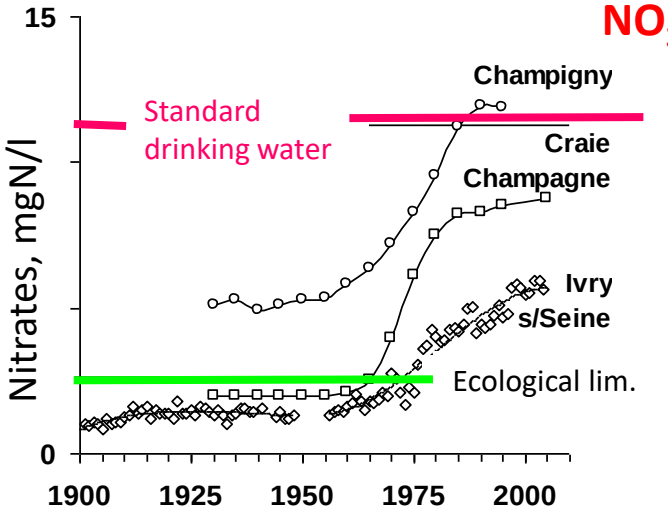
Riparian areas

NOx

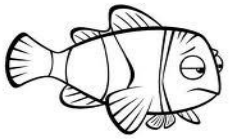
Urban areas

NO_3^-

Groundwater contamination



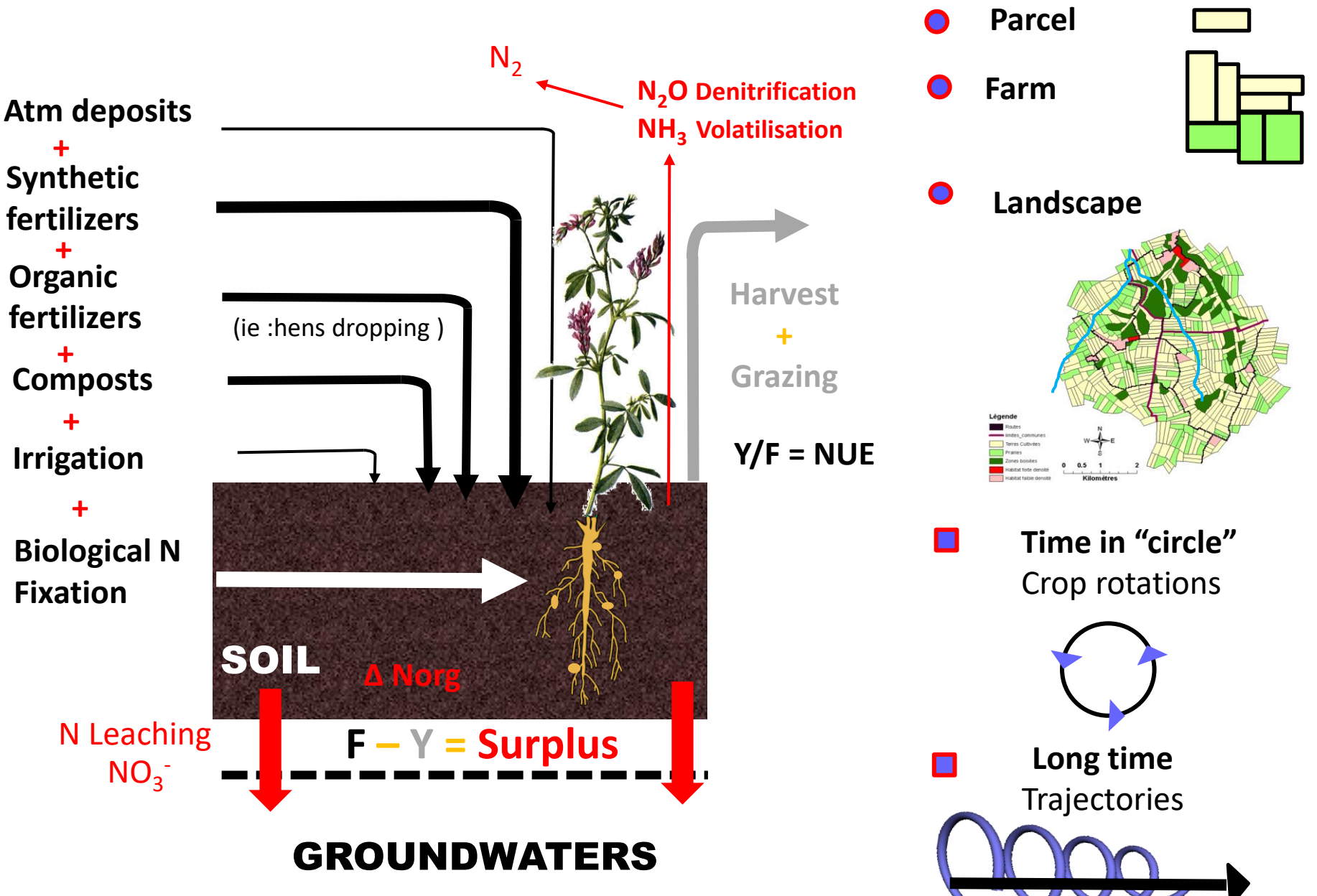
Surface water contamination



Coastal eutrophication

Evaluation of the agro-environmental performances of modern agricultural systems : N use efficiency (NUE) and N surplus

The Soil Surface Balance (SSB) approach



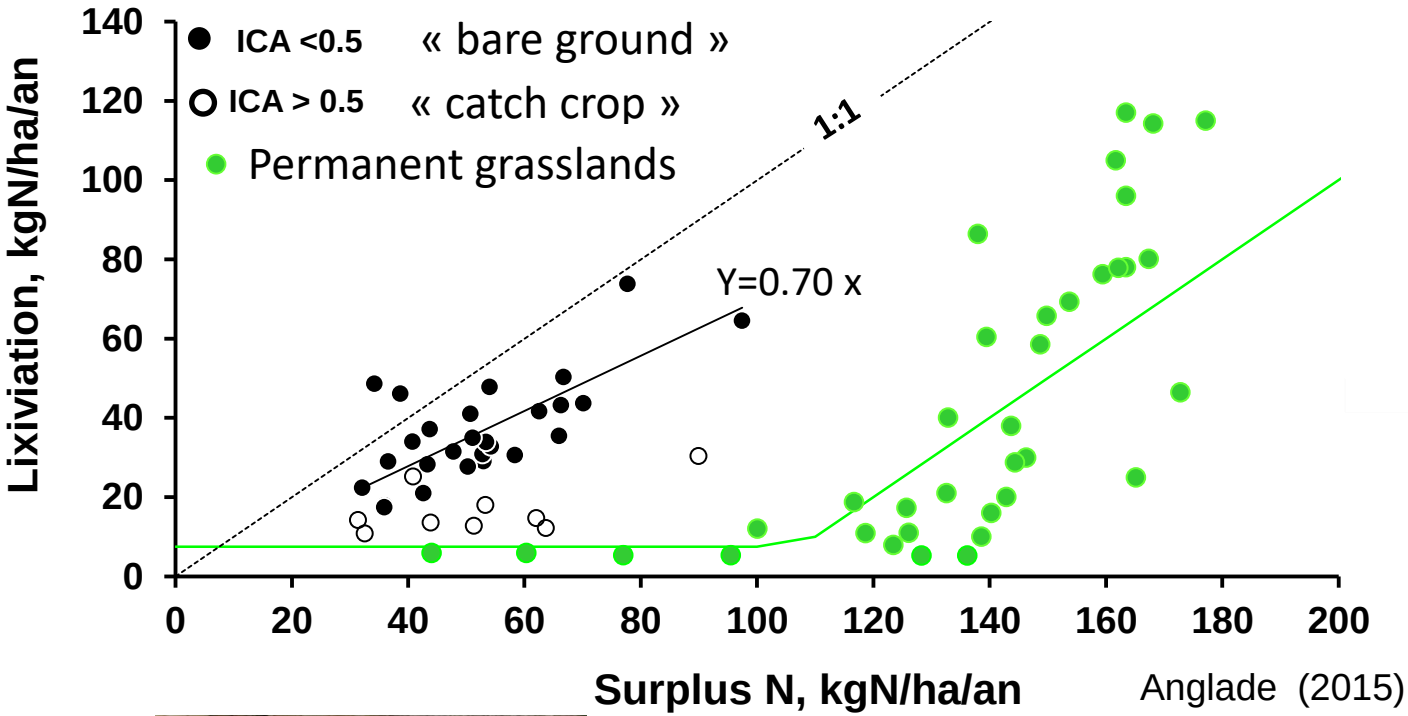
- Parcel
- Farm

- Landscape

- Time in “circle”
  Crop rotations

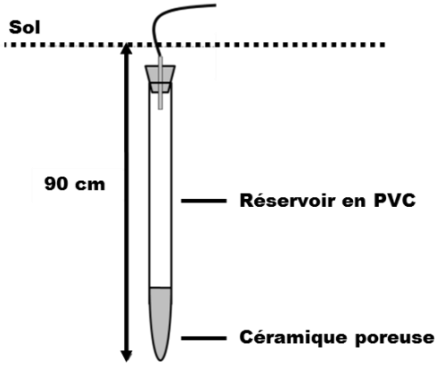
- Long time
  Trajectories

From surplus to N leaching : measurements of N leached fluxes



Anglade (2015)

Ceramic cups



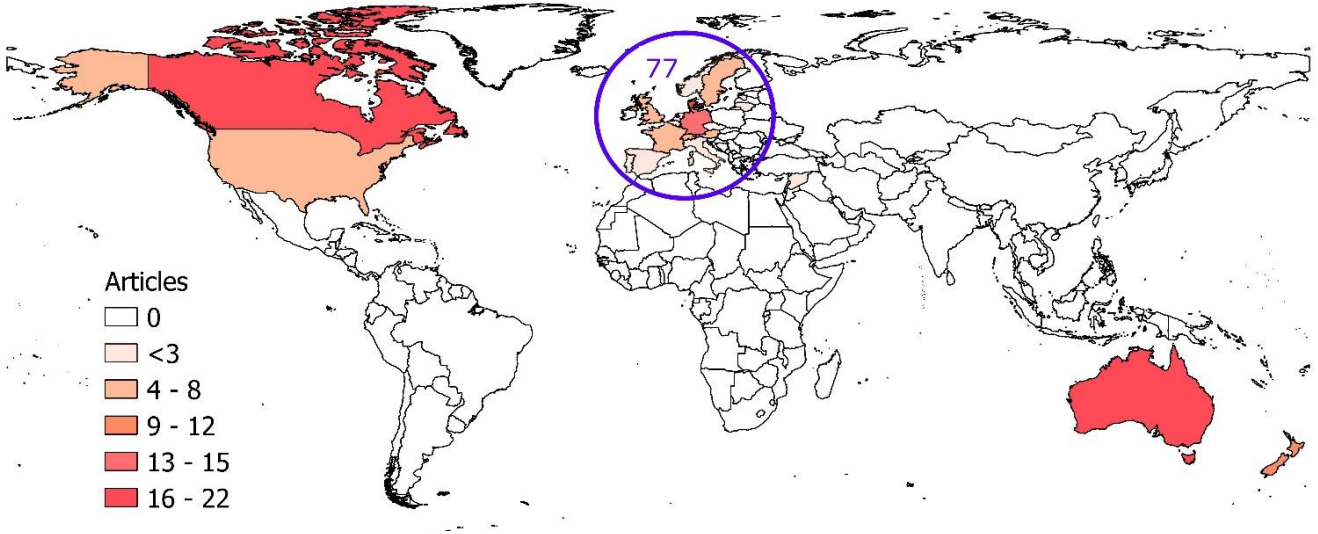
Drains

Coring

- On arable land ~70 % surplus is leached
- Cover crops reduce N leaching (depending of the occurrence of spring crops)
- Grasslands : Low N leaching for surplus< 120 kgN/ha/an (OM pool stock)

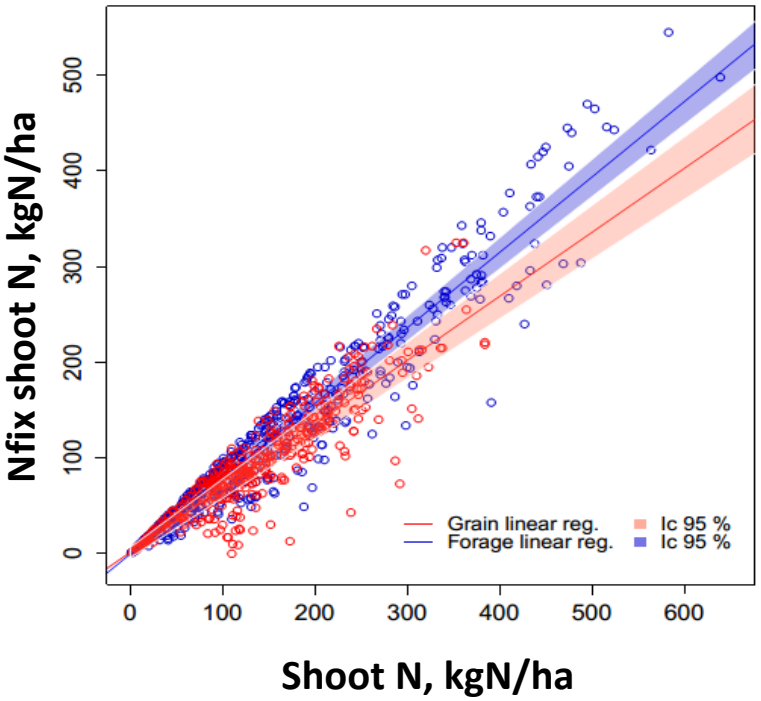
Lysimeters

Biological Nitrogen Fixation (BNF) : a meta-analysis



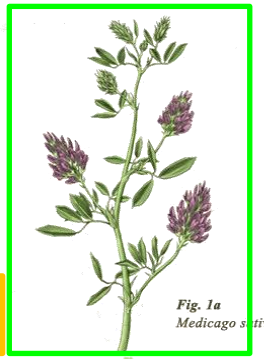
- A dataset of 170 articles [1986-2012] on shoot Nfix (isotopic measurments)

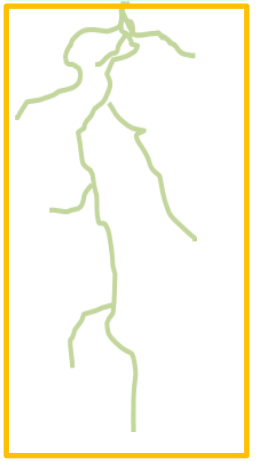
Anglade et al. (2015) ECOSPHERE



✓ **A reliable estimate by simple linear relationships with N yields**

$$\mathbf{Nfix}_{(kgN/ha/yr)} = \left[\alpha_{cult} * \frac{Yield}{NHI} * \beta_{cult}\right] * \mathbf{BGN}$$





Below Ground N = Nfix $_{roots}$ + Nfix $_{rhizodep}$

Fodder → **1.7** (41 ± 15 % N_{tot})

Pulses → **1.3** (26 ± 10 % N_{tot})

BNF estimates in fodder and pulses in northern France

Lentils

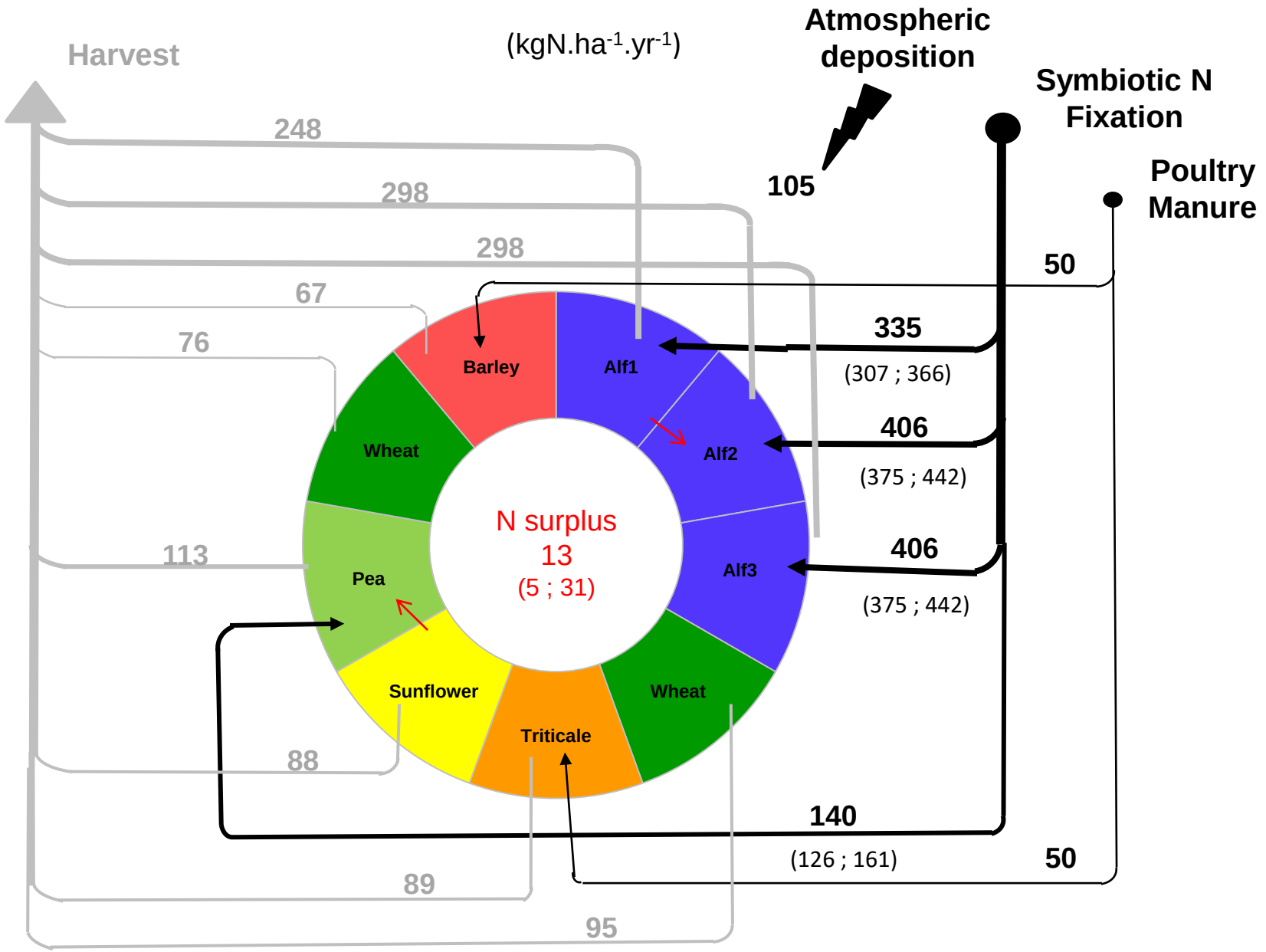
Faba bean

Alfalfa

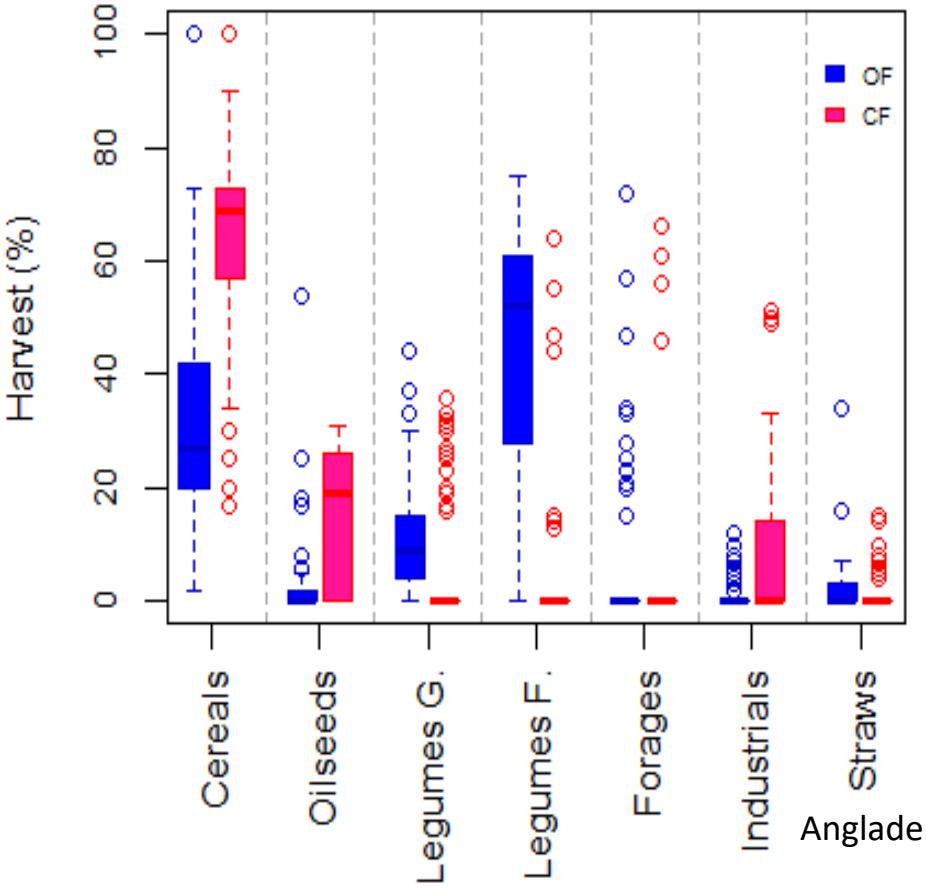
	Yield	Shoot N	Nfixtot	Nfix net
	t/ha	kgN/ha	kgN/ha	kgN/ha
Lentil	0,8	32,8	41	8
	2	82	101	19
Faba bean	2,5	95	117	22
	5	190	232	42
Alfalfa	8	248	310	62
	14	434	543	109

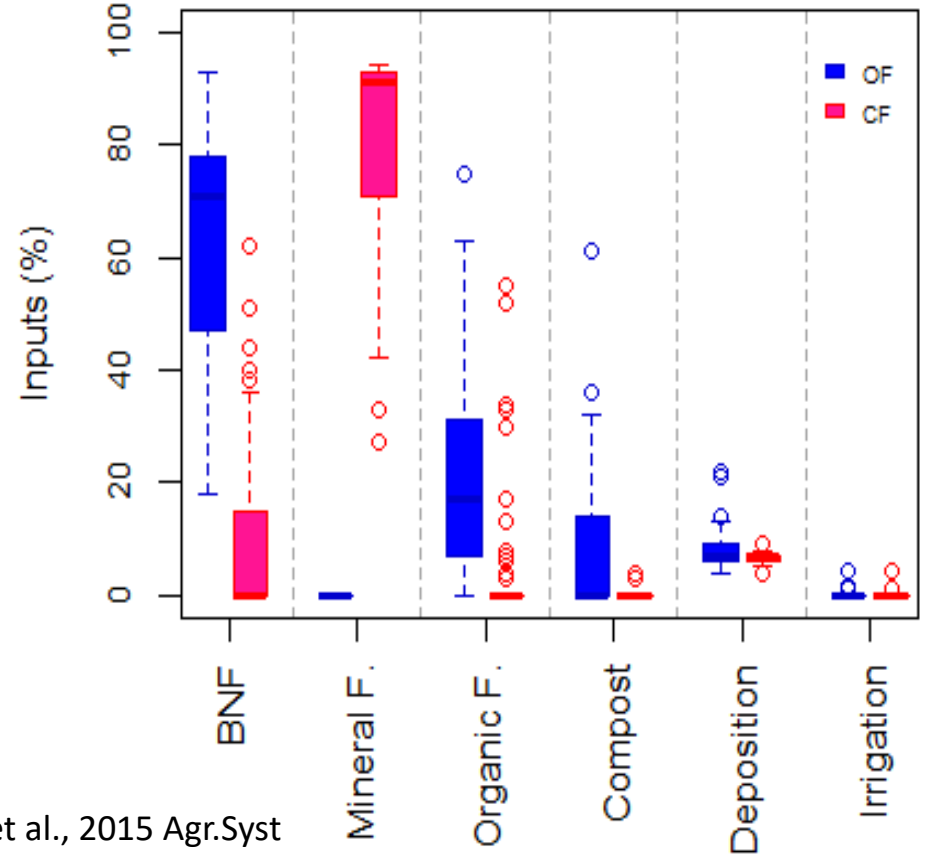
→ **Fodder legumes are able to fix more N than pulses**

BNF estimates in fodder and pulses in Organic Farming (Fr)



Organic Farming performances in the Seine Watershed (Fr)

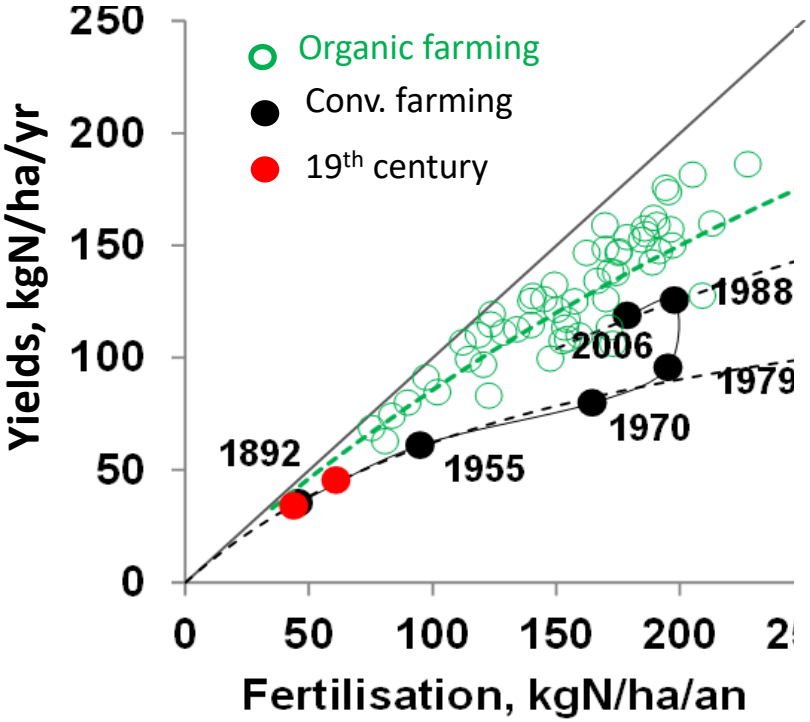




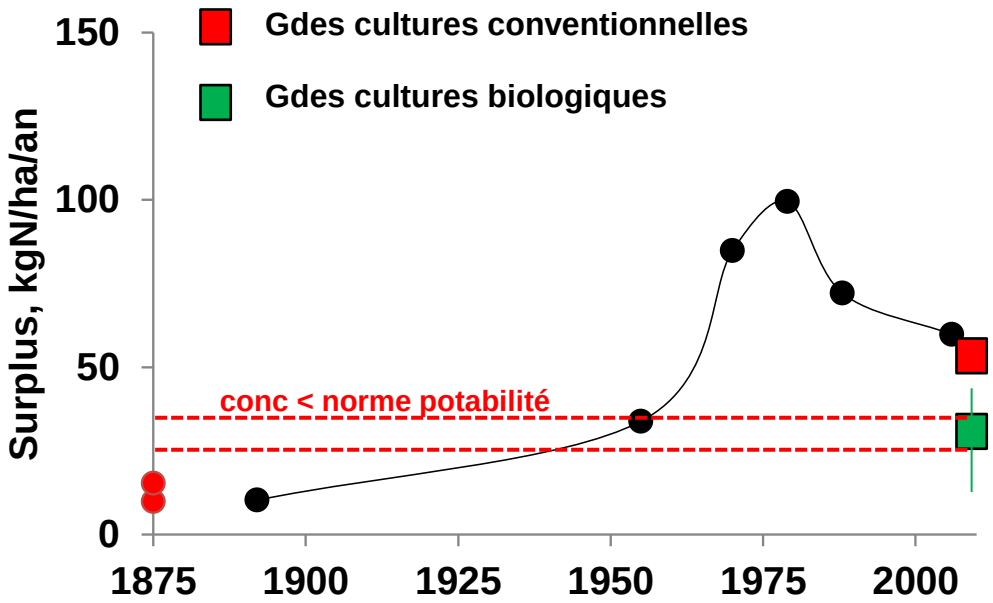
Anglade et al., 2015 Agr.Syst

- ✓ **68 cultural systems (12 mixed crop and livestock/ 56 cash crops**
- ✓ **Org Farm: 70 % of inputs from BNF / Conv Farm : 80% inputs from fertilizers**
- ✓ **Forage legumes account for 52% of harvested proteins in organic farming**

Organic Farming: turning back or moving forward ?

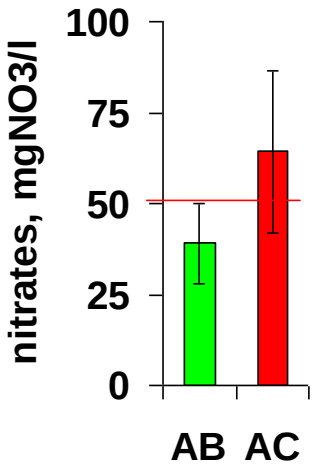


Anglade et al., 2015 Agr.Syst



Benoit M. (2014)

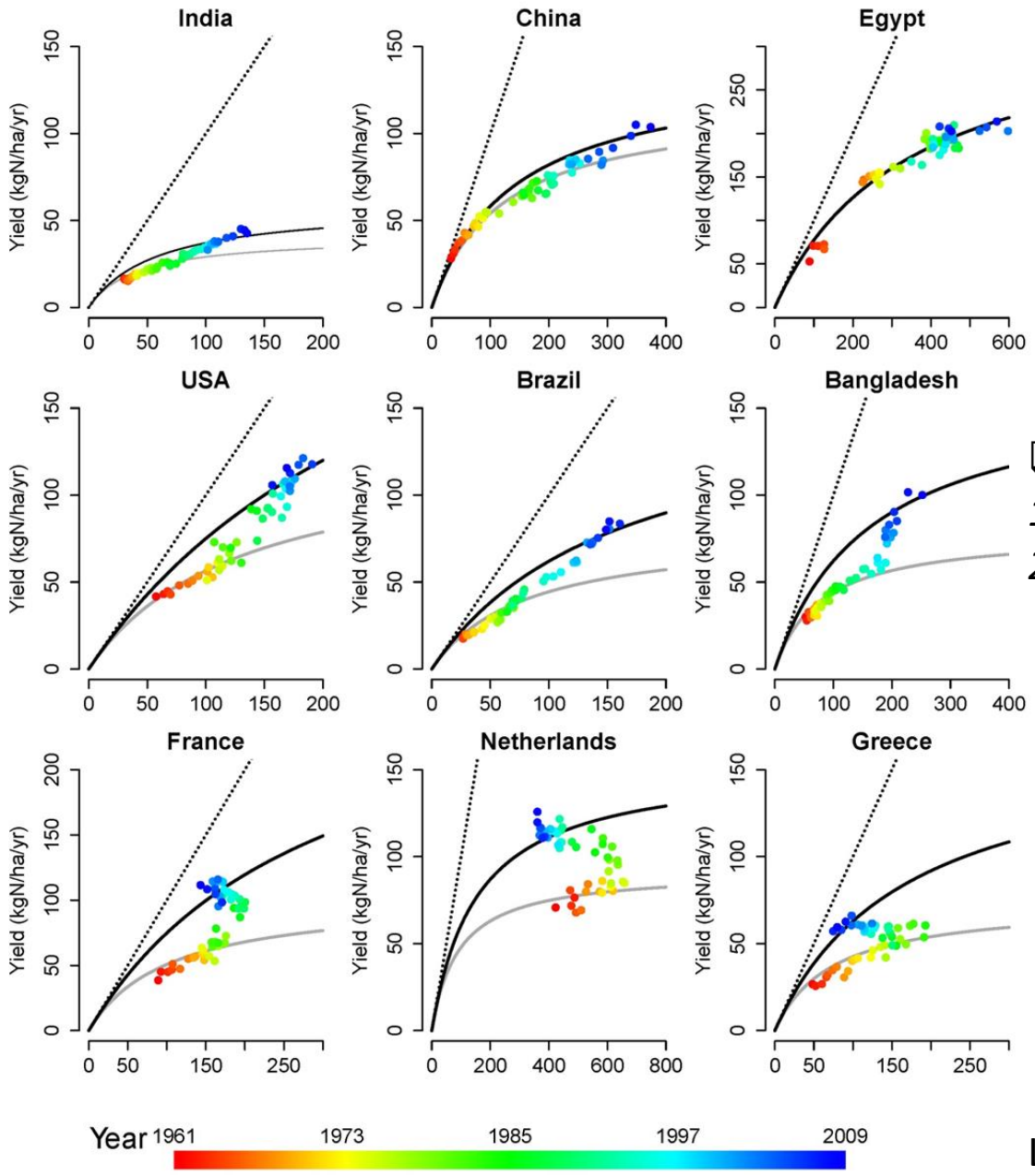
Ceramic cups
ABAC network



A diversity of pratices , and better yields than in the XIXth century.

At the rotation scale (taking into account legumes), yields of OF are closed to those of conventional farming

50 years trends of NUE at the global scale



- ❑ Type 1 monophasic

Regular increase :
fertilisation + / yield +

- ❑ Type II bi-phasic pattern

1960-1990 : fertilisation + / yield +
2000: higher Ymax

- ❑ Type III bi-phasic pattern

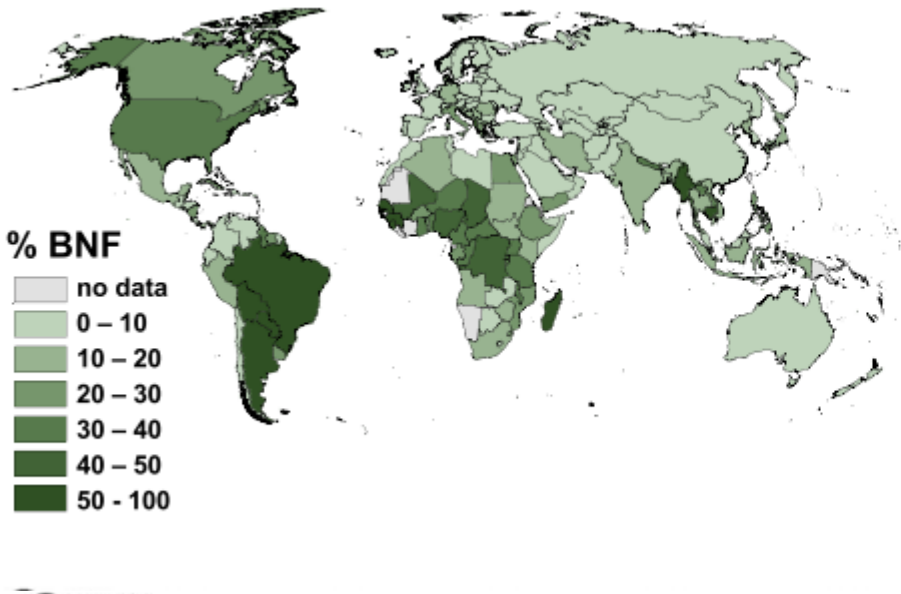
1960-1975: fertilisation + / yield +
1980-2010 : fertilisation + /yield –

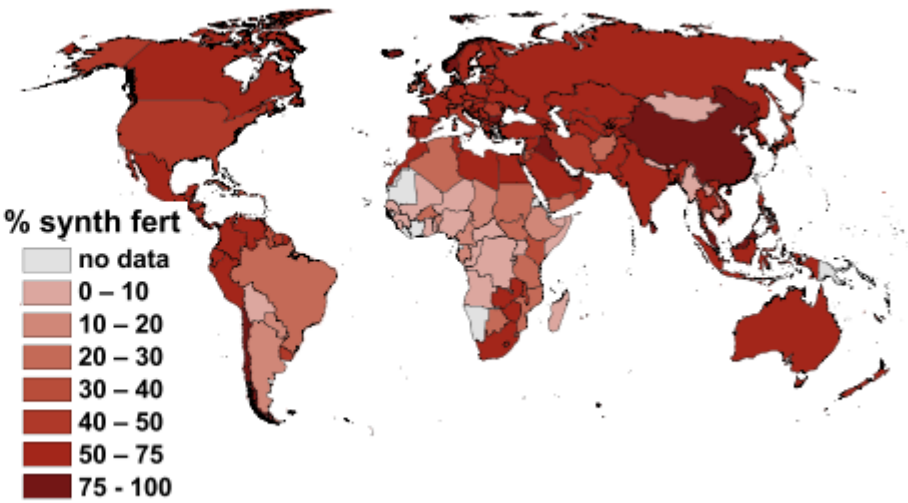
European Nitrate Directive (1991)

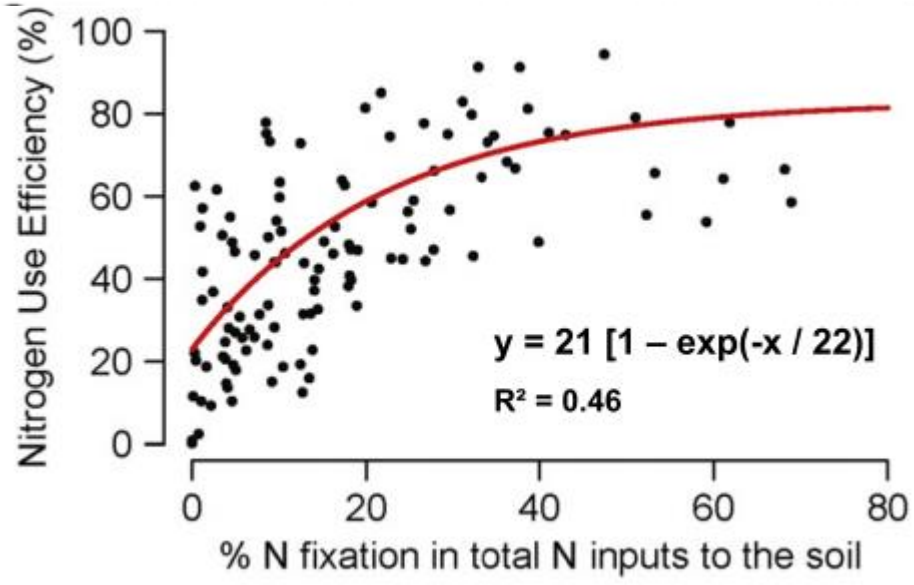
Lassaletta et al. (2014) EnvResLet

BNF inputs to croplands at the global scale

Total N inputs to croplands







Lassaletta et al. (2014) EnvResLet

A considerable margin of maneuver to reintroduce legumes crops and fodder to substitute fertilizers massive inputs and increase N use efficiency !

Conclusions

❑ N cycles in traditional agricultural systems were balanced thanks to a narrow accuracy between animal and crop production. The presence of legumes compensate harvest through BNF.

❑ The surabondance of reactive N is recent and has caused several environmental dammages

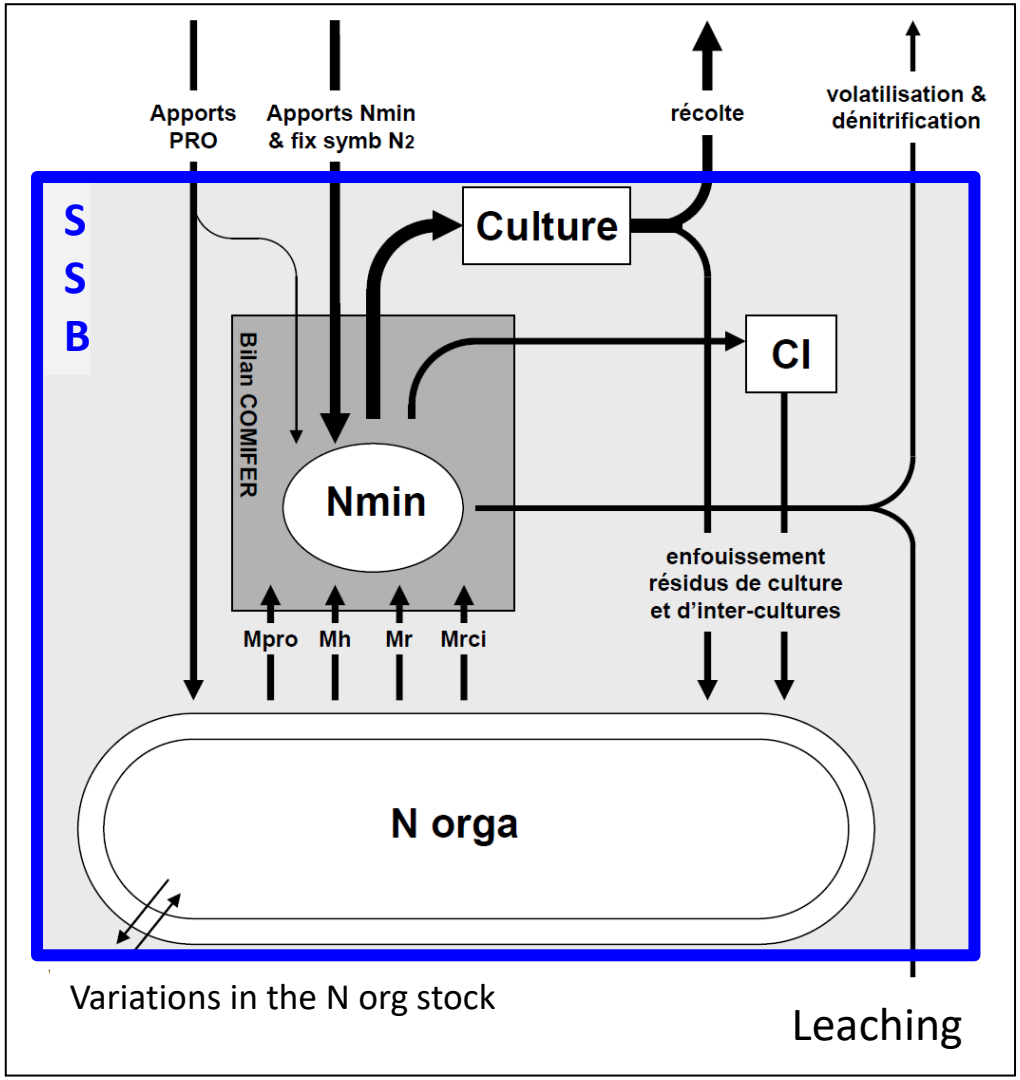
❑ BNF could substitute synthetic fertilizers

❑Thanks to legumes, organic crop systems have better agronomical performances than conventional systems (increase NUE, lower total inputs, high protein production,water quality).

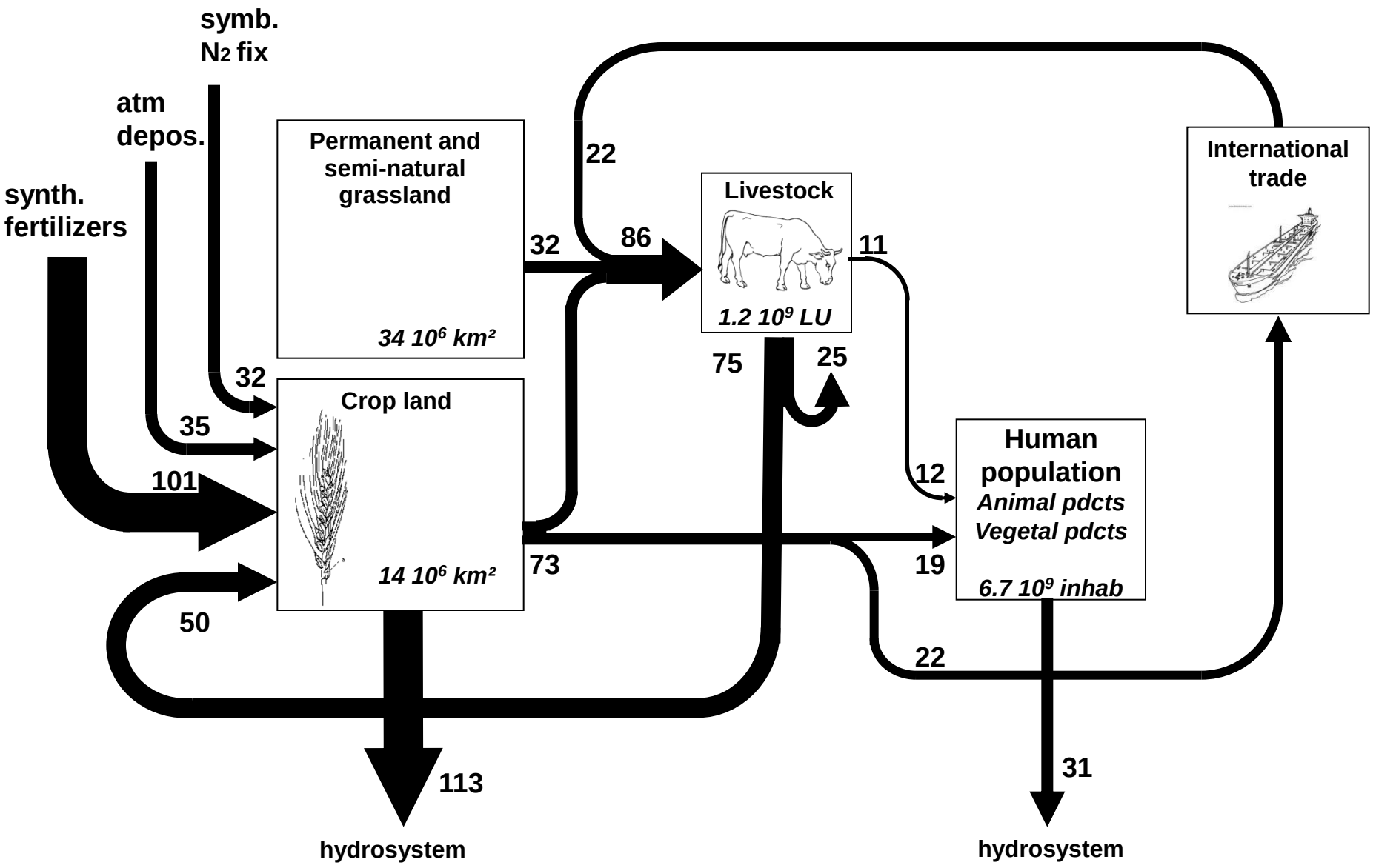
❑ We should encourage more mixed farming approach, thus reversing a 50 years trend to regional specialization into either crop or livestock farming.
Fodder legumes are a great source of protein for animal feed.
Without animal, Nr from legumes could be in excess and cause environmental dammages too.

❑ N inputs by BNF deserve peculiar attention in optimising inputs. We need to better assess below ground N for legume species, including rhizodeposited N

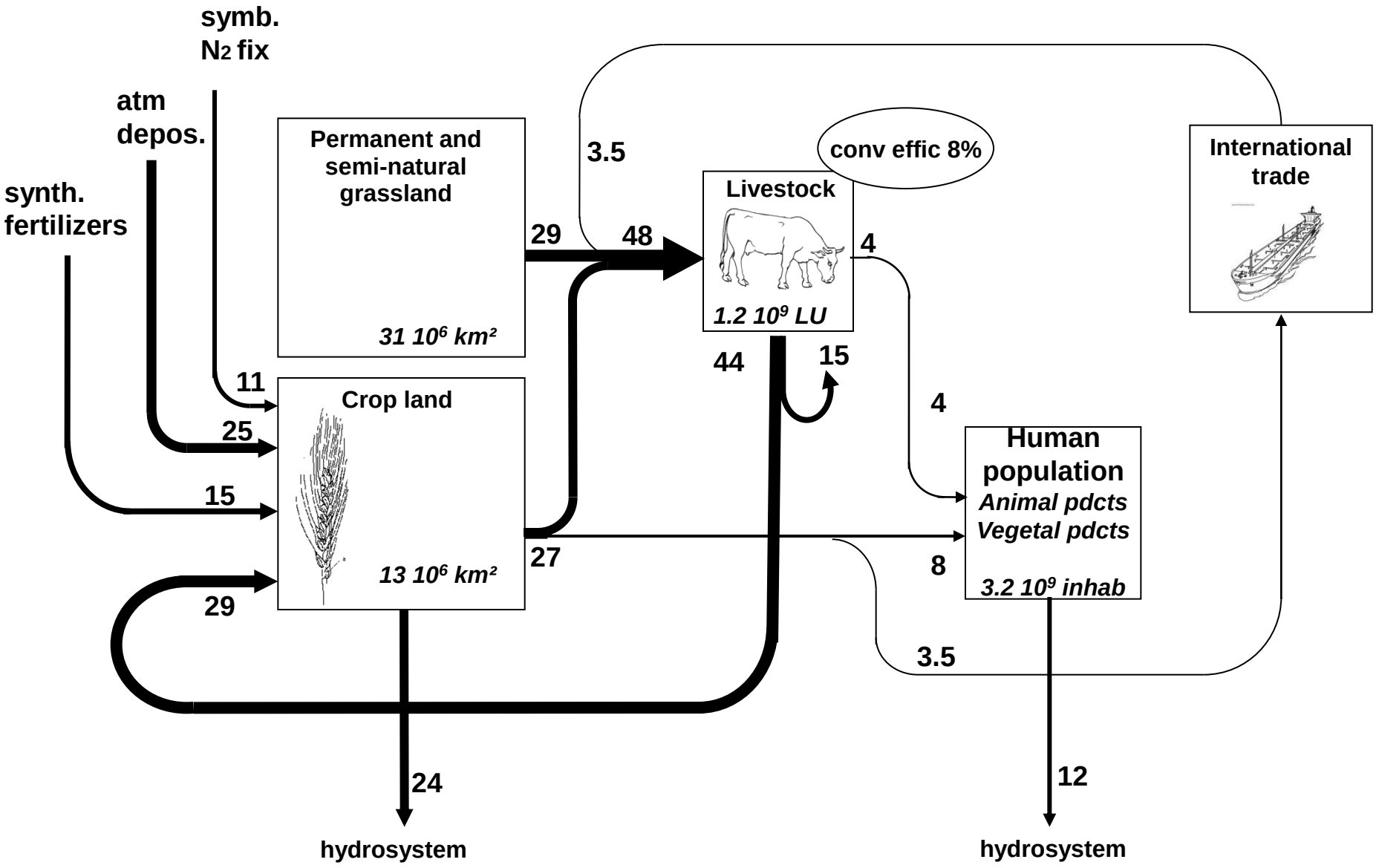
Mineral N balance and soil surface balance



World Agro-Food System, 2006-2010 (TgN/yr)



World Agro-Food System, 1961-1965 (TgN/yr)



A complex N cycle with lots of redox transformations
Unreactive atmospheric dinitrogen (N_2) is the main N reservoir