Bridging the gaps between ecological principles and actions for designing agroecological farming systems and landscapes

Michel Duru

http://grassland-research.com

http://www.toulouse.inra.fr/agir

Cartoons from Simon Kneebone

In Darnhofer et al 2012

INRA SCIENCE & IMPACT

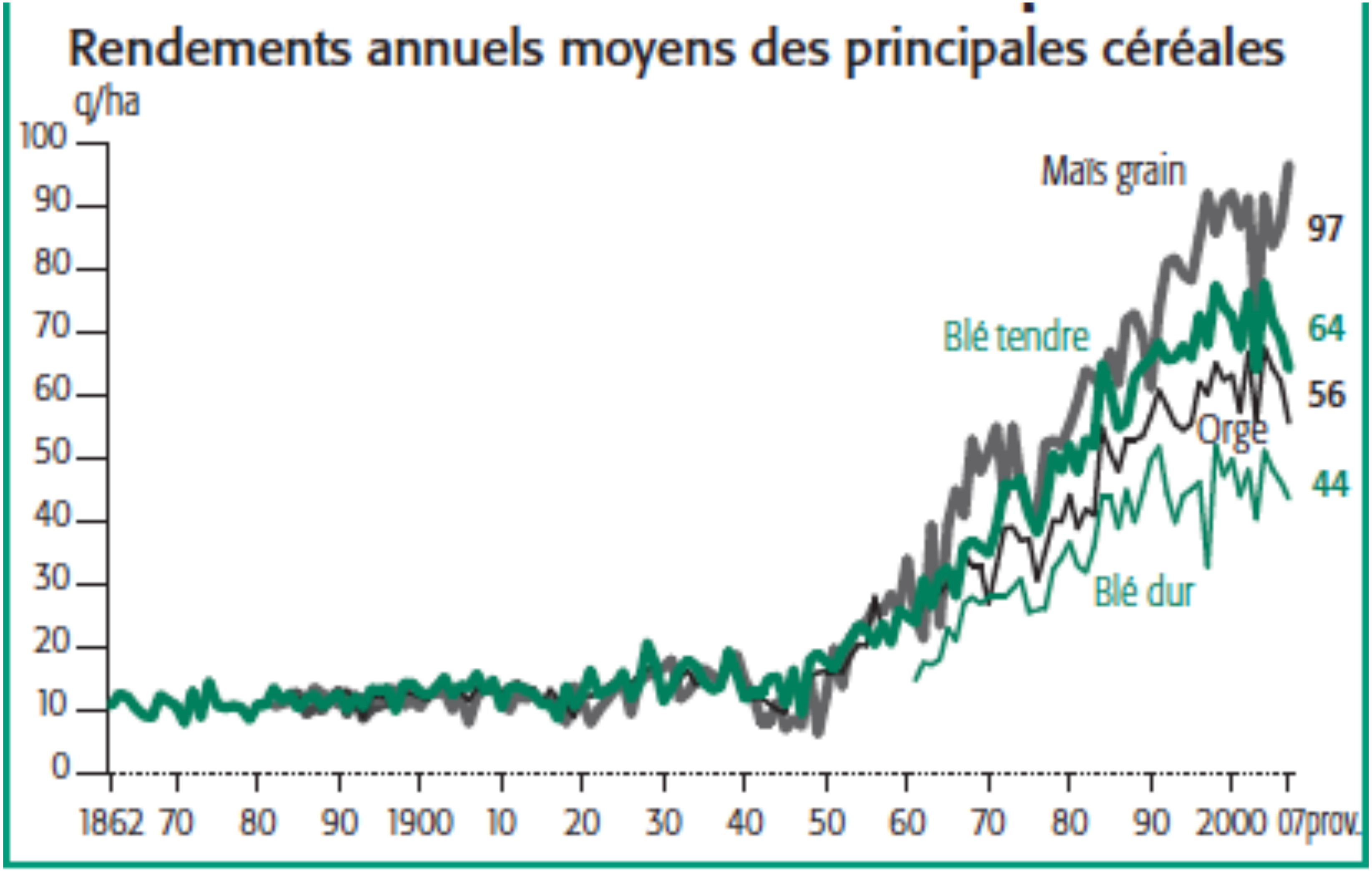
AGIR UMR 1248 INRA / INPT

AGroécologie - Innovations - TeRritoires

Outline

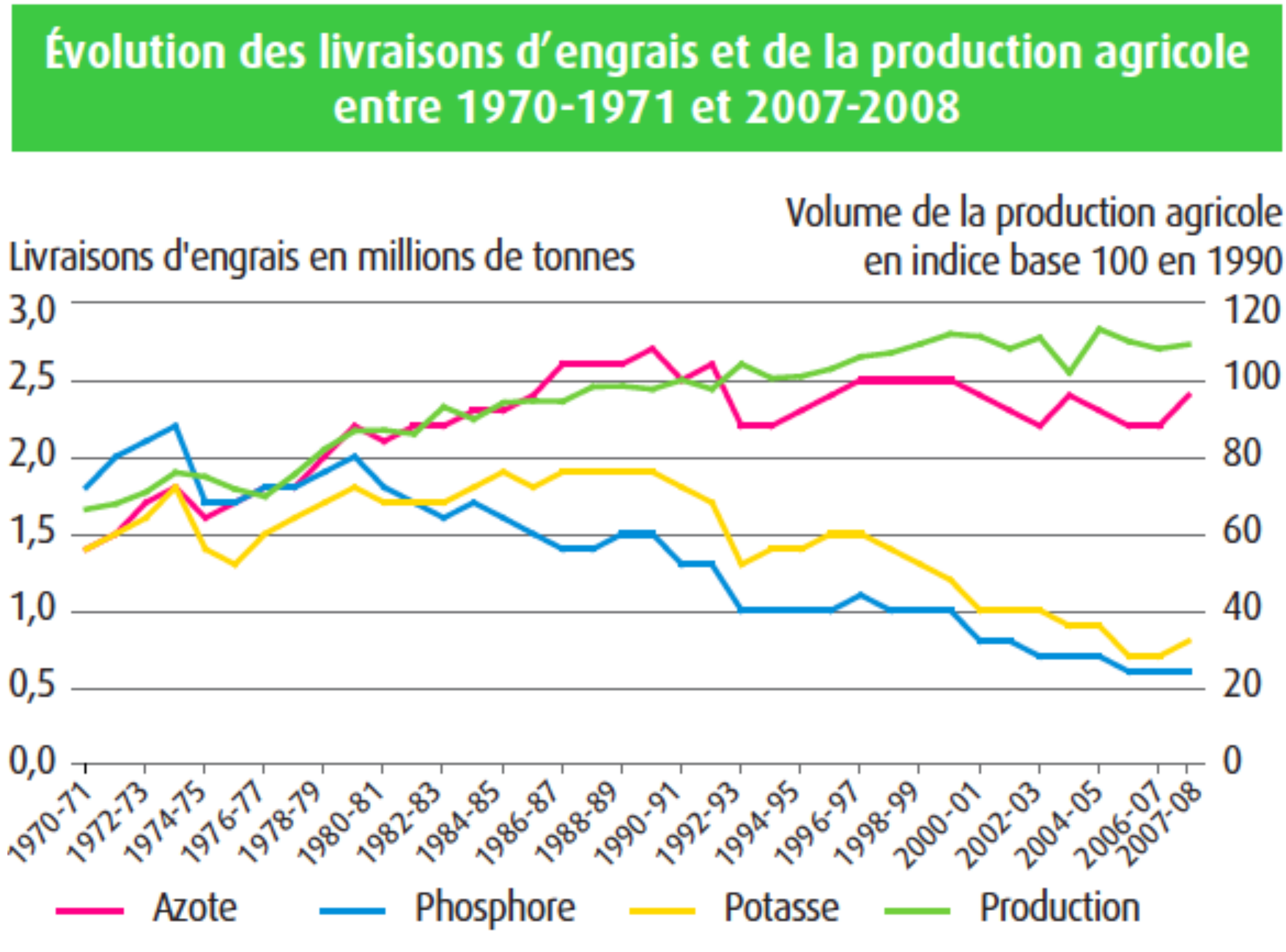
- Main trends in agriculture and their impacts on the environment
- Pathways for increasing sustainability of agricultural systems
- Issues and frameworks for promoting strong ecological modernisation of agriculture
- Examples
  - Grassland-based livestock systems
  - Crop mixtures
  - Crop-livestock at territory level
  - Agroforestry
- Conclusion

A large increase in agricultural production since the last decades



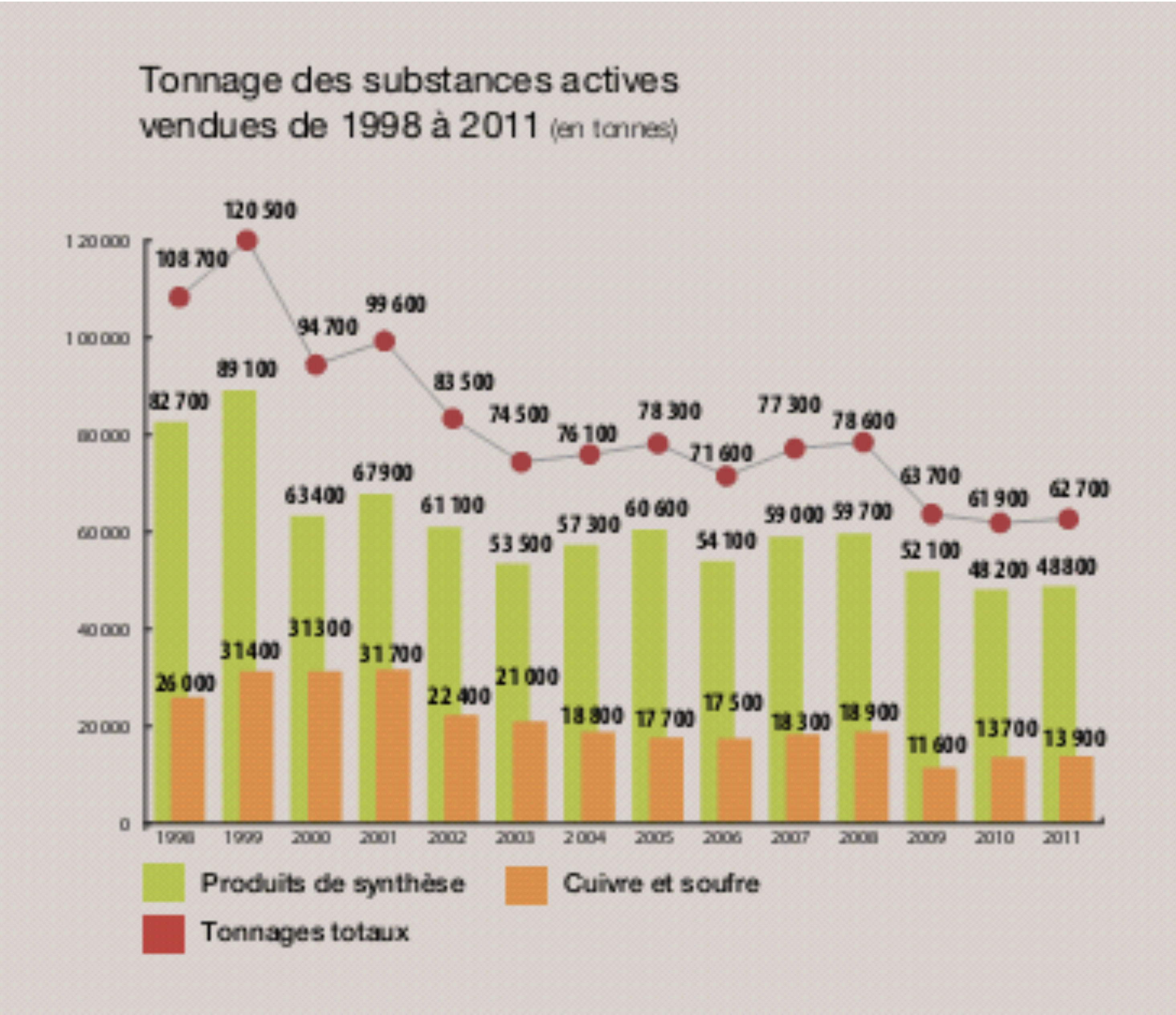
Source : Agreste - Statistique agricole annuelle

Allowed by large amount of fertilizers



Source : MAAP (Agreste) - Unifa – Insee, comptes de l'agriculture.

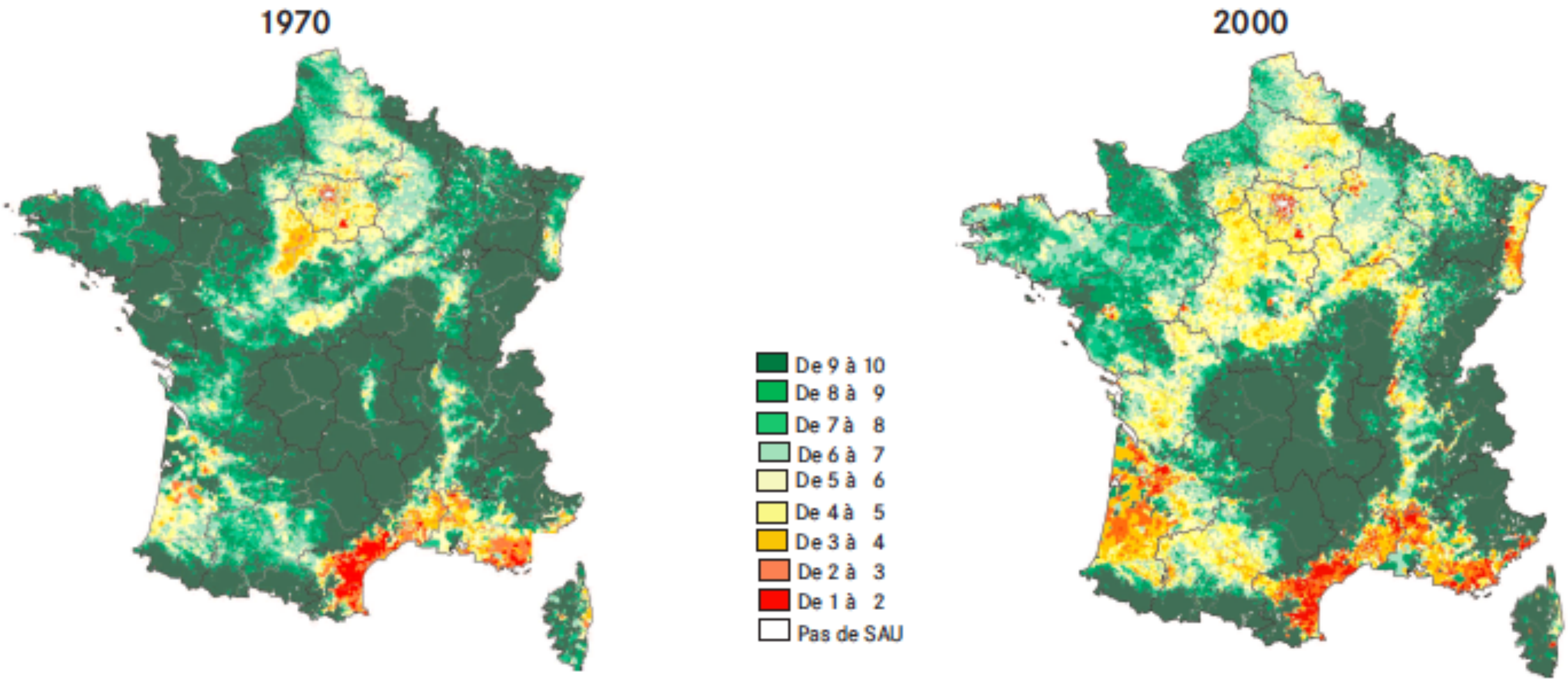
and pesticides



Source : UIPP

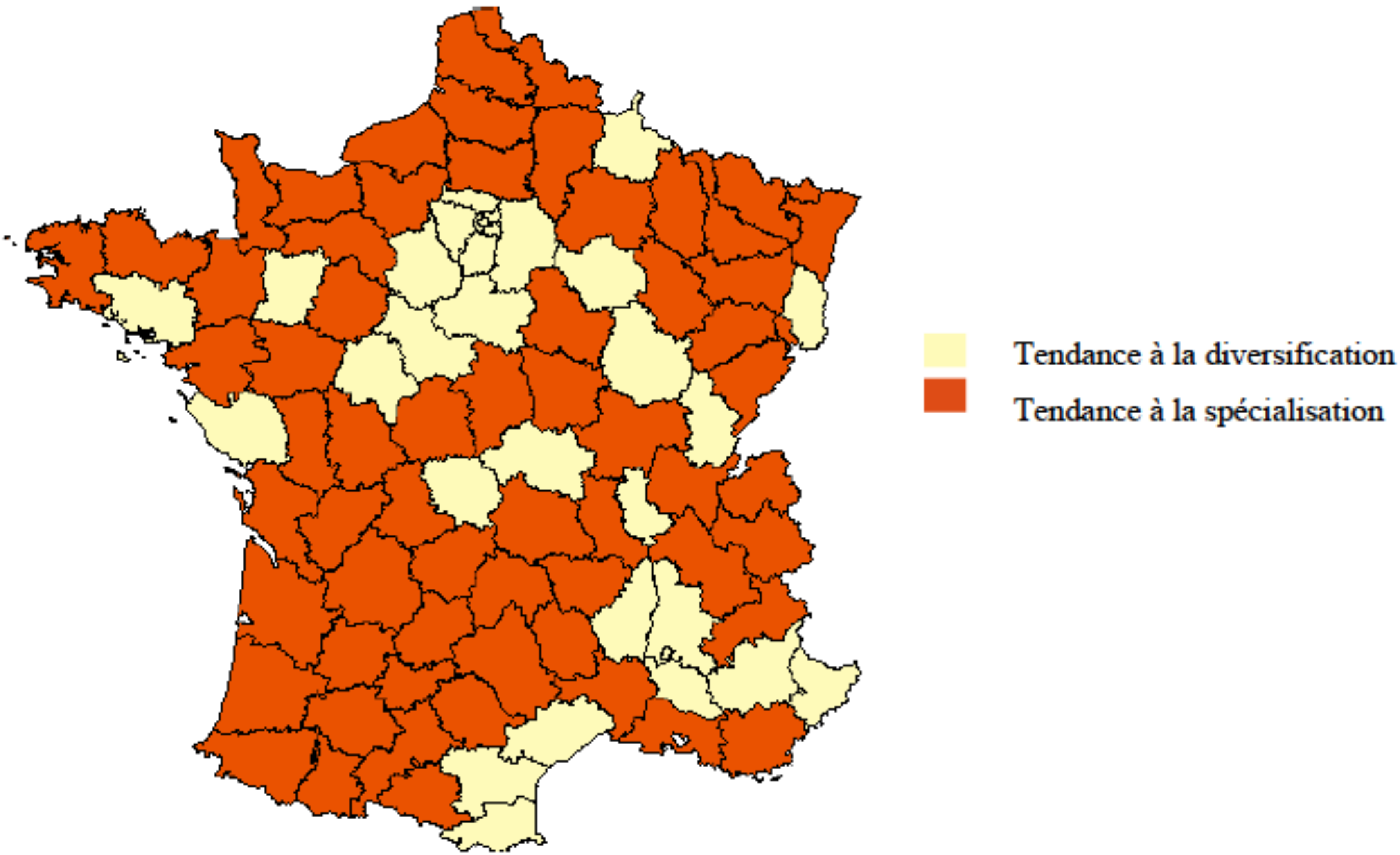
Accompagnied by: (1) farm specialisation

- Indicateur de diversité d'assolement par commune en 1970 et 2000

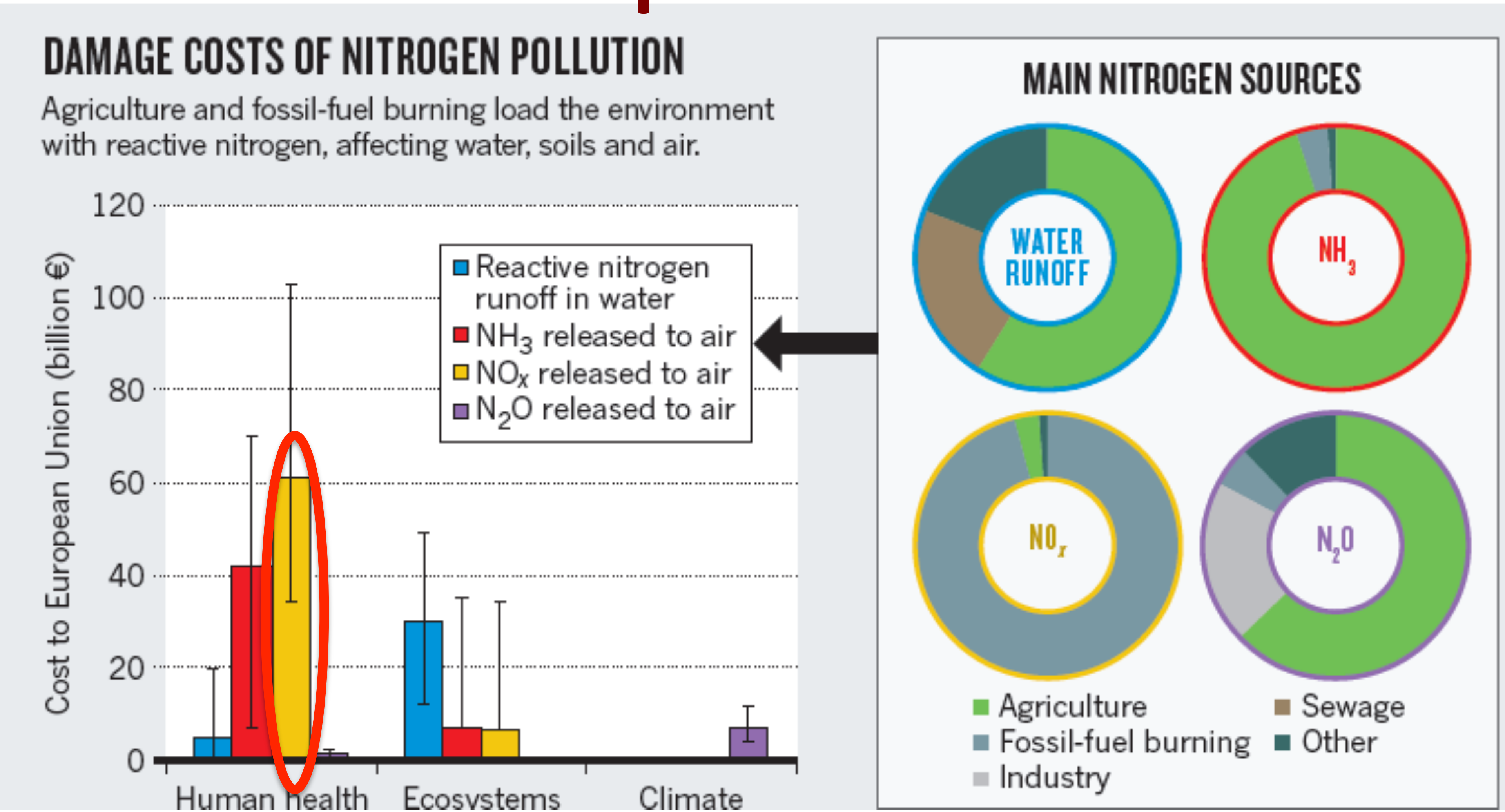


Accompagnied by: (1) region specialisation

Carte 2 : Evolution de l'indice de spécialisation au niveau départemental (1990-2006)

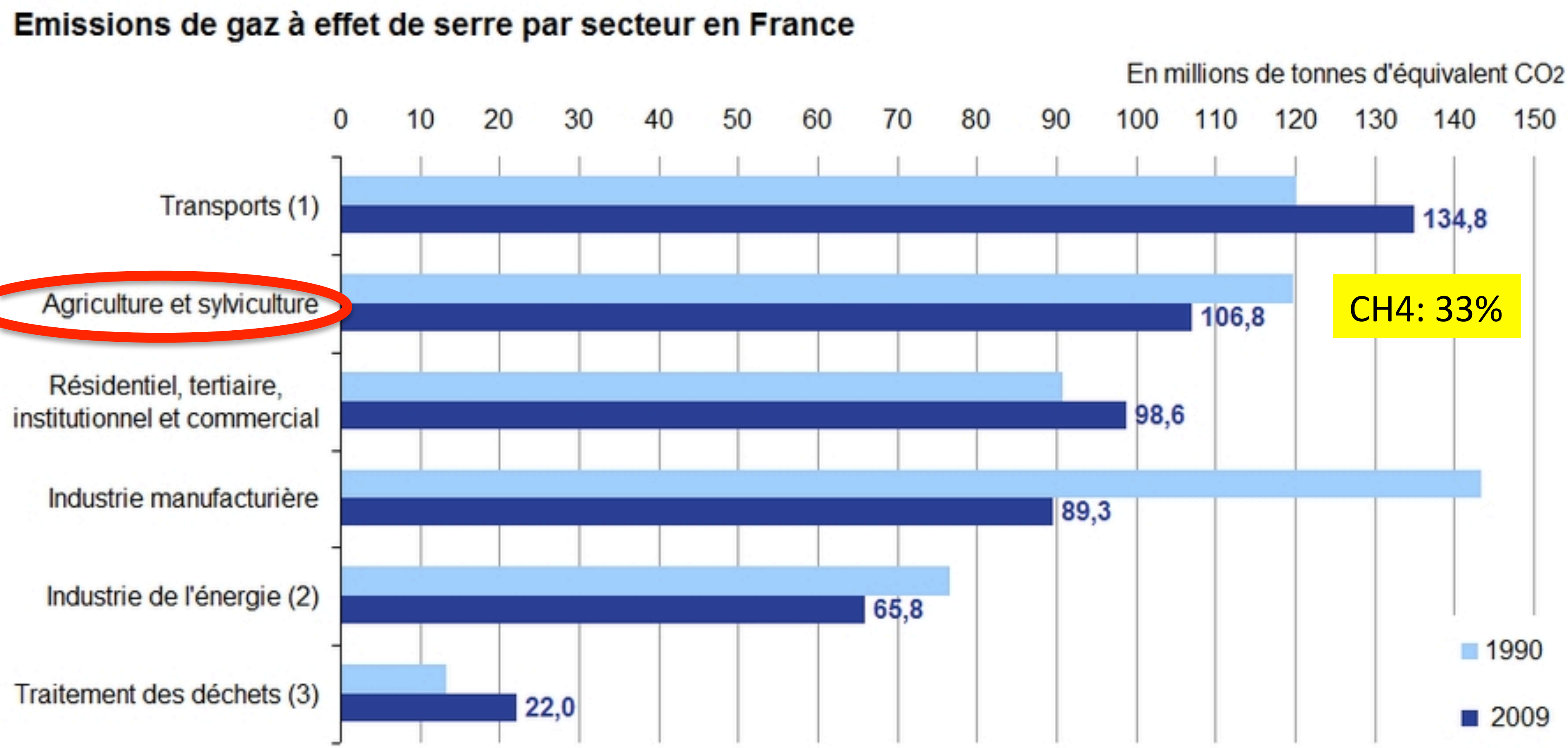


But having environmental impacts: N pollution



Sutton M (2011) Too much of a good thing. 5–7.

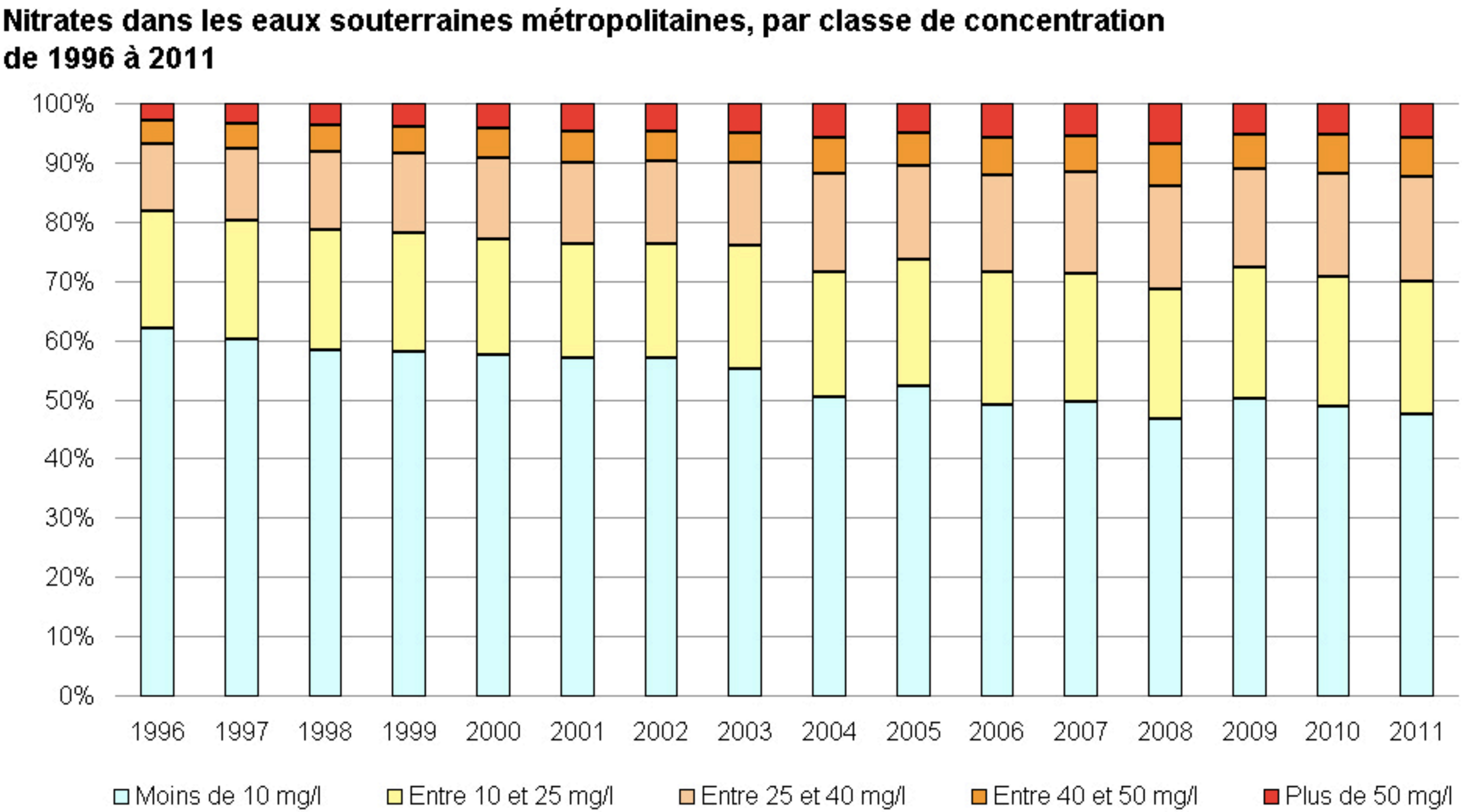
But having environmental impacts: GES



Notes : périmètre du protocole de Kyoto (Métropole, Guadeloupe, Martinique, Guyane, La Réunion, Saint-Martin, Saint-Barthélémy), hors UTCF (utilisation des terres, leurs changements et la forêt) ; (1) aérien et maritime : trafic domestique uniquement ; (2) y compris incinération des déchets avec récupération d'énergie ; (3) hors incinération des déchets avec récupération d'énergie, et hors captage de biogaz.

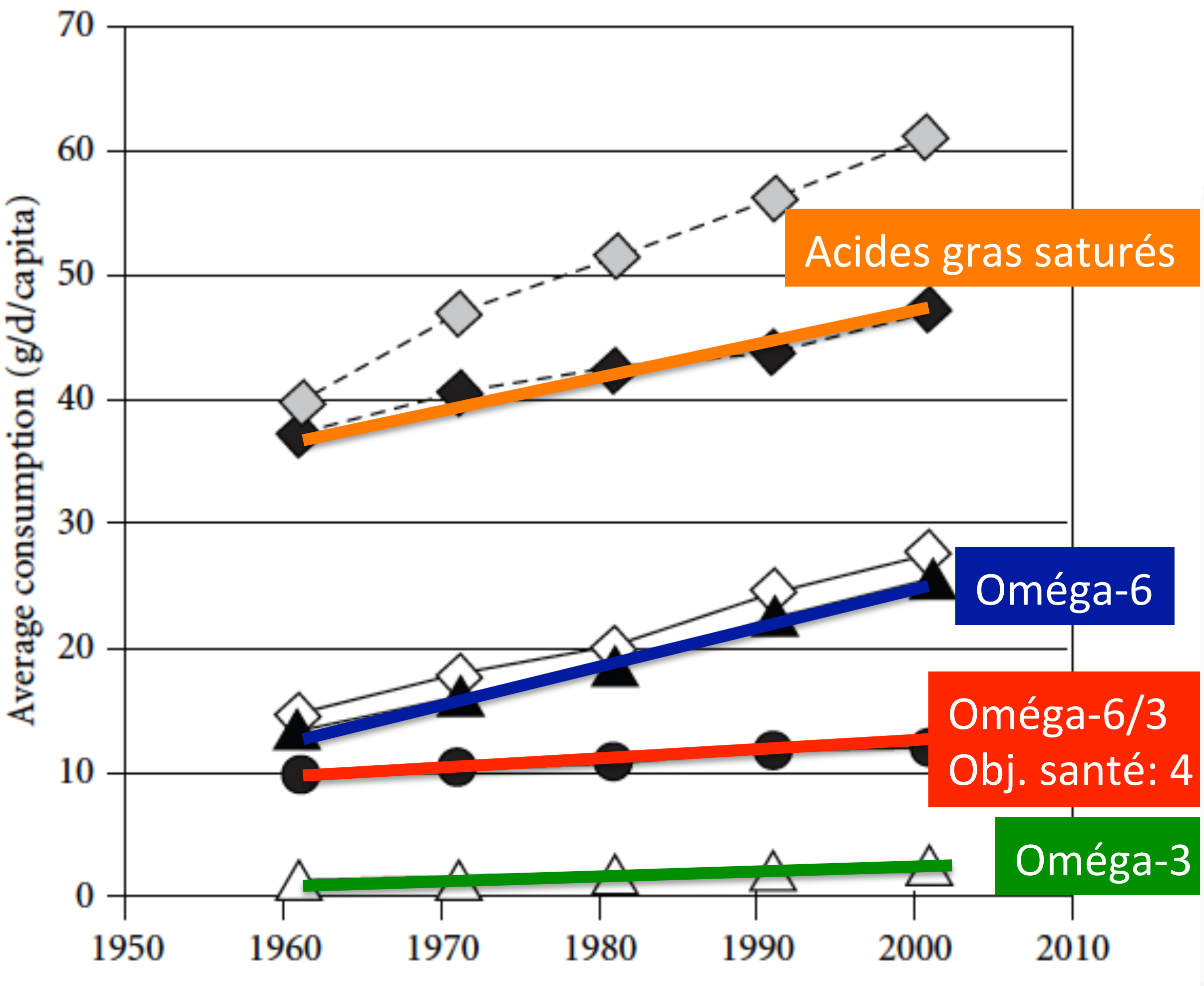
Source : Citepa (inventaire CCNUCC, format "Plan Climat"), mai 2011.

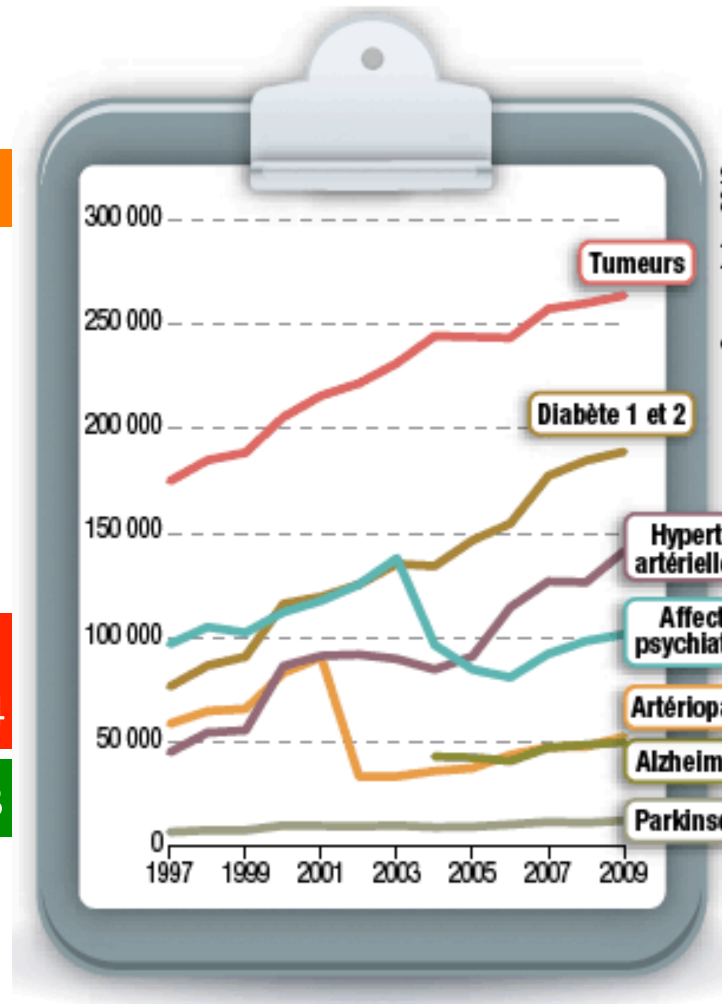
Water quality



Source : agences de l'eau, ARS, collectivités territoriales, syndicats d'eau - BRGM, banque de données ADES, 2012.
Traitement : SOeS, 2013

Fatty acids and human health





Molendi-Coste O, Legry V, Leclercq I a (2011) Why and How Meet n-3 PUFA Dietary Recommendations? Gastroenterology research and practice

FIGURE 2: Evolution of fatty acids consumption in European Union.

Overview

Despite numerous (bio)technological innovations

Trends over the past ten years

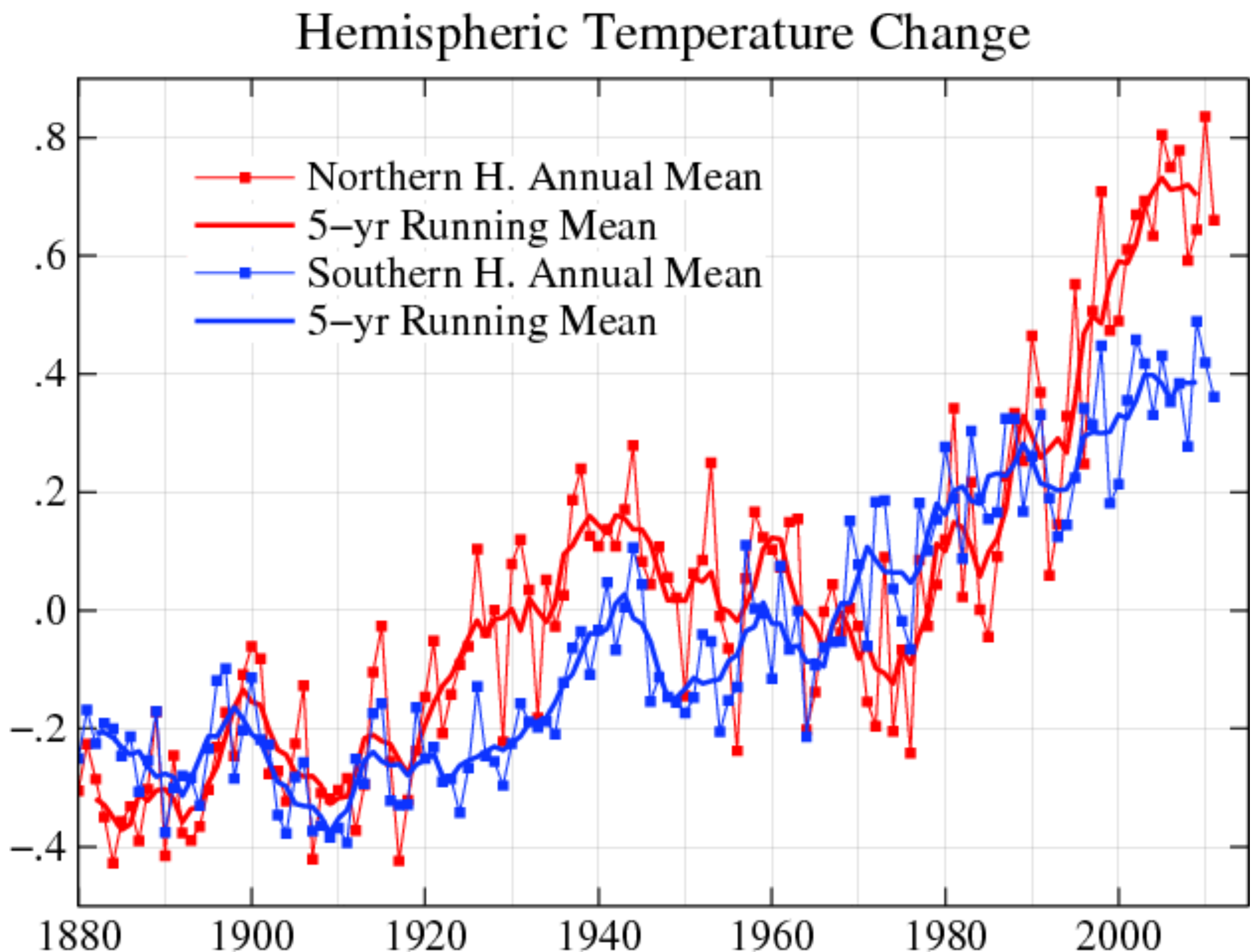
- **on-track:** reduction in greenhouse gas emissions, water pollution and waste management;
- **mixed progress** :improved energy efficiency, renewable energy production, and water use and quality;
- **worsening** : air pollution, eutrophication, species and habitat loss, and soil erosion.

Trends for the future

- it is anticipated that goals for biodiversity and soil health in Europe will not be achieved.

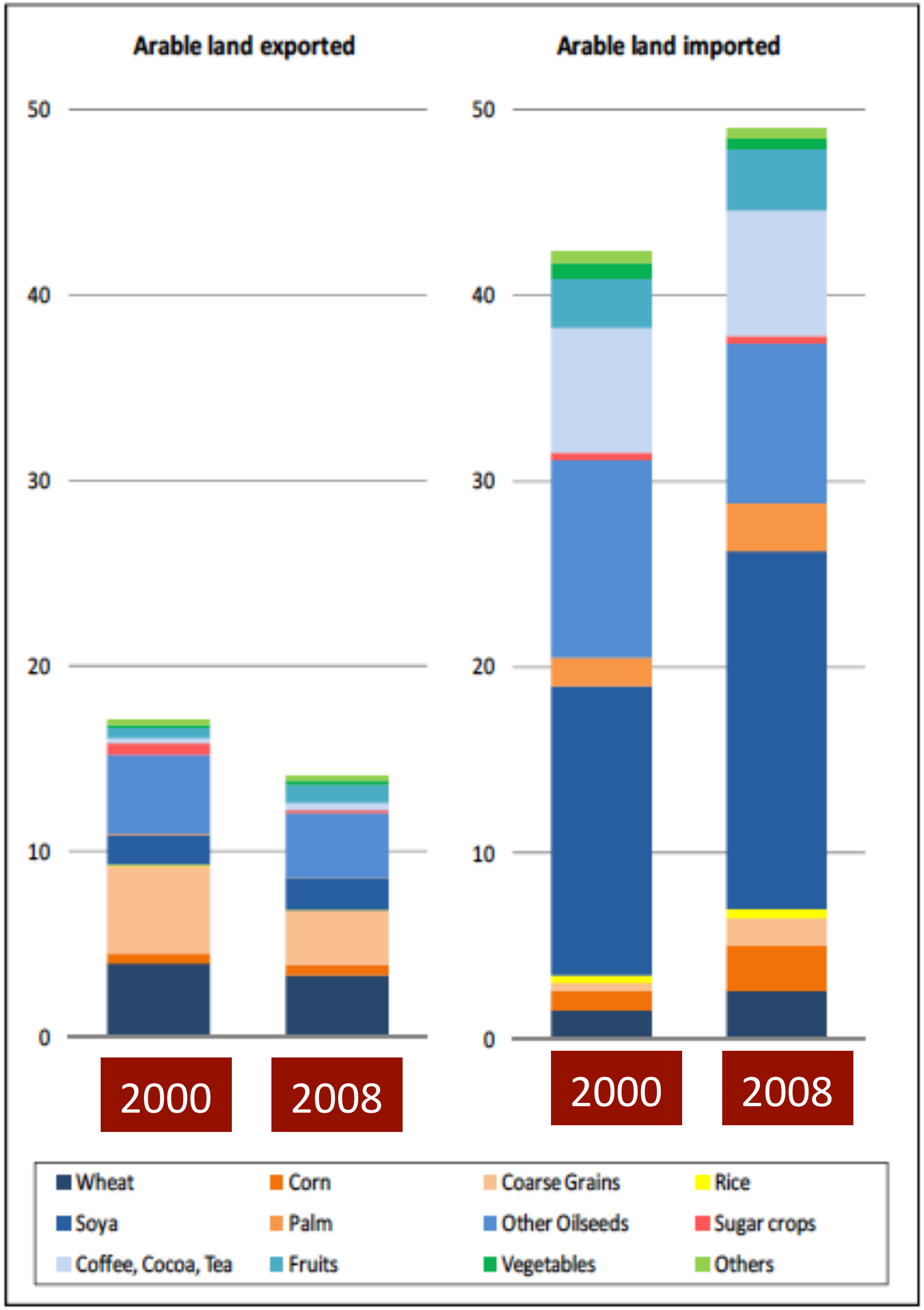
(EEA 2010)

Challenges: (1) climate change



Challenges: (2) food security

Figure 6: EU arable land virtually traded (in million ha)



Witzhe 2014

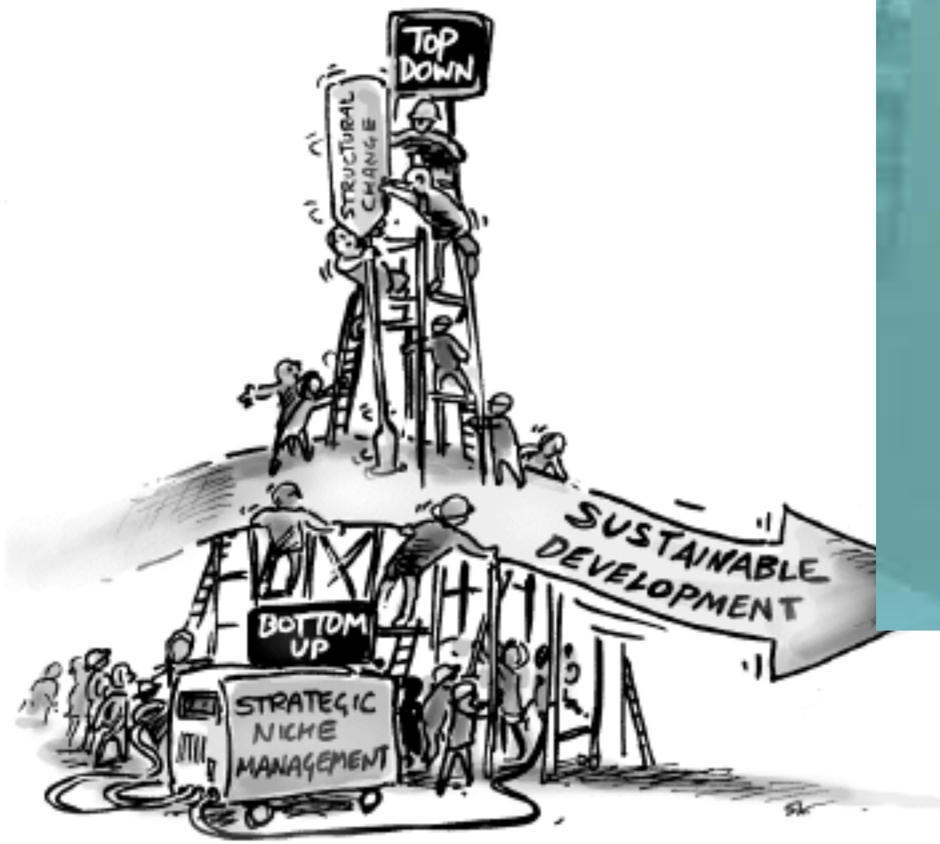
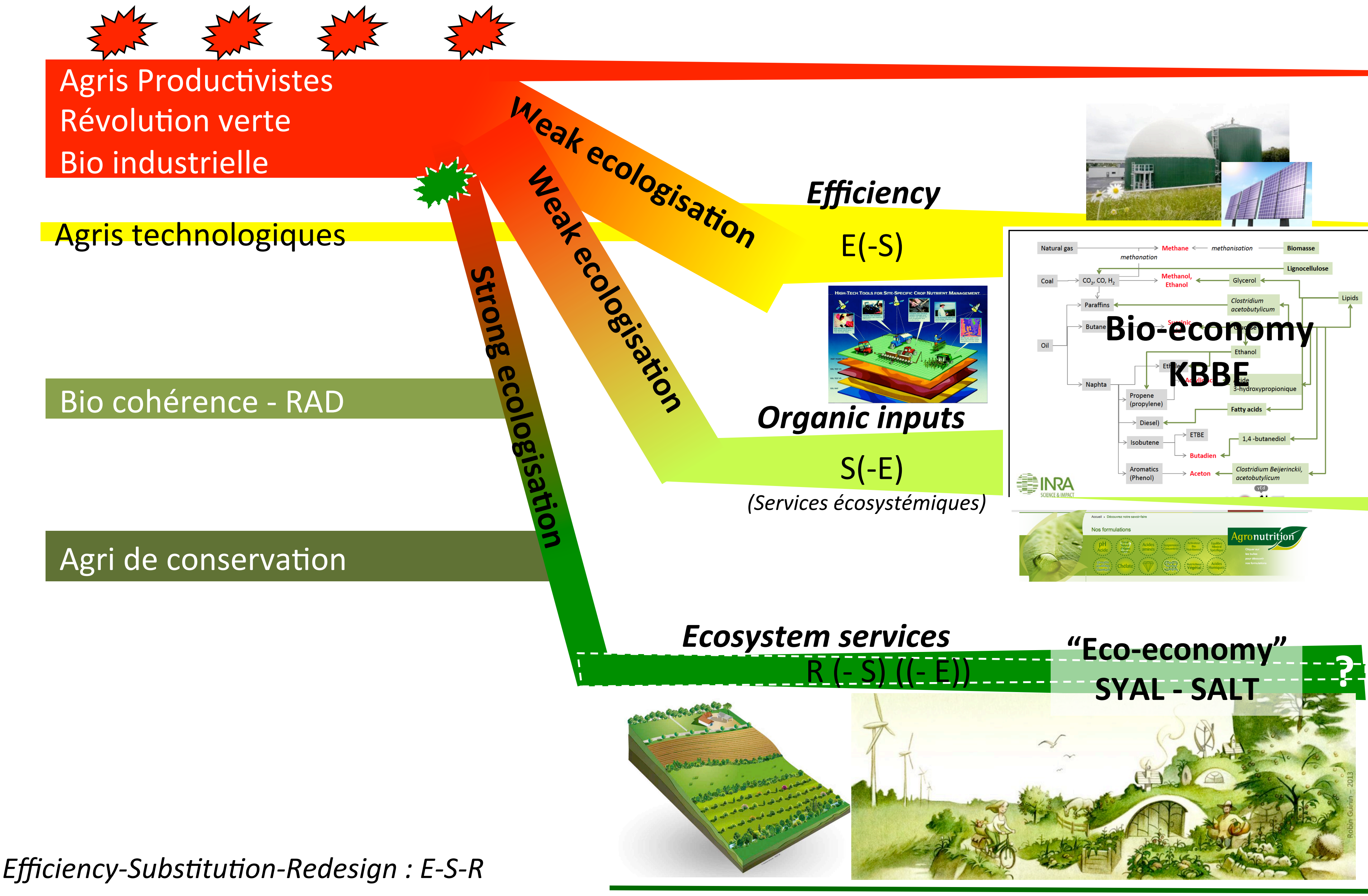
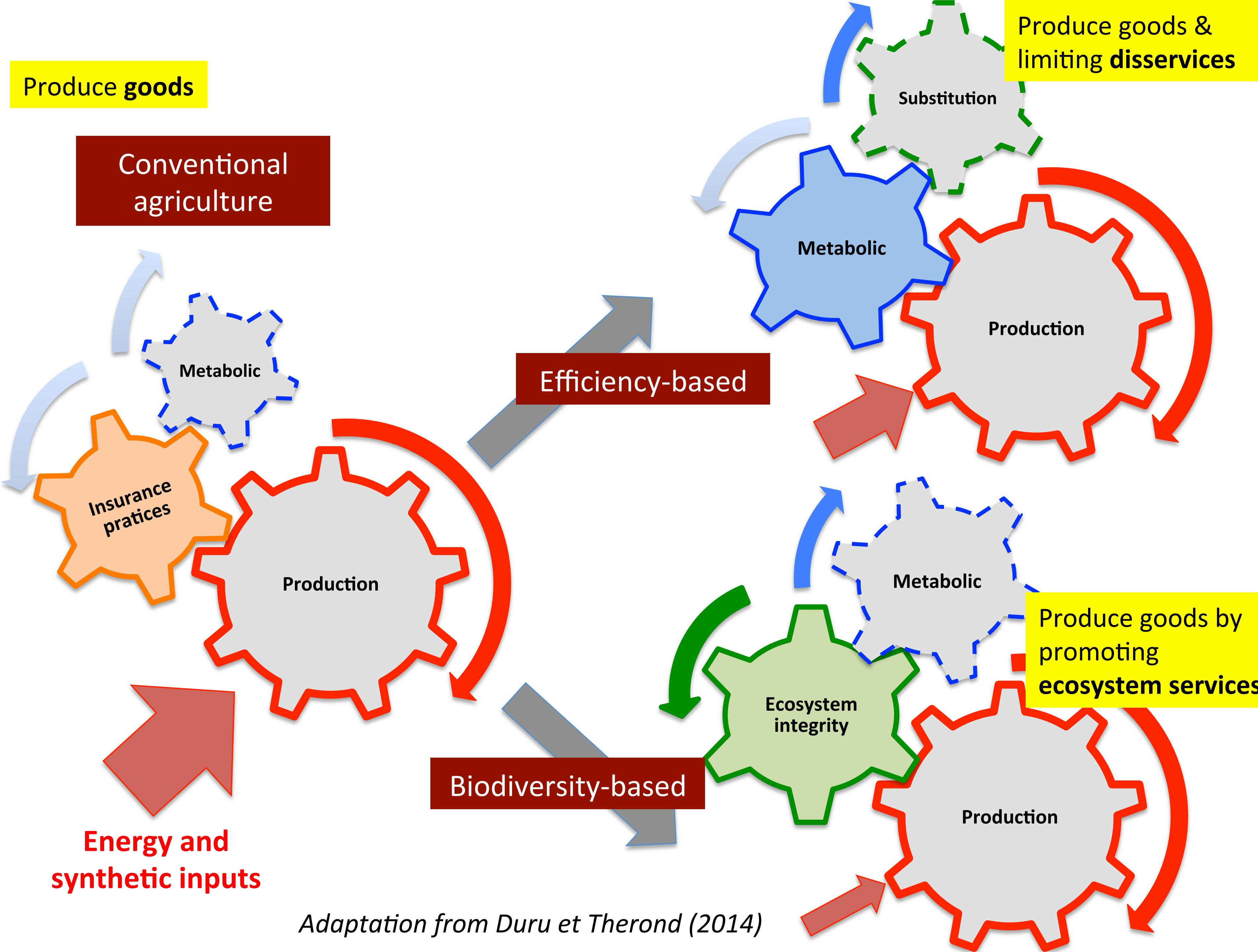


Fig. 19.3. A transition process requires the coordination of both top-down as well as bottom-up

Pathways for increasing sustainability of agricultural systems





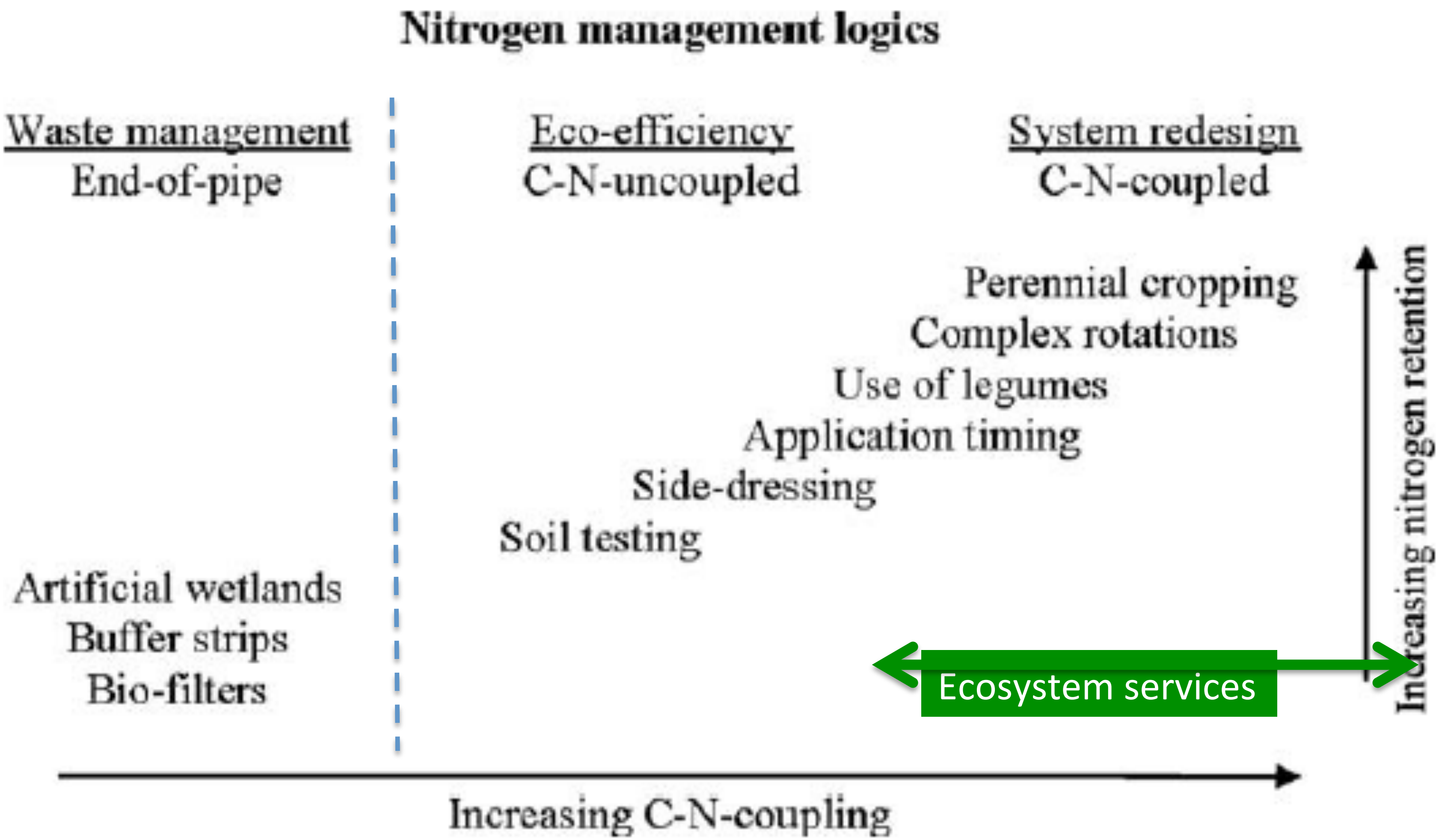
Adaptation from Duru et Therond (2014)

Ecological integrity of ecosystem

- To characterize basic requirements for the **stability of biotic**
- Based on the general concepts of **ecological self-organization**: the order of ecological systems emerges from spontaneous processes which operate without consciously regulating influences from the system's environment.
- The theory states that throughout the undisturbed complexifying development of ecosystems, there are certain characteristics that are increasing steadily and slowly, developing towards an attractor state which is restricted by the **specific site conditions**
- The related basic principles have consequences on many ecosystem features: *the food web will become more and more complex, heterogeneity, species richness and connectedness will be rising, and many other attributes will follow a similar long-term trajectory*.

Kandziora M, Burkhard B, Müller F (2013) Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. Ecological Indicators 28:54–78.

Why strong performed better for some environmental issues

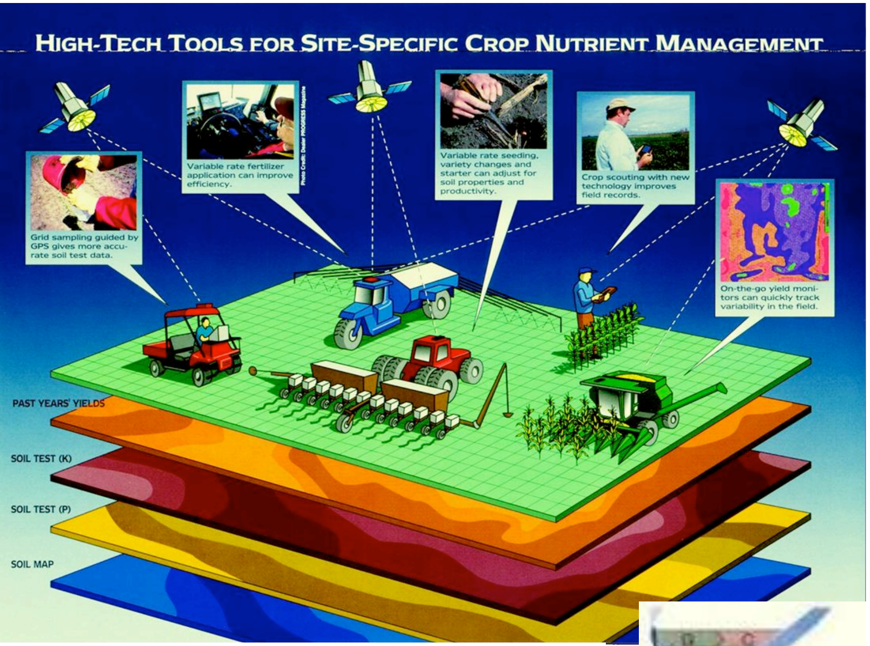


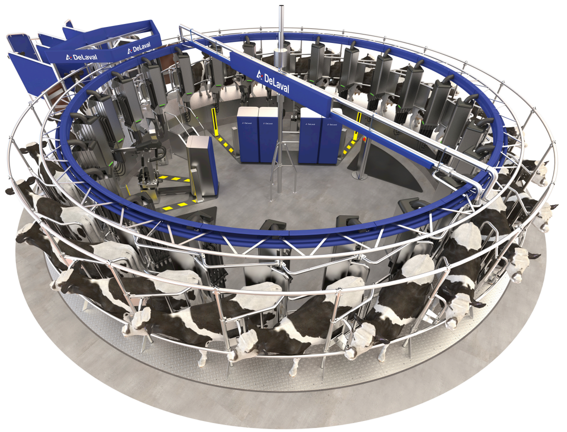
Soluble inorganic N and P pools rather than nutrient reservoirs with longer mean residence times (MRTs).

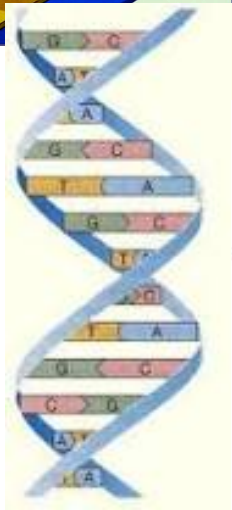
Drinkwater 2007 (adapted)

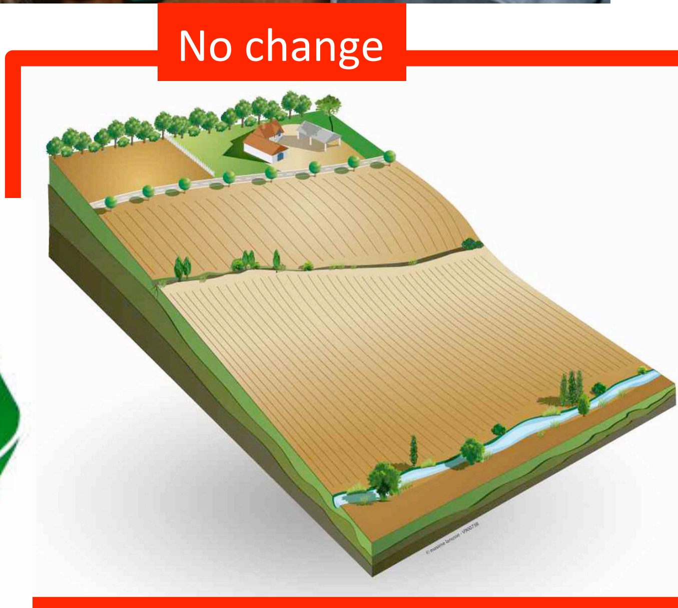
Enhancing biologically mediated N and P reservoirs will have long-term and cascading impacts on the internal cycling capacity agroecosystems

Limiting disservices for raw fluxes (N, P, C) and energy









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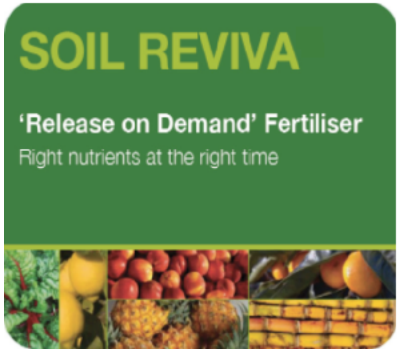
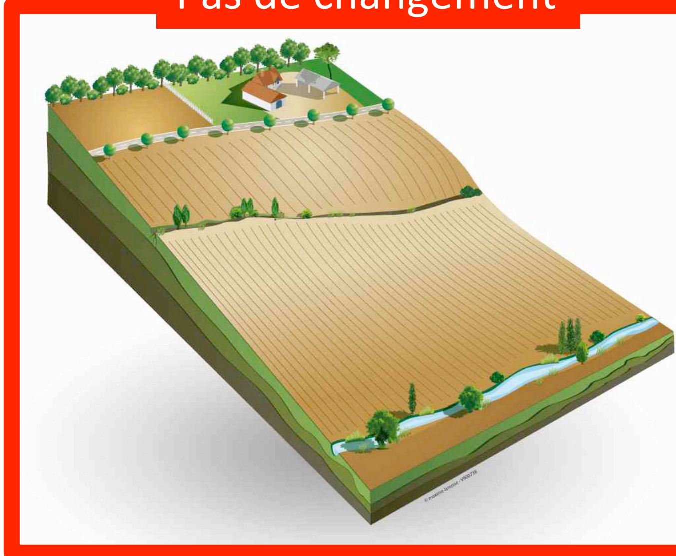
Substitution of synthetic by organic inputs

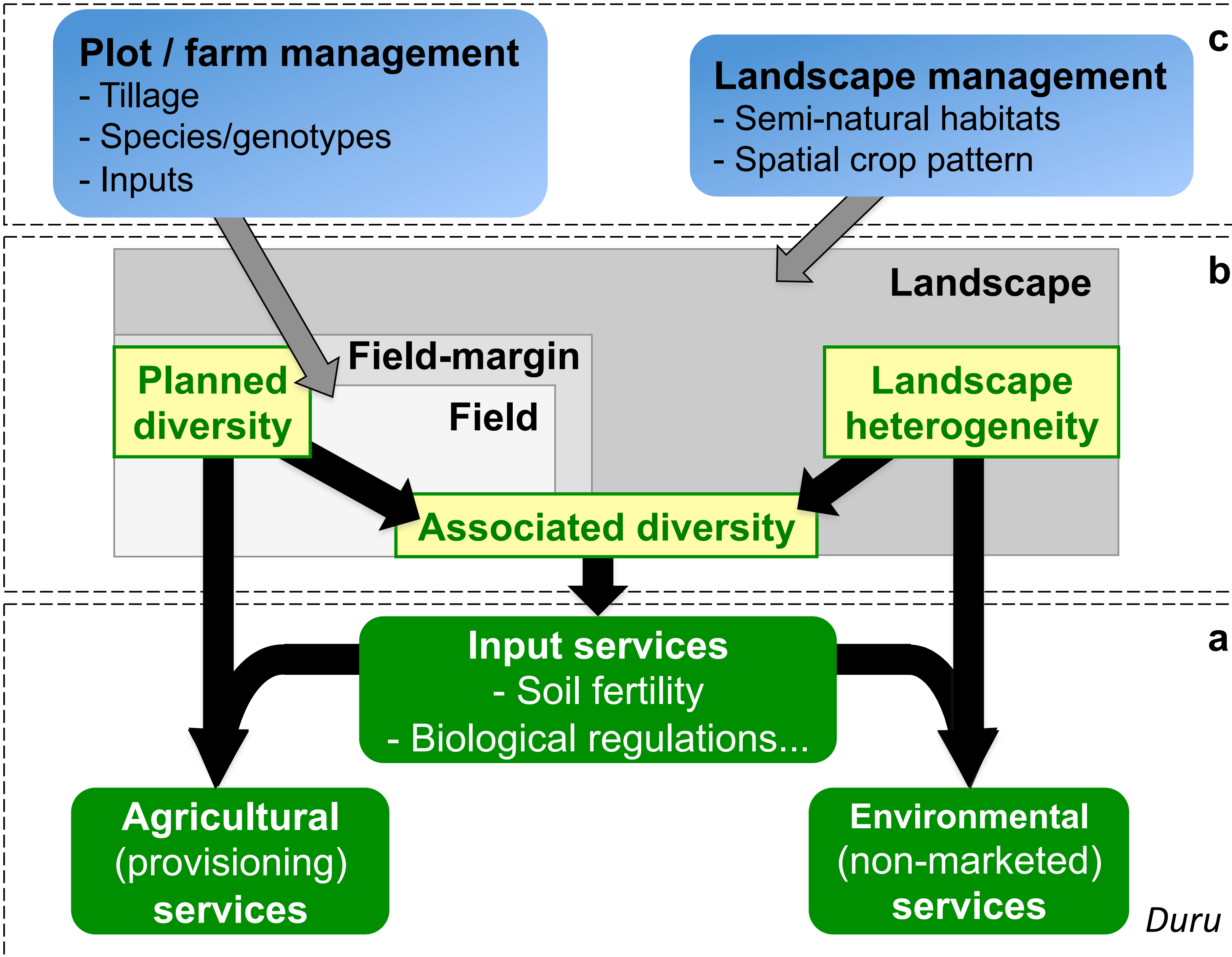
Bactisol ®



Pas de changement



Integrated diagram of relations between the ecosystem services provided by agroecosystems

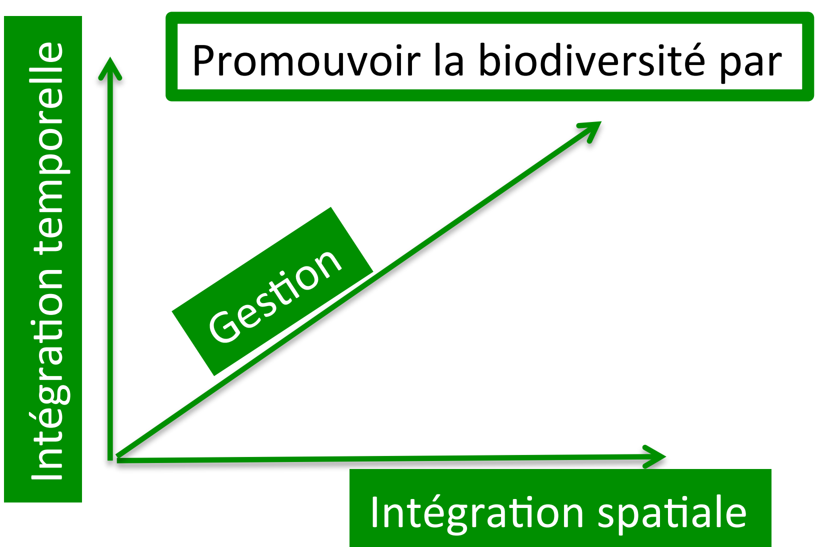


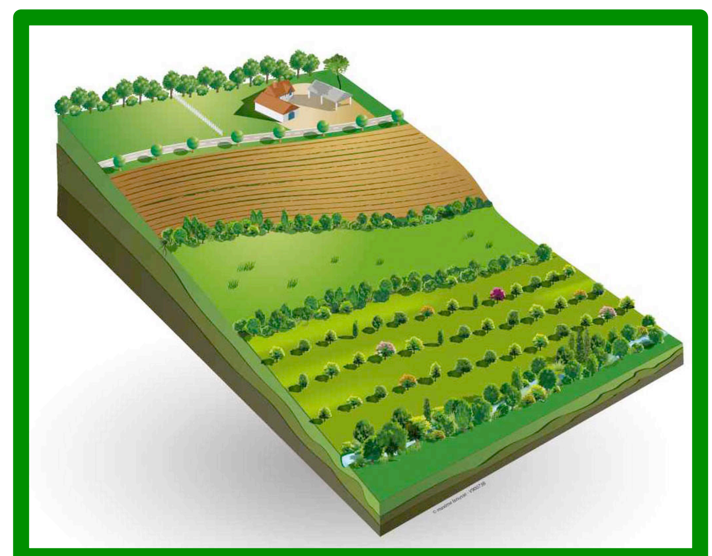
Duru et al 2015a

Biodiversity-based agroecological practices for enhancing ecological integrity of ecosystem

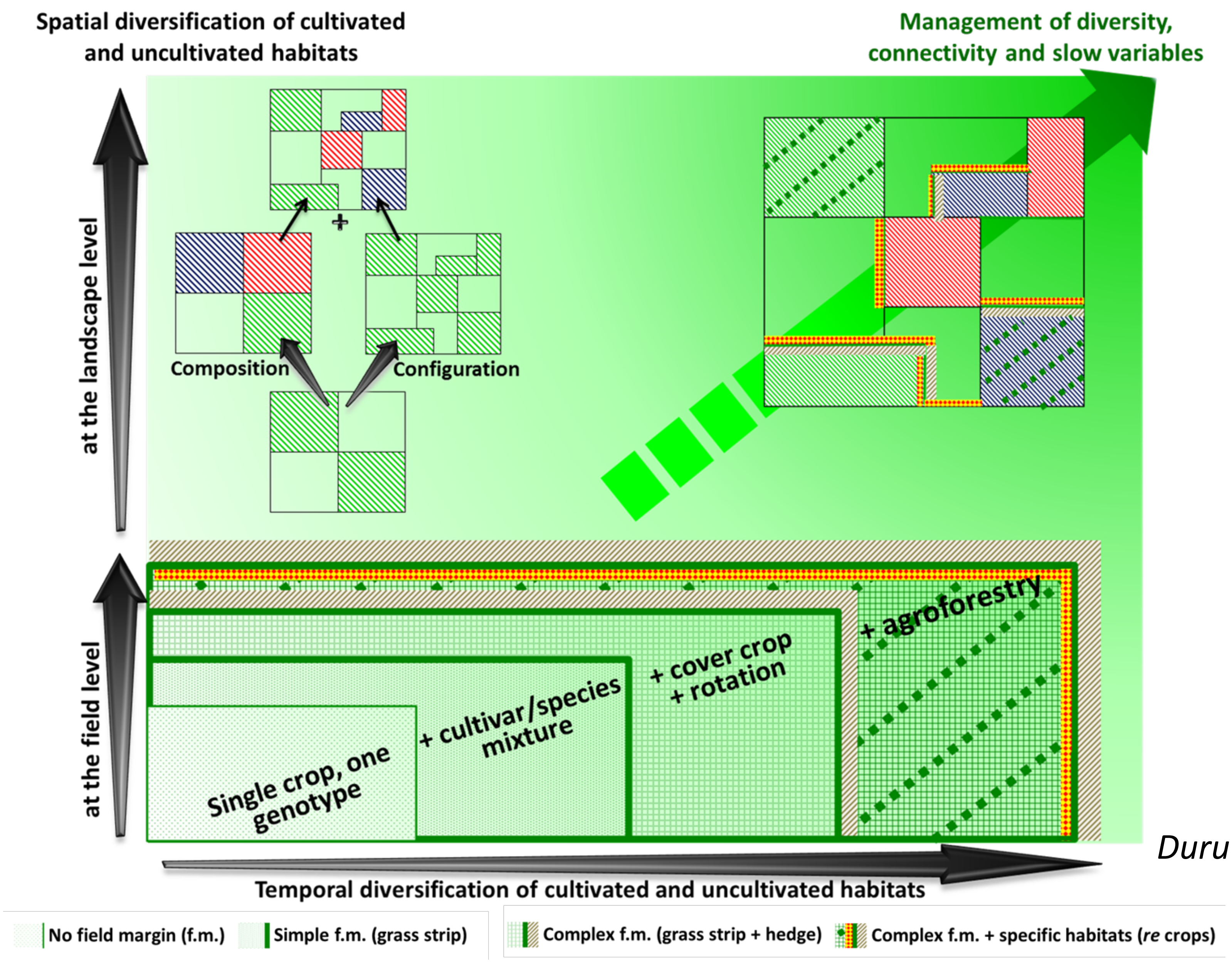
3 propriétés du système écologique à gérer :

- **Développer/maintenir Diversité et redondance**
- **Développer/maintenir Connectivité**
- **Gérer les variables lentes** (vs. rapides)





Minimizing mechanical and chemical disturbances of soil functioning



Duru et al 2015a

Comparison of weak and strong ecological modernization

Feature	Weak EMA	Strong EMA
Main aim	Reducing negative environmental impact; "ecological intensification" of agriculture	Producing ecosystem services for conserving resources; "ecologically intensive agriculture"
Paradigms	In continuity with the productivist agriculture paradigm: bio-economy and economy of scale	Breaks with the productivist agriculture paradigm: eco-economy and economy of scope
	Agriculture is considered as a separate and independent sector	Agriculture is considered as highly interdependent and integrated in the local human, cultural and ecological rural system
	Environment is considered through concerns about resource scarcity, waste and pollution	Environment is considered through its natural and cultural dimension (e.g., craftsmanship, stewardship, farming style)
	Competitiveness is in the global market	Competitiveness through sustainability and valorisation of natural resources

Duru et al 2015b

Innovation nature	Generic techno-science solutions ("one-size-fits-all") to improve efficiency of inputs based on genetics, organic inputs, mechanisation, precision farming and recycling (industrial ecology)	Place- and space-based diversified practices and farming systems based on ad-hoc spatial and temporal "planned" and "associated" biodiversity and local knowledge systems
Public policy	Top-down steering and regulation	Adaptive governance based on local stakeholder participation and facilitating local network/consortia development, knowledge sharing and collaboration

Promoting strong ecological modernisation of agriculture

- Issues
- Framework
- Examples

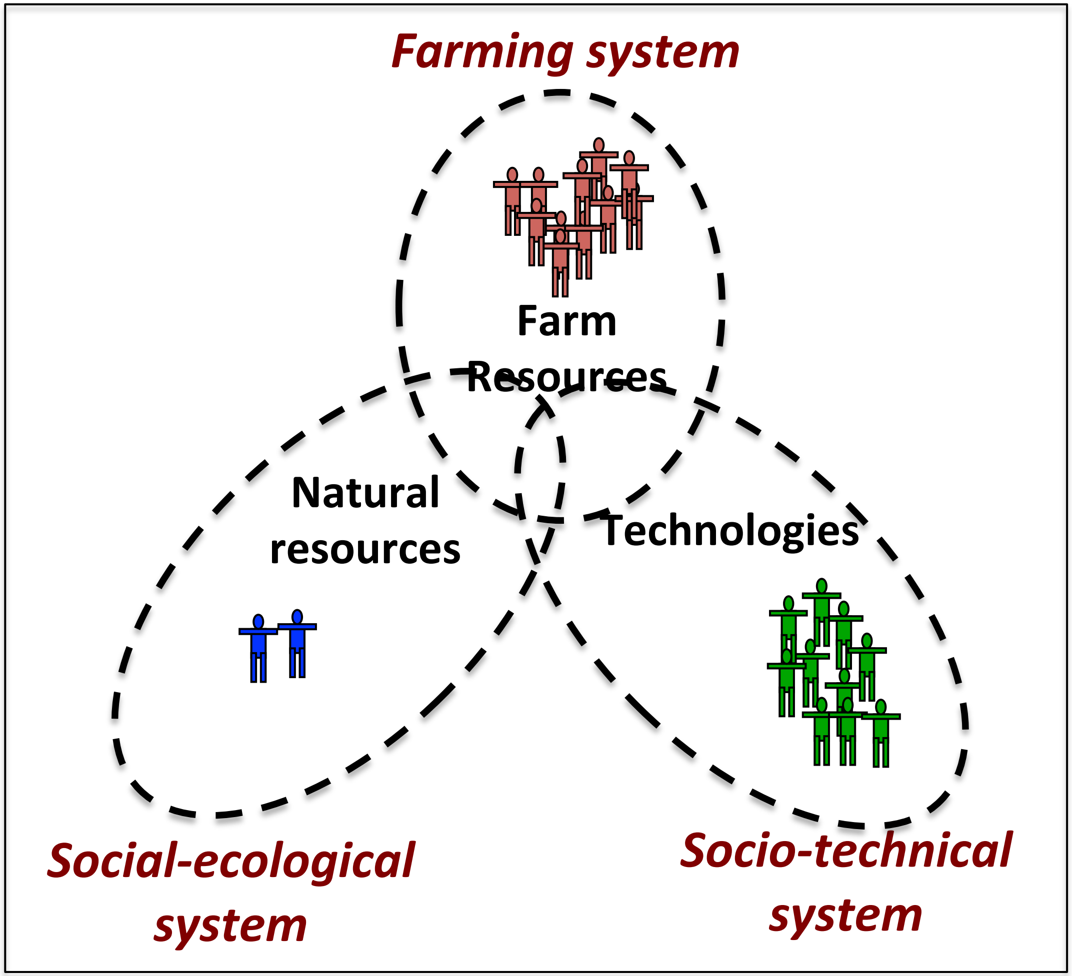
Issues for transition toward strong EMA

- **Complexity**: it cannot be accomplished by resorting to simple incremental agronomic innovations-> **Breakthrough innovations** that require a redesign of the systems concerned are necessary
- **Management practices for prompting ecosystem services are site-dependant ->** process of innovation must occur at **local level** in an agricultural system including a network of interacting institutions, businesses, and individuals
- **Incomplete information** during implementation of agroecological -> **require specific learning support tools**
- **Several stakeholders can be involved** for natural resource management at the landscape level -> **be able to coordinate**
- Development of new cropping systems based on crop or animal diversity may cause **technological or organisational problems** for production, collection and processing -> **reorganize supply chains**

The three systems potentially engaged in the agroecological transition

Ex 1: grassland-based livestock system

Ex 4: Agroforestry



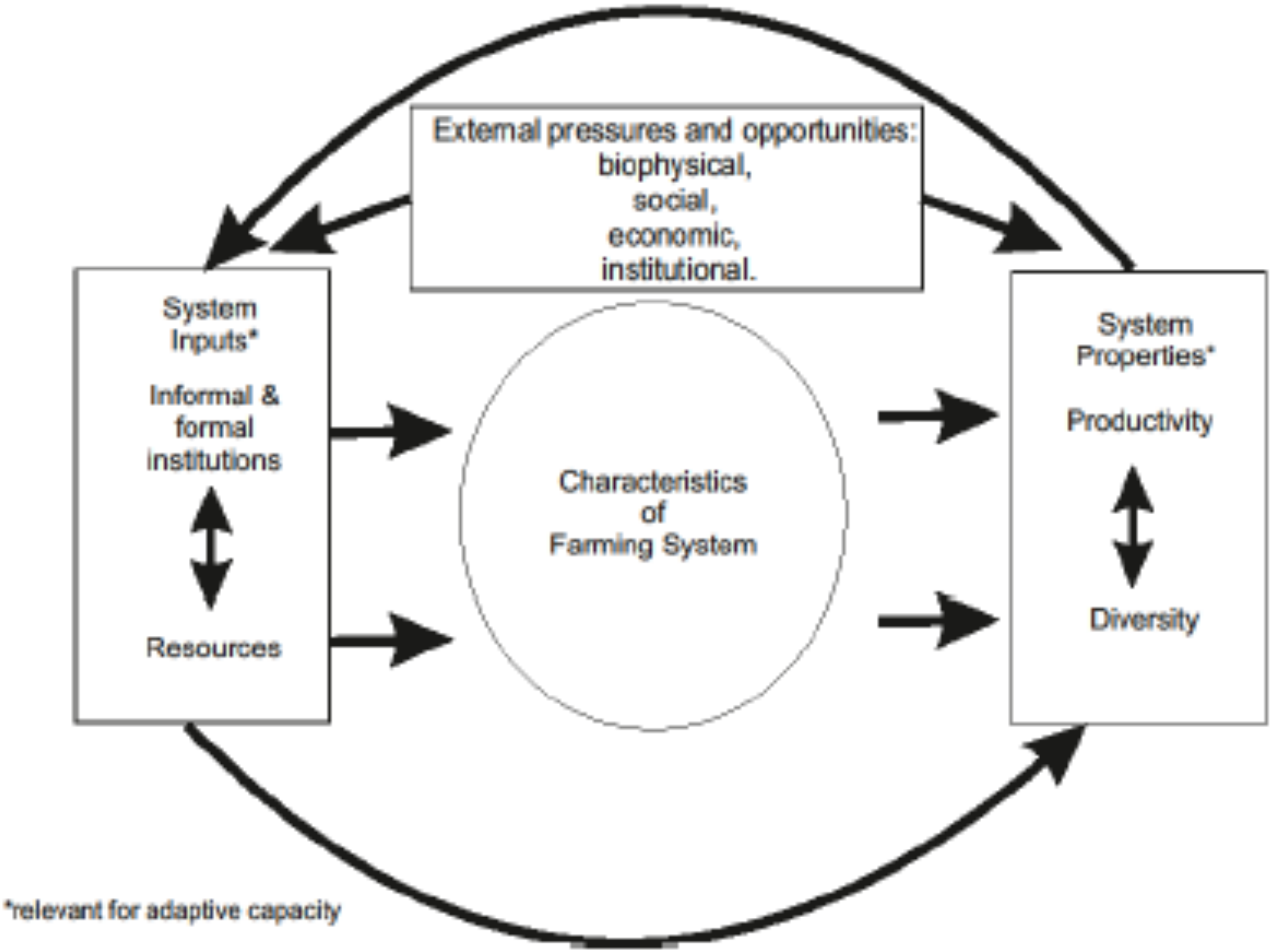
Ex 3: crop-livestock systems

Ex 2: cash crop diversification

Farming system and innovation

Ex 1: Grassland-based livestock system

Farming system approach



Dixon et al 2014

Principles for management

- Self-sufficiency
- Legumes within grasslands
- Well-tailored grazing management

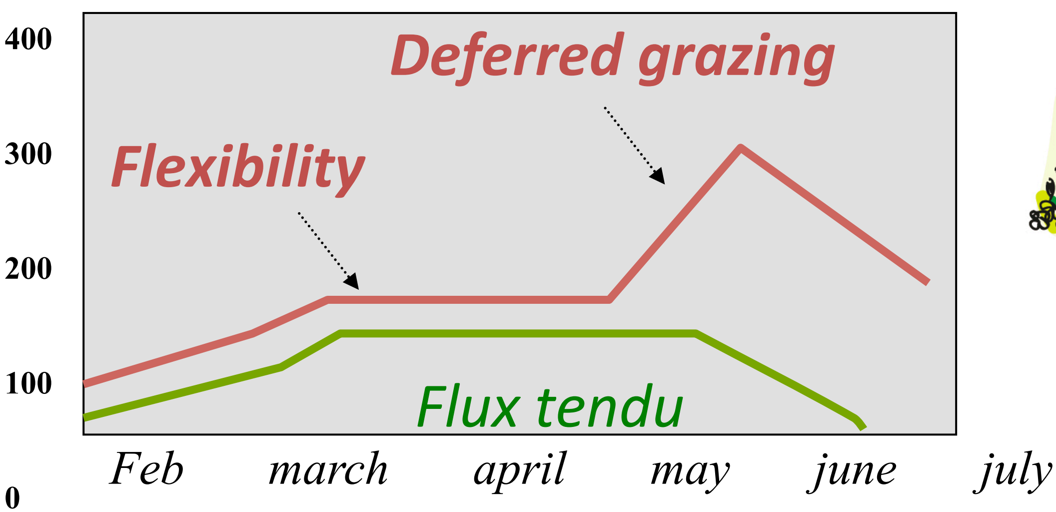
Comparison of conventional and emergent "sustainable" dairy systems (France)

Domain	Criteria	Civam	Conventional
Structure	Agricultural land (ha)	64	71
	Animal unit (dairy cows)	75 (49)	96 (48)
Land use and management	Stocking rate (number of animal units per ha)	1.28	1.61
	Land use in ha (grassland/maize/crops)	45/8/12	40/15/15
	Maize for silage (%SFP)	12	37
	Hedge (ml/ha)	>150 linear meter/ha	No obligation
Economy	Inputs (euros/ha)	100	240
	Milk / cow (kg)	5749	6636
	Food cost (euros/1000l)	78	120
	Mechanization cost (euros/ha)	400	500
	Farm incomes (euros)	134718	157309
	Gross operating profit (euros)	53365	42291
Environment	Pesticide treatment frequency for maize **	0.83-1.24	1.66
	GHG emissions (CH4, CO2, N2O (kg eq CO2/1000l) *	1100	1100
	Net GHG emissions kg eq CO2/1000l)	874	1018

Issues: grazing management and grassland composition

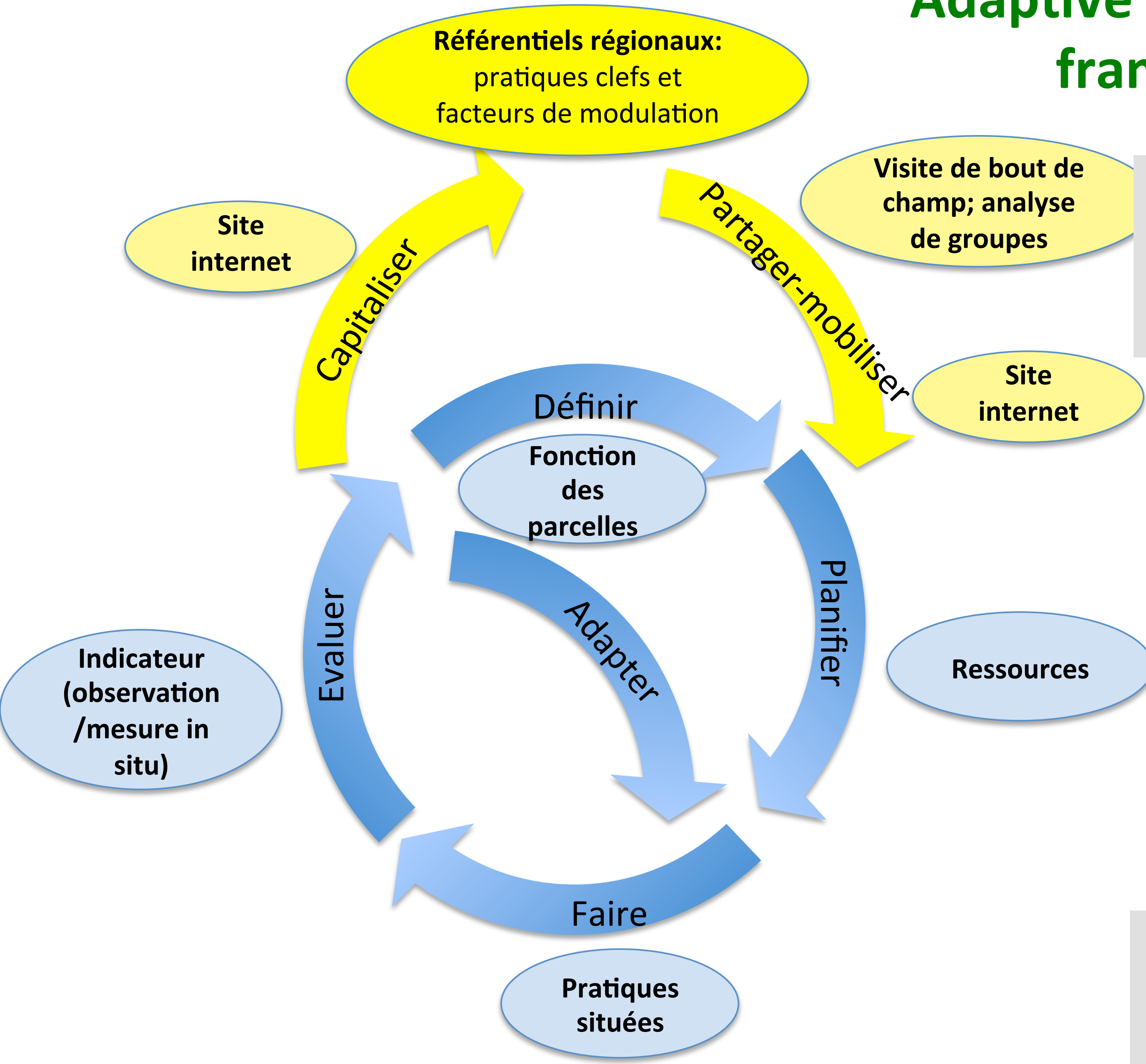
- incompleteness of knowledge
- practices against intuitive (sward height)
- situated practices

Herbage volume per cow
at the whole pasture level (m³)



Vidéo on est passé à l'herbe

Adaptive management framework



- Explicite
- Générique (conditions d'application)
- Collectif

- Tacite
- Implicite
- Individuel

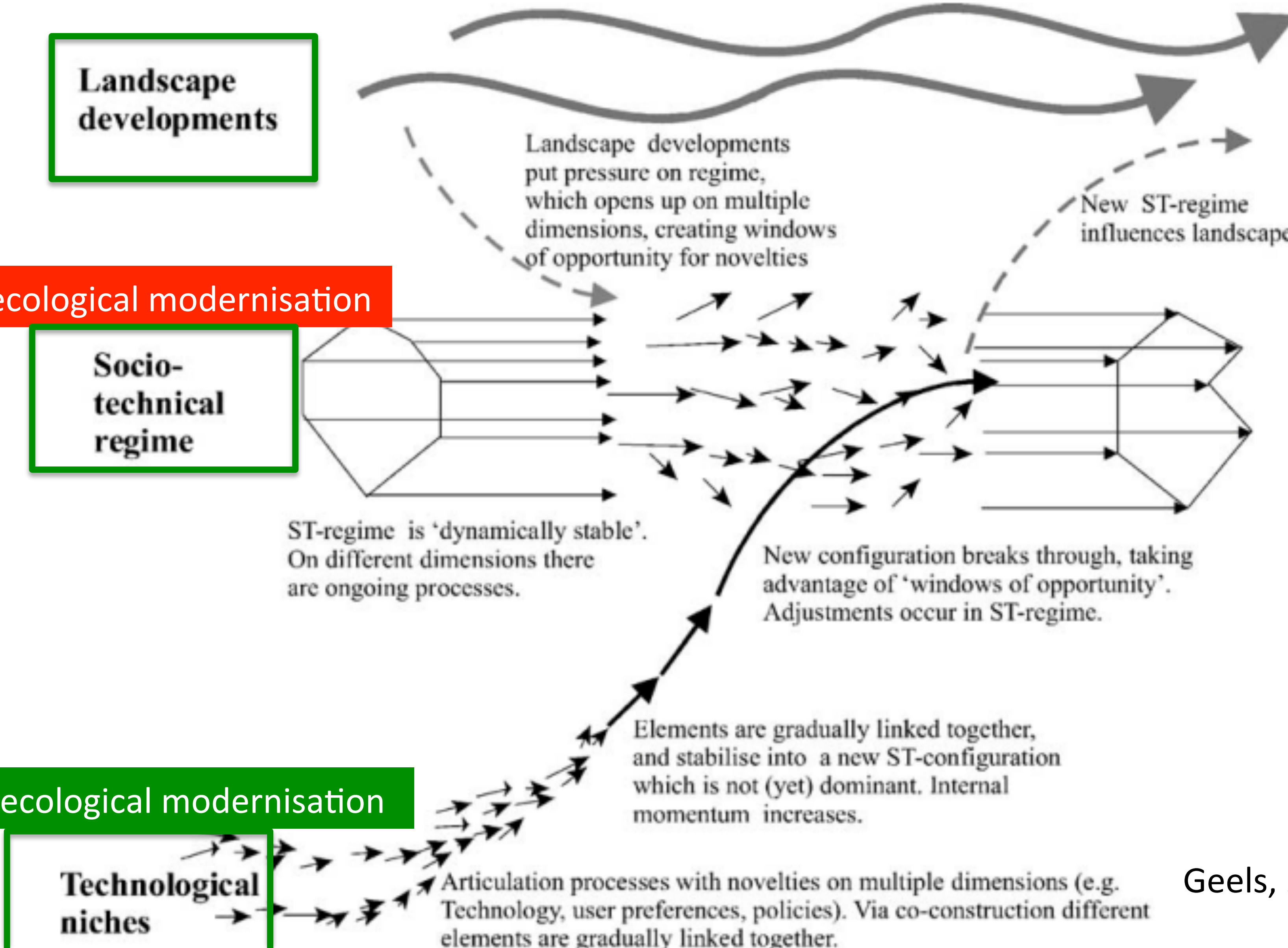
Sociotechnical system for studying lock'in in the supply chain

Example 2: mixed cropping

A multi-level perspective framework

Weak ecological modernisation

Strong ecological modernisation



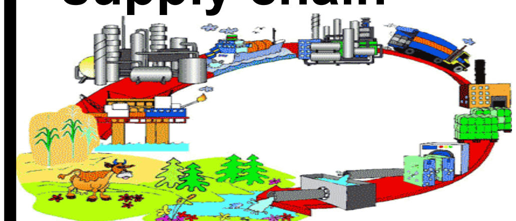
Geels, 2005

Can Agroecological practices be adopted ?

The organizational design of the supply chain

Changes in production practices

Integrated supply chain



Market

Market driven incentives

Farmers driven incentives

- Market can implement changes at farm level (e.g. with labels) but only through an integrated supply chain
- New farmers' practices (even leading to strong changes) can be adopted if leading to small adaptation of the supply chain

→ **Segmented supply chain may impeded the change of practices and generate lock-in**

→ **Lock-in effects can be overpassed by analyzing the supply chain (actors & functioning) to reveal:**

  - Resilient structures allowing the management of new practices
  - Inflection points susceptible to constitute primers to the transition

Bedoussac, Magrini 2012

Case study : durum wheat-grain legume intercrop

Durum wheat

- ❑ A supply chain economically important in southern France
- ❑ Many grain quality criteria difficult to satisfy in low input

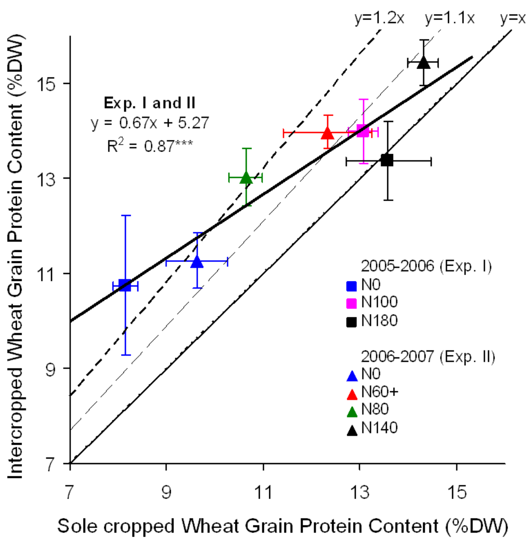
Grain legume

- ❑ Reduce the dependency on proteins
- ❑ Valorize the ability of legume to fix atmospheric N2

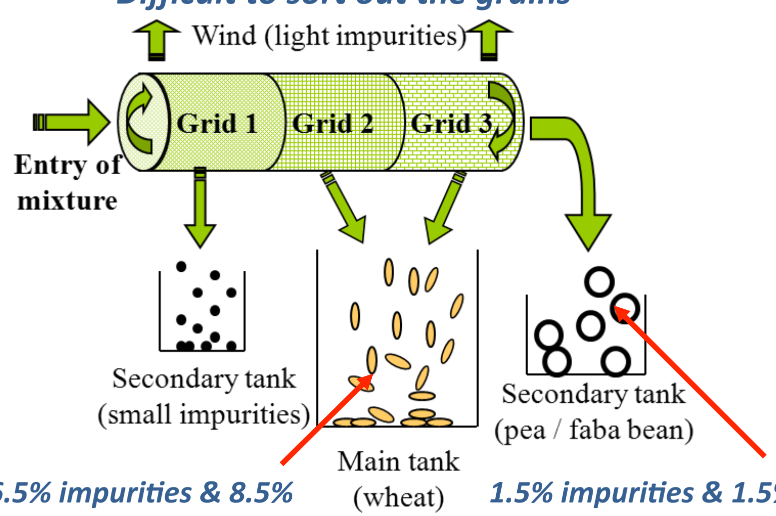
Intercropping

(Bedoussac & Justes 2010a,b)

Higher durum wheat grain quality



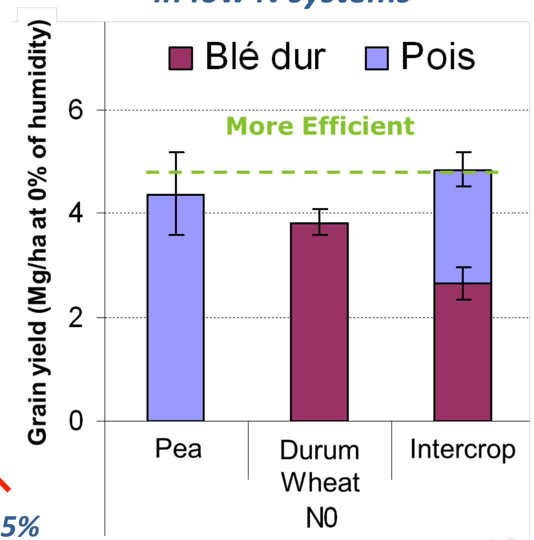
Difficult to sort out the grains



6.5% impurities & 8.5% broken peas

1.5% impurities & 1.5% durum wheat

Higher grain yield in low N systems



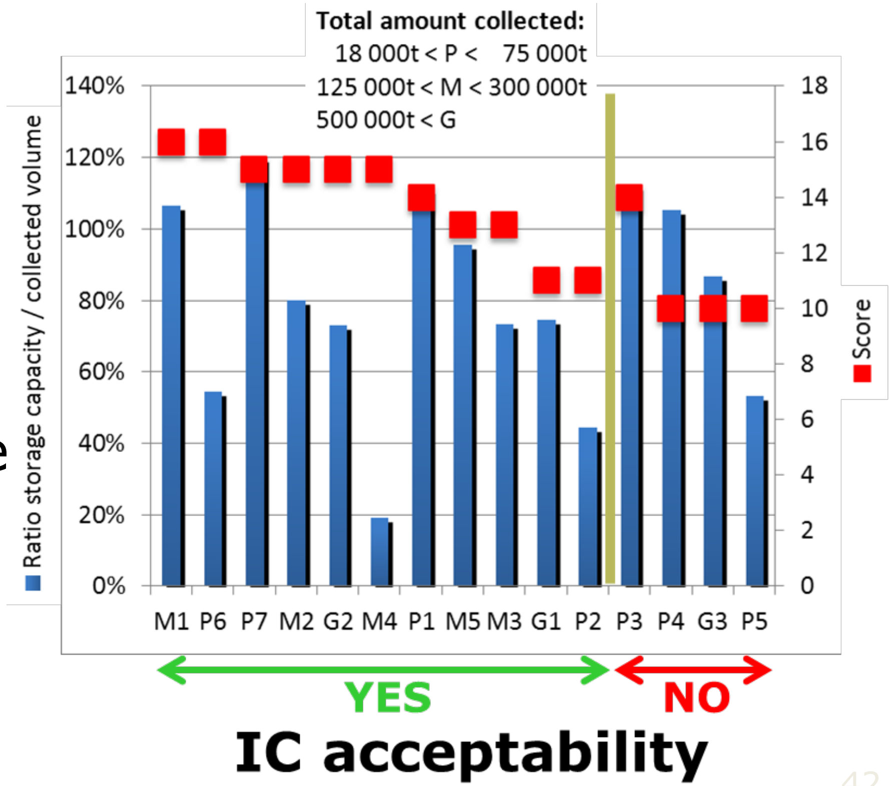
Can intercrops be adopted by farmers?

The cooperative's logistic

- **Adoption of intercrops by farmers must be compatible with cooperative's logistic** (ex: abilities to the collection, grading and marketing of the two species)
- The **logistic of cooperatives can be an obstacle but also a competitive advantage** (in a context of products differentiation by quality)

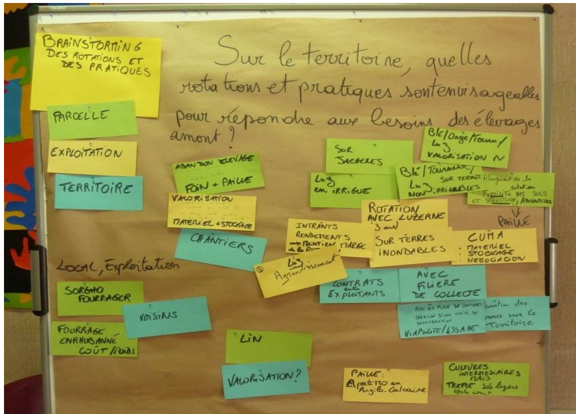
Conclusion: links between cooperative's logistic and intercrops acceptability

- **Intercrops acceptability depends on quality strategy:**
  - Competencies and technical means (material, grading…)
  - Number of durum wheat classes
- **Size and flexibility seems not discriminant**
- **Needs for the development of intercrops:**
  - Sufficient volumes
  - Homogeneous species choice
  - Commercialization capacity of the 2 species
  - Capacity to sort out grains

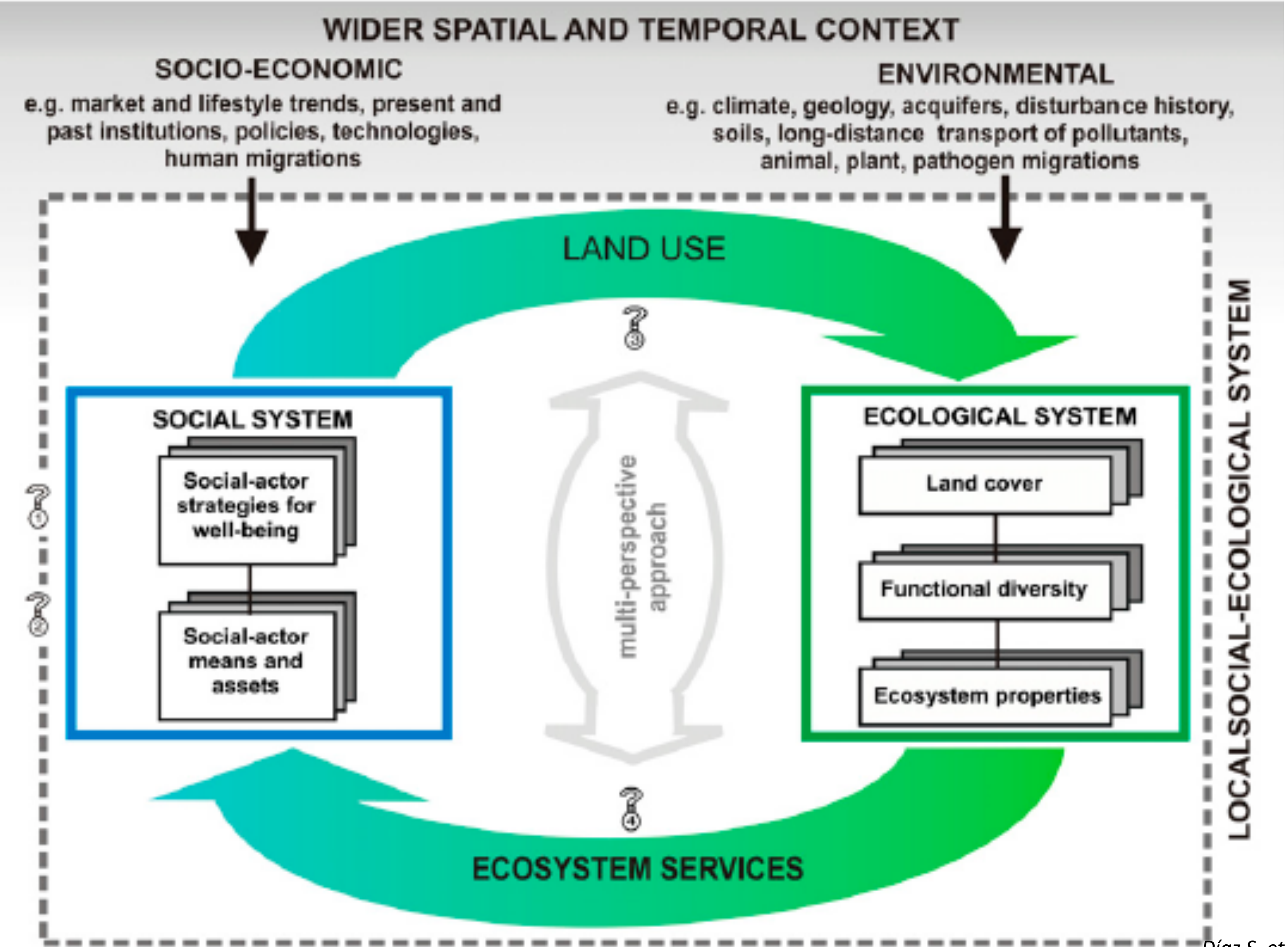


Socioecological system for managing natural resources at territory level

Ex 3: integrated crop-livestock system



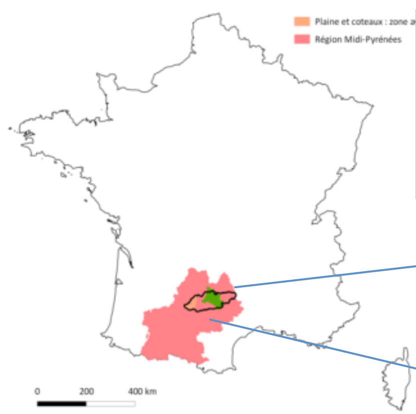
Social-ecological system



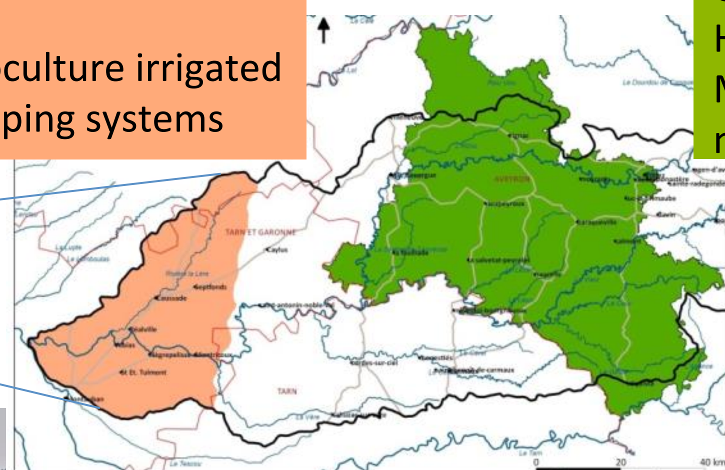
Díaz S, et al. (2011) PNAS

Context of the study: water deficiency

- Objective = design ICLS at territory level adapted to local challenges, resources and actors system.
- Field = Aveyron River Basin

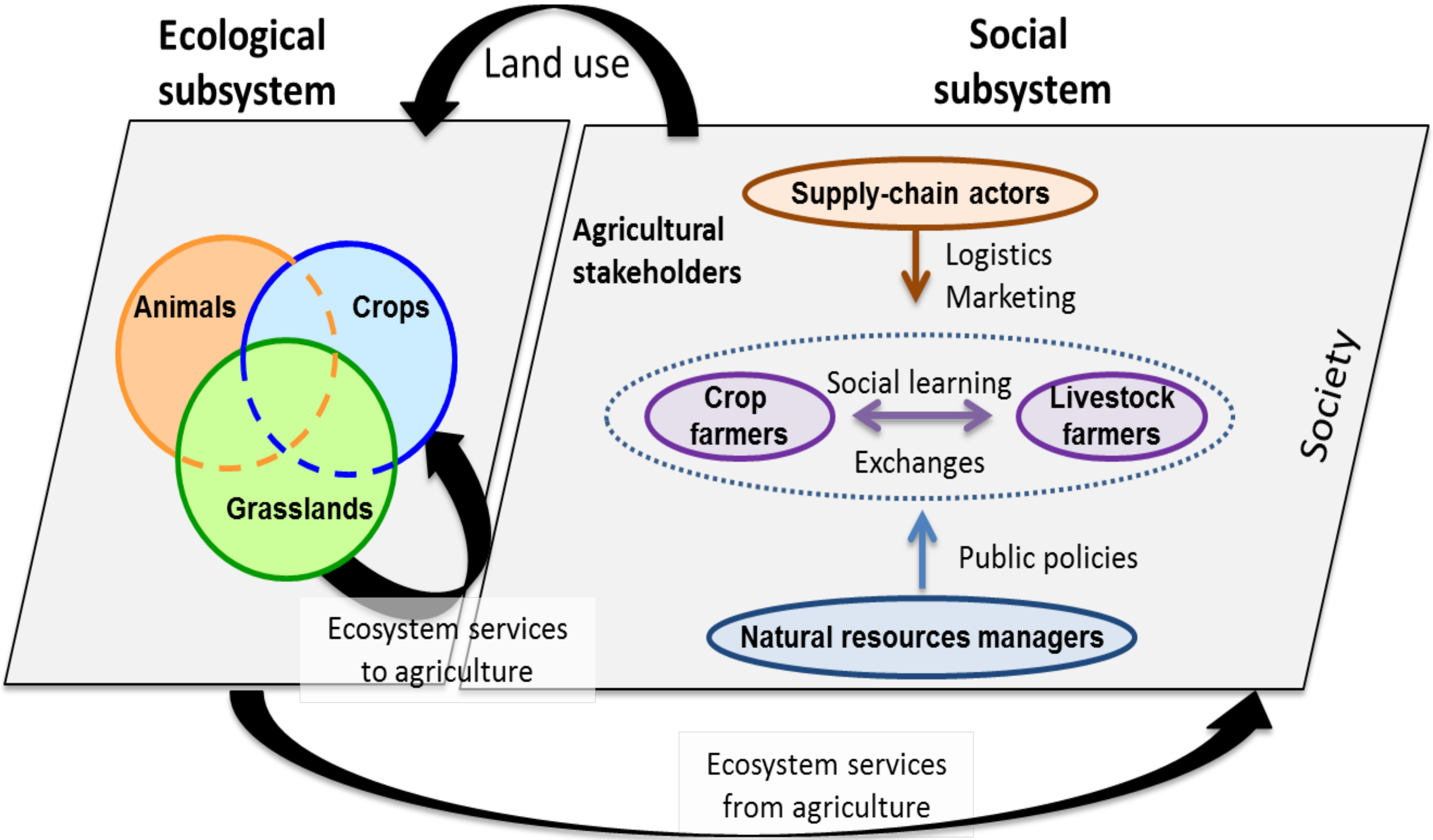


Lowlands
Maize monoculture irrigated
Cereals cropping systems



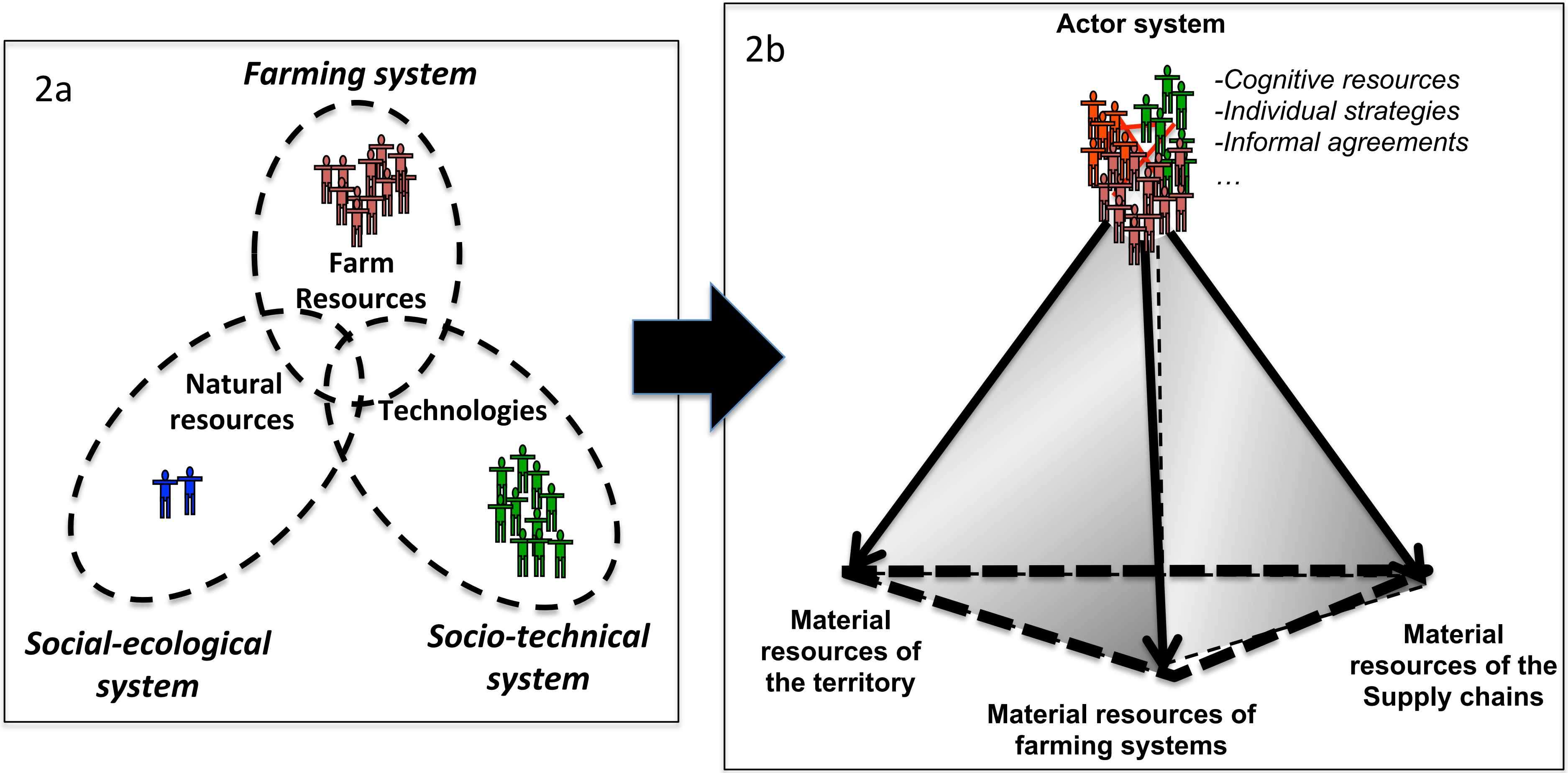
Uplands
High animal density
Multiple livestock systems, non self-sufficient

Interactions between social and ecological subsystems in a Territorial Crop-Livestock System



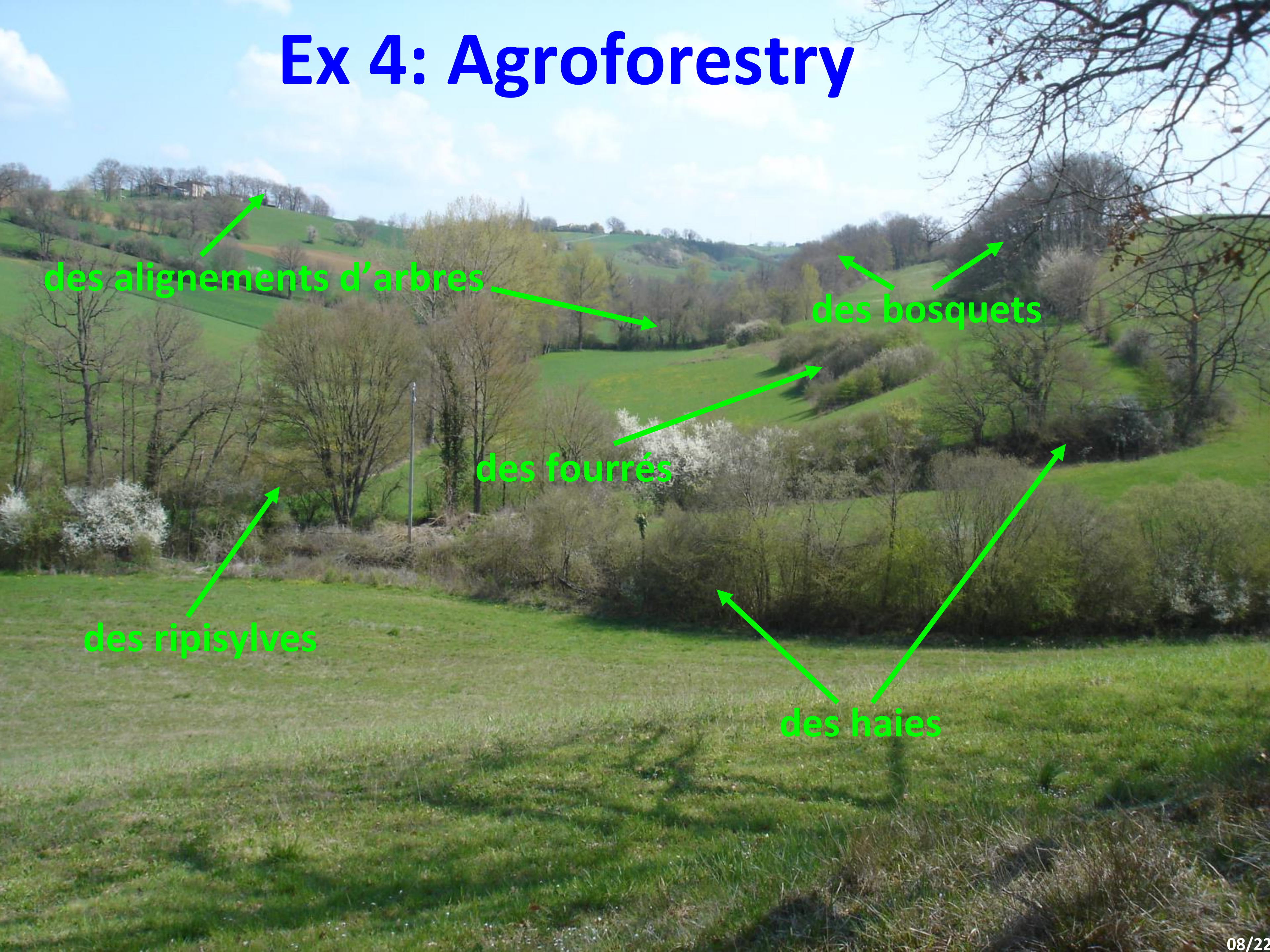
Straight arrows represent key interactions analyzed and designed in a territorial crop-livestock integration perspective.

Towards an integrated framework



Duru et al 2015b

Ex 4: Agroforestry




Trees for goods,
eg: wood, energy,
biocar, BRF
Trees for services TO
agriculture, eg: shading,
water lifting
Source INRA, R. Cardinael


Trees for services TO society, eg: at local (water filtration) and global (carbon strorage) levels
Source INRA, P. Merot

Agroforestry at territory level

Ecosystem services
(no market)

Products
(market)

Agroecology: what is changing here for science

Combining different research areas:

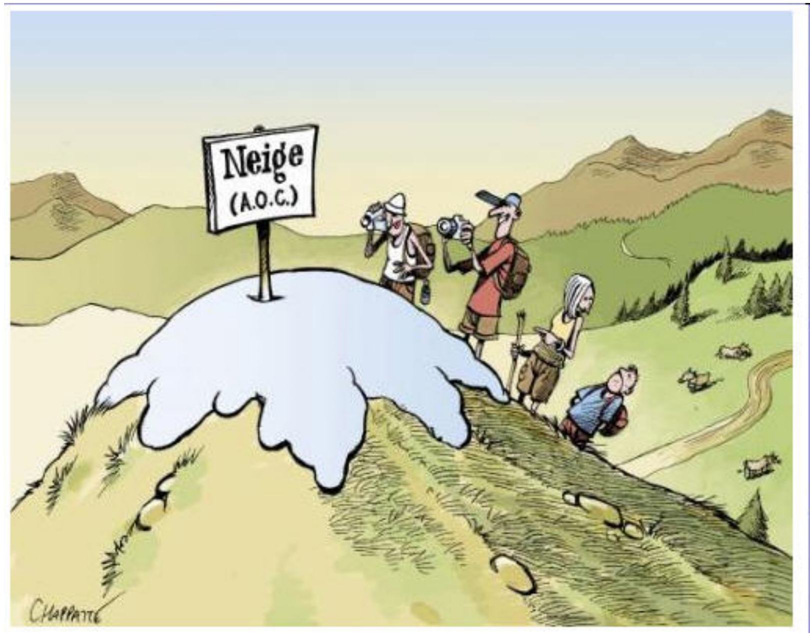
- **Advances in agricultural science**: Improving links among knowledge-production methods to build **learning-support tools**; de-contextualized analytical and modeling methods (e.g. experimentation, on-farm observations) need to better fit holistic and contextualized methods based on stakeholder participation
- **questions /** appropriate level of detail that analytical and modeling methods to represent the key biophysical interactions within farming systems &landscapes. Concerns the "**scaling-out"** of research methods and findings.
- **Advances in ecological science :** to characterize planned and associated biodiversity **responses** to locally controllable drivers and non-controllable or exogenous drivers eg climate change.
- **Questions** /development of **indicators** to characterize ecosystem services either directly, or indirectly, from related on-farm and landscape biodiversities. Be relatively simple & relevant and user-friendly to be easily applicable to farms and landscapes.

Agroecology: what is changing here for science

- ❑ **Advances in management science** : develop methods structured more specifically for **collaboration with stakeholders** involved in biodiversity-based agriculture and for evaluation of such collaborations
- ➢ **questions** /methods : incorporate stakeholder knowledge and feedback **into learning supports** such as knowledge bases, and the assessment of stakeholders' learning when using learning-support tools.
- ❑ **Advances in knowledge-management science** to capture, develop, share, and effectively use **decision-making knowledge**.
- ➢ **Questions** /data-reduction and knowledge-representation forms for self-organization of knowledge development and acquisition by a variety of actors. ITC.
- ❑ require taking the position of "**integration and implementation sciences**", which:
- ▪ attempt to provide sound theoretical and methodological foundations to address societal issues characterized by complexity, uncertainty, change, and imperfection;
- ▪ are based on systems and complex thinking, participatory methods, and knowledge management and exchange;
- ▪ are grounded in practical application and involve a large stakeholder panel.

Thank you for your attention

« Il nous faut dissiper l'illusion qui prétend que nous serions arrivés à la société de la connaissance. En fait, nous sommes parvenus à la société des connaissances séparées les unes des autres, séparation qui nous empêche de les relier pour concevoir les problèmes fondamentaux et globaux tant de nos vies personnelles que de nos destins collectifs. »
Edgar Morin, La Voie, Fayard, 2011.



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