The future of agriculture

The agriculture of the future.

LOME

(Leguminous, Oleaginous
MEthanisation

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Agriculture is in crises!

Since when? At least 50 years!

What are the solutions?
Challenges of sustainable societal development

1. **GROWTH.** *Gross Domestic Product / capita_year in Europe*
   - *west* ~€30 -40000 €
   - *east* ~ 20000 €

   *The share of agriculture & IAA in GDP:*
   - 0.7 - 2%
   - ≥3% (Ro 4.3 Mo10.2)

   What challenges agriculture should face if its future development is to become a priority

2. **L’ENVIRONMENT** = major challenge for future development
   - New geological era: *Anthropocene*
   - Climate change, LCA, resources ...

   W. Nordhaus and P. Romer (Nobel prize 2018): combine long-term sustainable growth of the world economy and environment (climate change…)

3. **ENERGY** is/ will be the key to the future
   - the EU with high energy dependency → **RENEWABLE ENERGIES**

Sustainable development → **capital & knowledge & environment**
The 3 MAJOR CHALLENGES for future agriculture in future society

FOOD SECURITY

PRODUCTIVITY

BIOECONOMY

Is it going down?
To feed the world?

Agriculture and Food
Comments at the end
<table>
<thead>
<tr>
<th></th>
<th>Amidon</th>
<th>Carbohydrate C5 C6…autres</th>
<th>Lipides</th>
<th>Total C</th>
<th>Protéines</th>
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BIOMASS
CARBON (50 à 90%) + NITROGEN (10 à 50%)

BIOECONOMY
_biomass production & processing
The 3 MAJOR CHALLENGES

- FOOD SECURITY
  - RESOURCES: water, soil, water pollution, NO3
  - HEALTH: pesticide, ....
  - Climat change

- PRODUCTIVITY

- ENVIRONMENT
The 3 MAJOR CHALLENGES

FOOD SECURITY

PRODUCTIVITY

ENVIRONNEMENT

ENERGY

RESOURCES: water, soil, water pollution NO3
HEALTH: pesticide, ...
Climate change

Décroissance? Nourrir le monde?

ENERGY
1. Territorialisation Regionalisation, high energy prices, autonomy, N-40%, yield -20%, methanisation > biofuels

2. Sustainable under energy realism, precision, intensive, multifunctional with environmental services, price volatility, globalization, CAP decreases, inputs increase, yield +1% Extensive or intensive organic farming for export,

3. Health without major energy constraints, sector, local, intensive or bio-urban food, biofuels 2nd generation

4. Intensive ecology with energy control, CO2 prices 56 € in 2020 and 100 € in 2030, strong CAP, legumes and oilseeds, high RTD, high methanisation and autonomy.

- N=element inputs (reduction of -61%, -15% and -40% under scenarios
- Soybean cake imports (protein autonomy in sc.4 versus increase in sc.2)
Conclusion

1. A radical change in the production method could save fossil energy
   ~ 500ktep 10% direct + ~ 1500ktep 30% indirect (N…)

2. The energy autonomy of agriculture contributes to the sustainable development of agriculture but it is not significant for the energy autonomy of the country
   because the energy consumed by agriculture represents only about 4% of the total energy consumed in a country like France
   It could even be subsidized!

3. But the agriculture can participate significantly in the energy autonomy of the country by the production of renewable energy,
   A major objective at country level.
3 DEFIS MAJEURS

FOOD SECURITY

PRODUCTIVITY

ENVIRONMENT

RESOURCES:
HELTH: pesticide, ....
Climat change

Renewable energy
ENR & nuclear

Do today’s modes of production meet these criteria?
Are current knowledge sufficient to develop a new agriculture?
The fate of N in cropping systems → environment

Uncoupled N and C

Management practices that alter inorganic fertilizer addition

Forme, rate application timing, methods...

Meta-analysis of 217^{15}N field Experiments

Cupled N and C

Complexed practices that coupled C and N

organic N sources, diversified crop rotation

Short-Term studies
Multi-process (30-42%) >> 1 technique réduction (2.6 - 20.9%)
5 New complex agro-ecosystems producing FOOD & FOODDER & BIOENERGY

1st approach

- 1.8 TEP / t N (NH₄NO₃) & 5.30 kg equivalent CO₂/ kg N

replacement of synthetic mineral nitrogen with nitrogen biologically fixed by legumes

comparison of conventional cropping systems without legumes with cropping systems with legumes in main crop and / or intercropping
First experiment: quantification

Long term experiment (30 years: 1969 – 2000), INRA Clermont-Ferrand

• 2 crops system of 6 years
  A: Wheat, Sugarbeet
  L: Alfalfa 2 years

• Mineral N: with or without Nmin on annual crops
• CI vetch: with or without EV behind a straw cereal
• R lignified culture residues: with or without

16 treatments = 2 CS * 2 Nmin * 2 CI * 2 R
A 2-year-old alfalfa produces about 1000 kgN, ± 800 in the aboveground biomass ± 200 in the soil

Can we satisfy the N requirements of a high productivity production system from legumes?
A second approach 2nd experiment:
N self-sufficiency crop system based on N brought by Legumes

**N-Sources**

1. Luzerne > 1000 kgN
   - residual effect
   - 200 kgN/4 years
   - alfalfa biomass used as “organic fertilizer”
   - 700 kgN/2 yrs

2. Legume Green Fertilizer
   - 50 - 100 kgN/yr
Fig. 2. DYNAMIQUE DU BILAN D’AZOTE

N inputs by underground biomass of Lucerne are not included in balance.
Relative yield (A), relative N concentration of grain (B) and relative N content in grain-Yield (C).

N treatment (mineral fertilisation) was used as reference treatment (100%). L1 to L4 = organic N treatments as in Table 2; N0 = without N input.


The relative grain-N yield and the relative total-N yield are high correlated (r=0.993).
CONCLUSIONS
1. The achievement of autonomous CSs in N is not a utopia
2. In animal-free production systems, pulse biomass can be used as a nitrogen source for self-sufficiency.
3. 10 to 20% of the surface area must be reserved for the production of this biomass

NOTE: Based on these results ARVALIS (former ITCF) organized a network research-development to answer this question for organic agriculture
3\textsuperscript{th} approach

In the conventional Intensive System
10 - 20\% of the area is used for
energy crops: biofuels

The production system is not improved because biofuel is
produced in centralized industrial facilities
that control the price of biomass
Crop systems with pulses in which 10 to 20% of the surface is reserved for the production of energy produced and consumed on the farm. The evaluation of the agro-system is carried out using criteria derived from the ecology of natural environments and agro-ecology.

The Value of Producing Food, Energy, and Ecosystem Services within an Agro-Ecosystem

Combined Food Energy (CFE) system was planted in May 1995 (11.1ha)

45% arable food (barley and wheat)%
45% pasture fodder crop (clover-grass) and
10% biofuels: four belts of fast-growing trees

= the benefits humans derive from **ecological processes** & **ecosystem function**

- provide a significantly increased net crop, energy, and nonmarketed ES
- require markedly less fossil-based inputs.
- provide environmental value for money for farming and nonfarming communities
- at European scale, the value of nonmarket ES > European farm subsidy payments

**Ecosystem services (ES): market and nonmarket ES**

ES associated with the CFE system were assessed by field monitoring and assessment methods in June 2006 (1995-2006)
Field assessment of each ES in **pasture**, **cereals**, and **wood biomass**

<table>
<thead>
<tr>
<th>Field process and/or state</th>
<th>Pasture 45%</th>
<th>Cereals 45%</th>
<th>Biomass 10%</th>
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<tr>
<td>Predation rate of aphids (% removal 24/hr) ES1</td>
<td>20</td>
<td>53</td>
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<tr>
<td>Predation rate of eggs (% removal 24 hr⁻¹) ES1</td>
<td>45</td>
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<td>N regulation: mineralization of plant nutrients (%) ES2</td>
<td>14.5</td>
<td>16.7</td>
<td>17.1</td>
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<td>Earthworm density (number m⁻²) ES3</td>
<td>104</td>
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<td><strong>Food/fodder (t dry matter ha⁻¹)</strong> ES4</td>
<td>6.1</td>
<td>4.1</td>
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<td><strong>Yield of wood (t dry matter ha⁻¹)</strong> ES5</td>
<td>0</td>
<td>0</td>
<td>10</td>
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<td>Carbon residue (t ha⁻¹) ES6</td>
<td>3.7</td>
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<td>Water recharged into ground (mm ha⁻¹) ES7</td>
<td>382</td>
<td>432</td>
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<td>Aesthetic (<strong>USD ha⁻¹</strong>) ES8</td>
<td>262</td>
<td>138</td>
<td>332</td>
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<td>Pollination (hives) ES9</td>
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*The ES value of the CFE system was calculated based on the ratio of 45 : 45 : 10*

J Porter et al., Ambio Vol. 38, No. 4, June 2009
The monetary value and field assessment of ES in pastures, cereals, biomass belts, and the CFE system.

<table>
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<tr>
<th>ES value USD/ ha/1 y*</th>
<th>PASTURE 45%</th>
<th>CEREALS 45%</th>
<th>BIOMASS 10%</th>
<th>CFE 100%</th>
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<td>Biological control of pests</td>
<td>13</td>
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<td>12</td>
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<td>N regulation: fixation &amp; mineralization</td>
<td>434</td>
<td>217</td>
<td>125</td>
<td>294</td>
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<td>Soil formation</td>
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<td>17</td>
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<td>Food and fodder production</td>
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<td>Row material (biomass) production</td>
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<td>Carbon accumulation</td>
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<td>Hydrological flow</td>
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<td>Anesthetics</td>
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<td>138</td>
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<td>Pollinisation</td>
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<td>47</td>
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<td><strong>Total economic value of ES</strong></td>
<td><strong>1134</strong></td>
<td><strong>998</strong></td>
<td><strong>1146</strong></td>
<td><strong>1074</strong></td>
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<td><strong>Nonmarked ES value NMV</strong></td>
<td><strong>918</strong></td>
<td><strong>483</strong></td>
<td><strong>546</strong></td>
<td><strong>685</strong></td>
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<td><strong>NMV/ES value</strong></td>
<td><strong>0.81</strong></td>
<td><strong>0.48</strong></td>
<td><strong>0.48</strong></td>
<td><strong>0.64</strong></td>
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</tbody>
</table>

Ambio Vol. 38, No. 4, June 2009
5th approach

LOME CONCEPT

FOOD & FIBER & ENERGY

CH4
biofuel
wood

autonomy
D. The Future agriculture could be

\[
\begin{align*}
L &= \text{legumes} \\
O &= \text{oilseeds} \\
Me &= \text{methanisation}
\end{align*}
\]

The 3 levers are interdependent because the L produce nitrogen (N) but also energy (Carbon), the O produce energy, and the two constitute a substrate for the production of energy by methanisation.

C-energy will be the main export

The other elements N, P, S, K, Ca, Mg, etc. will be returned to the ground with the digests of methanisation in an easily assimilable form par les plantes.
like Legumes
• Disappearance of legumes in CS: Implications (French agriculture)

• IF 3 400 000 ha was in 1959 et < 400 000 ha actually, the loss of ~ 3,000,000 ha of legumes represents

\[
\text{N loss of 3,000,000 ha } \times 200 \text{NFB/ha} = 600,000 \text{ tN} = 600,000 \text{ tN}
\]  
(corresponds to 6 000 000 ha at 100 kg N/ha)  
1 kgN = 1 l fuel for its synthesis

Massive protein import: 80% of the requirements (soybeans):

Environment: excess - pollution: 835,000 tonnes of nitrogen per year

Will we be able to meet the N requirements of a high productivity crop system by N from legumineous crops?
ESSAI 1

Essai de longue durée (30 ans: 1969 – 2000), INRA Clermont-Ferrand

• 2 rotations de 6 ans:
  A: Blé, Betterave S, blé, maïs (colza), blé, orge (blé)
  L: LUZERNE 2 ans blé, maïs (colza), blé, orge (blé)

• N minéral : avec ou sans N\text{min} sur cultures annuelles
• EV vesce: avec ou sans EV derrière une céréale à paille
• R résidus de culture lignifiés: avec ou sans

\[16 \text{ traitements} = 2 \text{ rot} \times 2 \text{ N\text{min}} \times 2 \text{ EV} \times 2 \text{ R}\]

The alfalfa crop grown for two years about produced about 1000kg N of which 200 are in the soil.
OILSEED

ENERGY
Recovery of C
HVP

CAKES
Recycling of N, P, K, Mg, ...

- Animals → manure
- Direct use as fertilizer
- Novel substrate for methanisation.
Définition
Avantage
Les substrats
Le digest : composition
Agronomie: 
utilisation digest//biomasse
fertilité du sol
Transformation of organic matter C to CH4 by anaerobic fermentation by mesophilic bacteria 30-35°C thermophilic 50-60°C

This results in:

BIOGAS = 50 -70% CH4 +35% CO2 → electricity + heat

Purification

Biogas → Bio-methane → injected into the gas network bio-CNG fuel

DIGESTAT: contains *a portion of unprocessed C
*other elements N, P, K, Ca, Mg...
<table>
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<tr>
<th>Légumineuses</th>
<th>Potentiel CH4 (m3/kg VS)</th>
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<tr>
<td><strong>Maïs</strong></td>
<td>0.38</td>
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<td><strong>Rye gras</strong></td>
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<td><strong>Lucerne</strong></td>
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<td><strong>Trèfle</strong></td>
<td>0.35</td>
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<td><strong>Lupin</strong></td>
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<tr>
<td><strong>Fève</strong></td>
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<td><strong>Pois</strong></td>
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<td><strong>Vesce</strong></td>
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<td><strong>Maïs frais</strong></td>
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<td><strong>Maïs ensilage</strong></td>
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<td><strong>Trèfle frais</strong></td>
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<td><strong>Trèfle ensilage</strong></td>
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<td><strong>Graminées</strong></td>
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<td><strong>Phleum Pr- Trèfle violet (10%)</strong></td>
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<td><strong>Vesce (50%)-avoine</strong></td>
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*VS* = Solid volatiles = MS - ash (550°C)

Jensen, 2012
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<th>Crop</th>
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<th>OM</th>
<th>N</th>
<th>Yield</th>
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<tr>
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<td>%MS</td>
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<td>6 à 9</td>
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<td>Straw wheat</td>
<td>88</td>
<td>92</td>
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<td>8 à 10</td>
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<td>4 à 8</td>
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<td>960</td>
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<td>LOME Crop rotation // Energy crops (EC)</td>
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<tr>
<td>EC: Maïs</td>
<td>Maïs</td>
<td>wheat +IC</td>
<td>oilseed</td>
<td>maïs</td>
<td>betterave</td>
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<td></td>
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<tr>
<td>LOME: Alfalfa 2 ans</td>
<td>10</td>
<td>10</td>
<td>30</td>
<td>10+10</td>
<td>20</td>
<td>10</td>
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<table>
<thead>
<tr>
<th>Energy yield</th>
<th>Ha</th>
<th>MS t/ha</th>
<th>LOME (20% alfalfa)</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Tota l it DM</td>
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<td></td>
<td></td>
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<td>CH4 m3</td>
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<td></td>
<td></td>
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<td>Total CH4</td>
</tr>
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<td></td>
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<td>Total kg N</td>
</tr>
</tbody>
</table>

| Alfalfa 1 | Wheat straw | 10 | 10 | 7 | 5 | 70 | 50 | 335 | 190 | 24000 | 9500 | X | 750 |
| Alfalfa 2 | Rapes straw | 10 | 10 | 15 | 2 | 150 | 20 | 335 | 150 | 50250 | 3000 | 10000 | 100 |

200 000 m³ CH₄ → 2000 MWh

Energy thus

~800 MWH electricity

(~100 kw power)

800 * 0.15 = 120 000€
Contribution of agriculture to France's energy self-sufficiency

For ~ 100,000 ha energy crops (fuels, etc.)
energy production is
100,000 ha * 6,000 m³ CH₄/ha = 600 millions m³ CH₄

If the 100,000 ha are integrated into a LOME system
(rotation 5 years, 500,000 ha)
then energy production would be
500,000 ha * 2000 m³ CH₄/ha = 1 milliards m³ CH₄

Et si *4000 m³ CH₄/ha (Autriche) = 2 millions tep
Energy autonomy: 1 milliards m³ CH₄

The new role of biogas in electricity production: Flexibility instead of base load.

20% Renewable Energy Sources

40% Renewable Energy Sources

80% Renewable Energy Sources

CARBURANT

1 millions tep

And if *4000 m³ CH₄/ha (Autriche) = 2 millions tep

Cons France: transport ~50 millions tep (agriculture 3 à 4 M tep)
Approach

**supply – demand**

confrontation

1. Crop system
2. Animal Feeding
   - Ration x number
   - What kind of ration?
   - What number?

3. Methanisation at farm level
   - Minimum Demand

SOJA
   - Externalisation

autonomie

Husbandry bovin \( \rightarrow \) \( \sim 1,000,000 \) t Norganique
Manure supply and use

For 1000t MANURE

If 10t manure/UGB, than for 100UGB = 1000t manure

With 60m3 biogaz /t HM or 200m3/t DM
BIOGAZ yield =1000*60 =

60,000 m³ biogaz (for 100ha> 185 000m³ biogaz)

• The manure has a low methanogenic potency
• Need for complementary substrates richest in C\rightarrow\text{Cl}
• Association of several farms

• BUT is a source of micro-organisms and has an important buffer capacity
Composition of digests according to the origin of the substrate.

(CG=clover & grass; CC=vetch)
(CG&CC stored by silage; fermentation 2 steps, 4 to 10 days)

<table>
<thead>
<tr>
<th></th>
<th>Liquide</th>
<th>SOLIDE</th>
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<tr>
<td></td>
<td>CG&amp;CC</td>
<td>Paille Pois</td>
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<tr>
<td>MS%</td>
<td>2.5</td>
<td>18</td>
</tr>
<tr>
<td>MS org%</td>
<td>52</td>
<td>74</td>
</tr>
<tr>
<td>%N (MF)</td>
<td>0.25</td>
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<td>N-NH4 (MF)</td>
<td>0.18</td>
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<td>NH4/Ntot</td>
<td>71</td>
<td>26</td>
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<tr>
<td>C% (MS)</td>
<td>36</td>
<td>40</td>
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<tr>
<td>C/N</td>
<td>3.7</td>
<td>11</td>
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<tr>
<td>P% (MS)</td>
<td>0.62</td>
<td>0.40</td>
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<tr>
<td>K (MS)</td>
<td>18.5</td>
<td>2</td>
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<tr>
<td>Mg (MS)</td>
<td>0.72</td>
<td>0.36</td>
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<tr>
<td>pH</td>
<td>7.69</td>
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</table>

Stinner, Möller, Leithold, EJA, 2008
Digest = the best fertilizer!

- Méthanisation / compostage
- Allows for relative separation of cycles C and N
- Better distribution in time and in crop system.
- Better BNF because lower N content
- Reduction of N losses by leaching
- Higher N use
- Reduction of Greenhouse Gases Effects
Autonomy in nitrogen

- is no longer a utopia because the digestate would replace the N-mineral synthesis by biological N fixation and recycle the other elements P, K, Ca, Mg, etc.
- this concept is applicable even in organic farming where nitrogen is the main limiting factor.
- At present, Austrian, German, Dutch and Italian colleagues (the most advanced countries in this field) are insisting on this role of methanisation!
In the future in the evaluation of the various economic activities (including agriculture) the effect on the environment will be an important objective.

- Agro-environmental analyses on GGE, pollution/contamination of the environment, life cycle analysis (energy, autonomy..) etc. ... will be generalized and incentives & coercive measures will be put in place (carbon tax...).

- LOME was an essential link in this process
CONCLUSION 1

- The current policy is largely insufficient because LOME not only makes a major contribution to the energy autonomy of agriculture and the country, but also the radical transformation of agriculture because the integration of the methanisation process makes the increase in productivity compatible with the environment, including climate change. (PV, wind turbine)

- Should we copy Germany?
  - YES for efficiency and speed of development
  - NO, for the concept, because to facilitate “industrial” efficiency our neighbours chose corn as a substrate and promoted industrial methanisation
Conclusion 2.
To put an end to the recurrent crisis in agriculture, the agriculture should challenge itself and develop its plan for a new agriculture that responds to the country’s major challenges.

We have all the knowledge needed to change if Agroecology is complemented by the Bioeconomy, because we ensure the maximum use of solar energy through the production of biomass (renewable carbon) on the one hand, while preserving and even improving the environment, and optimizing the use of biomass according to the major interests of the country, between food and non-food such as energy production, fertilizers, etc. on the other hand.

This is a sine qua non for ending the recurrent crisis in agriculture and making it a priority again in the future.
It’s time to act: SENECA Letters to Lucilius

...it is hours that we are taken away by force,
others by surprise,
Others are falling from our hands.
But the most shameful loss is that which comes from neglect; and, if you take heed of it,
the greater part of life
goes on to do wrong,
a great one to do nothing,
the whole to do something other than what we should.
... be completely in control of all your hours.
You will depend less on tomorrow, if you make sure of today.
As we adjourn, life passes.

.....everything else is borrowed, time alone is our good.
END

for INSTANT.....

Now it’s your turn to act!