An advanced study

Storing 4 per 1000 carbon in soils: the potential in France

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Context and rationale

- The objective of carbon neutrality in 2050
- Two pillars
  - Drastically reduce GHG emissions
  - Increase C sinks (biomass, soils)
- A scientific controversy about the potential for additional C storage in soils (4 per 1000 initiative)
Context and rationale

- The 4 per 1000 initiative
- At the early beginning of the initiative a very simple calculation:
  - Soils contain about 2400 Gt C at the global scale
  - Anthropogenic emissions of CO\textsubscript{2} (fossil fuel consumption and deforestation) amount about 9.4 Gt C per year
  - 9.4/2400 \approx 0.004 \rightarrow an increase of the soil C stock of 4‰ per year would theoretically compensate CO\textsubscript{2} emissions
- Numerous political and scientific controversies about this initiative
- A need for an accurate assessment of the potential additional C storage in soils, but a lack of methodology and a lack of economical approaches

\rightarrow INRA was appointed by the French ministry of Agriculture and the French Environment and Energy management Agency (Ademe) to carry out an advanced study on this topic at the national scale
Objectives

- To identify soil C storing practices
- To assess and map the potential for additional carbon storage in soils following their implementation
- To assess their implementation cost
- To propose an optimal cost-efficient strategy for additional soil C storage at the national scale
Scope

- Mainland France only
- No land use change (no afforestation, no artificialisation of agricultural areas)
- No production systems modification or relocation
- No change in demand or food regimes

=> only management practices readily implementable
General organisation

The advanced study was carried out during two years (2017-2019), under the umbrella of the DEPE-INRA, following its charter and basic principles:

- Two scientific leaders
- A multidisciplinary panel of 28 experts (soil scientists, agronomists, economists, modellers)
- A project team (including two non-permanent junior scientists for modelling)
- An advisory board and a technical committee

Denis Angers (AAC Canada)
Jérôme Balesdent (INRA)
Isabelle Basile-Doelsch (INRA)
Claire Chenu (Agroparistech)
Rémi Cardinael (Cirad)
Eric Ceschia (INRA)
Joel Darroussin (INRA)
Sabine Houot (INRA)
Safya Menasseri (Agrocampus)
Delphine Mézière (INRA)
Thierry Morvan (INRA)
Jean Roger-Estrade (Agroparistech)
Valérie Viaud (INRA)
Olivier Thérond (INRA)
François Gastal (INRA)
Anne Isabelle Graux (INRA)
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Manuel Martin (INRA)
Valentin Bellassen (INRA)
Philippe Delacote (INRA)
Nathalie Delame (INRA)
Elodie Letort (INRA)
Claire Mosnier (INRA)
Method: overview

1. Baseline and current (2009-2013) practices description
   C storing practices description
   - Agro-pedo-climatic context
   - Technical and economic context
   - Modifications in management practices
   - Applicability criteria

2. Potential applicability (ha)

3. Technical cost (€/ha/ C storing practice)
   - Crops – Grassland – Forest

3. Additional C storage (tC/ha/ C storing practice)
   - STICS – PASIM – Expert calculation
   - Crops – Grassland – Forest

4. «Technical» C storage potential
   at the national level

5. C storing practice efficiency (€/tC)

6. «Economic» C storage potential
   - Minimizing the total cost of C storage
   - Optimisation model BANCO

Bioeconomy and its trade-offs
Toulouse, 19 Nov. 2019
Method

Nine soil C storing practices were selected, based on a literature review

- no-tillage
- expansion of cover crops (longer and more frequent cover crops)
- new C inputs (not already spread on agricultural soils under current management practices)
- expansion of temporary grasslands (instead of silage maize)
- agroforestry
- hedges
- moderate intensification of extensive grasslands (+50kgN/ha)
- animal grazing instead of mowing
- grass cover of vineyard

For each selected practice, its potential applicability was calculated considering technical constraints (ex no reduced tillage for sugar beet, no cover crop for intercrop period < 2 months, no agroforestry if soil depth < 1m or plot size < 1ha...)

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The additional C storage following the implementation of C storing practices was assessed using a modelling approach at a fine spatial-scale resolution (≈1 km²). Each grid cell was characterized by its:
- dominant land-use
- local climate
- dominant soil type
- dominant cropping system (crop rotation and current farming practices)
- initial soil C stock value
Method

Two models were used for simulations:
- STICS for arable crops
- PaSim for permanent grasslands

Both models include an explicit representation of the C cycle.
Method

For each grid cell, changes in soil C stock were simulated for a period of 30 years
- under current management practices (= baseline)
- under C storing management practices (ex expansion of cover crops)

The additional C storage was calculated as the difference between the simulated soil C stock under C storing practices and the simulated soil C stock under current management practices.

Simulations were performed under current climatic conditions for a 30 years period. New simulations are currently run under a second climatic scenario (RCP 8.5, 2040-2070).

Simulations were performed for the 0-30cm horizon, and then extrapolated to the whole soil profile.

For each C storing practice, a complete greenhouse gases budget was calculated.
Implementation cost assessment

« additional cost » = « cost » C storing practice – « cost » current practice

Cost = loss or gain for the farmer

- Δ overheads
  - Δ inputs (fertilizer, feedstuff, …)
  - Δ crop management operations (labour, machinery, fuel)
  - Dedicated investments (e.g. tree planting)

- Δ revenue
  - Δ yield
  - New revenue (e.g. sale of wood)
  - Change in land allocation (e.g. crop area substituted with trees or hedges)

- Excluding « optional subsidies »
  - E.g. CAP payments, AEM, regional subsidies

- Constant annuity with a 4.5% discount rate (CGDD)

Cost were calculated for each C storing practice and each French region
Cost-effective allocation of the additional C storage effort

Which C storing practices implementing? And where? To reach a global C storage target at the lowest price?

- Cost for farmer (region, practice) €/ha/yr
- Additional C storage (region, practice) tC/ha/yr
- Potential applicability (region, practice) ha
- Compatibility (practice, practice’)

STICS, PASIM, litterature ...
Experts

BANCO

Uptake level (region, practice) (ha)
Marginal C storage cost (€/tC/yr)
Total C storage cost (€/yr)

National additional C storage target

Marginal carbon storage cost curve

Cumulated additional C storage (Mt C/year)

Marginal cost (€/tC)

C storage target (MtC/yr)

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Example of results: baseline

Carbon storage under current farming practices (baseline) for croplands (arable crops and temporary grasslands)

- 91 ±160 kg C/ha/yr for crop rotations without temporary grasslands

+259 ±280 kg C/ha/yr for crop rotations with temporary grasslands

C storage (in kg C/ha/yr)

Kg C/ha/year
Example of results: expansion of cover crops

Percentage of intercrop periods with a cover crop during the crop rotation

In the baseline (current farming practices, mostly during winter)

In the scenario with expansion of cover crops (CC during winter and summer fallows)

Potential applicability: 16.6 Mha (96.1% of the cropland area)

Cover crops:
9.3 Mha in 2009-2013 (baseline)
Additional carbon storage provided by the expansion of cover crops

Average additional C storage

+126 ± 93 kg C/ha/yr
Map of the additional C storage provided by the expansion of cover crops

- Less additional carbon storage provided by cover crops in the western part of France;
  - Due to crop rotations already including perennial temporary grasslands, which provide less opportunities for incorporating cover crops

- By contrast, more additional carbon storage in arable cropping systems of the Parisian Basin and South-western France

Many other environmental benefits (ecosystem services) including other net climate mitigation effects (surface albedo increase, decrease in surface heat fluxes...) ➔ not accounted for!
### Aggregated results for all C-storing practices

<table>
<thead>
<tr>
<th>Arable cropping systems</th>
<th>Additional C storage 0-30 cm soil layer Kg C/ha/an</th>
<th>Potential applicability Mha</th>
<th>Potential additional C storage at the national level 0-30 cm soil layer Mt C/year</th>
<th>Relative yearly increase of soil C stocks (=949 Mt C for cropland soils in mainland France) ‰ /year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expansion of cover crops</td>
<td>+126</td>
<td>16.03</td>
<td>+2.019</td>
<td></td>
</tr>
<tr>
<td>No tillage</td>
<td>+60</td>
<td>11.29</td>
<td>+0.677</td>
<td></td>
</tr>
<tr>
<td>New carbon inputs</td>
<td>+61</td>
<td>4.21</td>
<td>+0.257</td>
<td></td>
</tr>
<tr>
<td>Expansion of temporary grasslands</td>
<td>+114</td>
<td>6.63</td>
<td>+0.756</td>
<td></td>
</tr>
<tr>
<td>Agroforestry</td>
<td>+207</td>
<td>5.33</td>
<td>+1.102</td>
<td></td>
</tr>
<tr>
<td>Hedges</td>
<td>+17</td>
<td>8.83</td>
<td>+0.150</td>
<td></td>
</tr>
<tr>
<td><strong>Total for croplands</strong></td>
<td></td>
<td></td>
<td><strong>+4.960</strong></td>
<td><strong>+5.2 ‰</strong></td>
</tr>
</tbody>
</table>

!!! Carbon storage limited in time ➔ e.g. for cover crop new equilibrium reached after 50 years !!!
## Aggregated results for all C-storing practices

<table>
<thead>
<tr>
<th>Practice</th>
<th>Additional C storage Horizon 0-30 cm</th>
<th>Potential applicability</th>
<th>Potential additional C storage at the national level Horizon 0-30 cm</th>
<th>Relative yearly increase of the soil C stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent grasslands</td>
<td>Kg C/ha/year</td>
<td>Mha</td>
<td>Mt C/year</td>
<td>‰ /year</td>
</tr>
<tr>
<td>Moderate intensification of extensive grasslands</td>
<td>+176</td>
<td>3.94</td>
<td>+0.694</td>
<td></td>
</tr>
<tr>
<td>Grazing instead of mowing</td>
<td>+265</td>
<td>0.09</td>
<td>+0.023</td>
<td></td>
</tr>
<tr>
<td>Total for permanent grasslands</td>
<td></td>
<td></td>
<td>+0.720</td>
<td>+0.9 ‰</td>
</tr>
<tr>
<td>Vineyard</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass cover</td>
<td>+182</td>
<td>0.56</td>
<td>+0.103</td>
<td></td>
</tr>
<tr>
<td>Total for vineyard</td>
<td></td>
<td></td>
<td>+0.103</td>
<td>+3.7 ‰</td>
</tr>
<tr>
<td>Total for French agricultural soils (without forests)</td>
<td></td>
<td></td>
<td>5.78</td>
<td>+3.3 ‰</td>
</tr>
</tbody>
</table>

Bioeconomy and its trade-offs
Toulouse, 19 Nov. 2019
A potential for additional C storage of about 5.78 Mt C/year (in the 0-30cm soil layer)

This represents an annual increase of
- +5.2 ‰ for croplands
- +0.9 ‰ for grasslands
- +3.3 ‰ for all agricultural soils

This potential is mainly found in arable soils (86% of the total potential), partly because initial soil C stocks are low

Extrapolated to the whole soil profile (5.78 → 8.43 MtC = 31MtCO₂e), this additional C storage would compensate 6.8% of national GHG emissions (458 MtCO₂e)
### Costs

<table>
<thead>
<tr>
<th>C storing practice</th>
<th>Potential applicability (Mha)</th>
<th>Cost for farmer (€/ha/year)</th>
<th>Storage cost (€/tC)</th>
<th>Storage cost (€/tCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New carbon inputs</td>
<td>4.21</td>
<td>-52 (-117; -8)</td>
<td>-494 (-1 192; -134)</td>
<td>-135 (-325; -37)</td>
</tr>
<tr>
<td>Grass cover of vineyards</td>
<td>0.15</td>
<td>-26 (-27; -22)</td>
<td>-56 (-44; -77)</td>
<td>-15 (-21; -11)</td>
</tr>
<tr>
<td>In winter</td>
<td>0.41</td>
<td>-15 (15; 15)</td>
<td>-51 (-51)</td>
<td>-14 (-14)</td>
</tr>
<tr>
<td>Expansion of cover crops</td>
<td>16.03</td>
<td>39 (12; 147)</td>
<td>180 (69; 1 104)</td>
<td>49 (19; 301)</td>
</tr>
<tr>
<td>Moderate intensification of extensive grasslands</td>
<td>3.94</td>
<td>28 (12; 38)</td>
<td>130 (60, 1 189)</td>
<td>35 (16,324)</td>
</tr>
<tr>
<td>Grazing instead of mowing</td>
<td>0.09</td>
<td>73 (-85; 146)</td>
<td>203 (-2 791; 518)</td>
<td>55 (-761; 141)</td>
</tr>
<tr>
<td>Expansion of temporary grasslands</td>
<td>6.63</td>
<td>91 (-40; 263)</td>
<td>473 (-242; 1 667)</td>
<td>129 (-66; 455)</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>5.33</td>
<td>118 (63; 179)</td>
<td>302 (195; 386)</td>
<td>82 (53; 105)</td>
</tr>
<tr>
<td>Hedges</td>
<td>8.83</td>
<td>73 (54; 87)</td>
<td>2 322 (2 013; 3 618)</td>
<td>633 (549; 987)</td>
</tr>
</tbody>
</table>

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Toulouse, 19 Nov. 2019
Storing 4 per 1000 carbon in soils
Brussels, 14 oct. 2019

Marginal carbon storage cost curve

No incentive 0€/tC
New C inputs; Grass cover of vineyards
Total C storage 0.66 MtC/yr (=7.8% of the potential)
+0.26‰/yr
% compensation of French GHG emissions 0.5%
Total cost -228M€/yr

Bioeconomy and its trade-offs
Toulouse, 19 Nov. 2019
Marginal carbon storage cost curve

Current carbon price 25€/tCO₂e = 91.75€/tC
New C inputs; Grass cover of vineyards; cover crops; temporary grasslands
Total C storage 1.58 MtC/yr (=18.7% of the potential)
+0.62‰/yr
% compensation of French GHG emissions 1.3%
Total cost -162M€/yr
Current carbon price 91.75 €/tC = 25 €/tCO2e

Contribution of C storing practices

- Cover crops (51%)
- New C inputs (27%)
- Grass cover of vineyards in winter (12%)
- Temporary grasslands (6%)
- Permanent grass cover of vineyard
- Moderate intensification of grasslands

- Total C storage: 1.58 MtC/yr = -5.8 MtCO2e/yr
- 97% in croplands and vineyard
- % compensation of total French emissions: 1.3%
- Total cost = -162 M€/yr = gain

Bioeconomy and its trade-offs
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Current carbon price 91,75 €/tC = 25 €/tCO2e

Contribution of French regions

The main contributing region is « Centre-Val de Loire », an intensive cropland area

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Marginal carbon storage cost curve

Shadow price of carbon in 2020 55€/tCO₂e=201.7€/tC
Cover crops, Moderate intensification of grasslands, New C inputs, Temporary grasslands, Grass cover of vineyards in winter, Permanent grass cover of vineyard, Agroforestry
Total C storage 4.06 MtC/yr (=48.2% of the potential)
+1.52‰/yr
% compensation of French GHG emissions 3.3%
Total cost 156M€/yr
Shadow price of carbon in 2020 (201.7 €/tC = 55 €/tCO$_2$e)

- Cover crops (58%)
- Moderate intensification of grasslands (19%)
- New C inputs (11%)
- Temporary grasslands (6%)
- Grass cover of vineyards in winter
- Permanent grass cover of vineyard
- Agroforestry
- Grazing instead of mowing

- Total C storage: 4.06 MtC/yr = 14.9 MtCO$_2$e/yr
- % compensation of total French emissions: 3.3%
- Total cost = 156 M€/yr

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Shadow price of carbon in 2020 (201,7 €/tC = 55 €/tCO₂e)

Bioeconomy and its trade-offs
Toulouse, 19 Nov. 2019
Storing 4 per 1000 carbon in soils

Marginal carbon storage cost curve

Marginal cost (€/tC)

Cumulated additional C storage (Mt C/year)

- No incentive
  - 0€/tC
  - 0.66 MtC/yr
  - +0.26‰/yr
  - %comp. 0.5%
  - -228M€/yr

- Current carbon price
  - 25€/tCO₂-e=91.75€/tC
  - 1.58 MtC/yr
  - +0.62‰/yr
  - %comp. 1.3%
  - -162M€/yr

- Shadow price of carbon in 2020
  - 55€/tCO₂-e=201.7€/tC
  - 4.06 MtC/yr
  - +1.52‰/yr
  - %comp. 3.3%
  - 156M€/yr

- Total potential
  - 8.43 MtC/yr
  - +3.3‰/yr
  - %comp. 6.8%
  - 2297M€/yr

Bioeconomy and its trade-offs
Toulouse, 19 Nov. 2019
A potential for additional C storage of about 5.78 Mt C/year (in the 0-30cm soil layer)

This represents a relative increase of +3.3% for agricultural soils (+ 5.2% if only arable soils are considered)

This potential is mainly found in arable soils (86% of the total potential), partly because initial soil C stocks are low

Extrapolated to the whole soil profile, this additional C storage would compensate 6.8% of national GHG emissions

About half of this potential is at a lower cost than the shadow price of carbon

The optimal combination of C storing practices depends on the regional context