# Dynamic of organic phosphorus in the plough soil layer of three contrasting long-term field experiments

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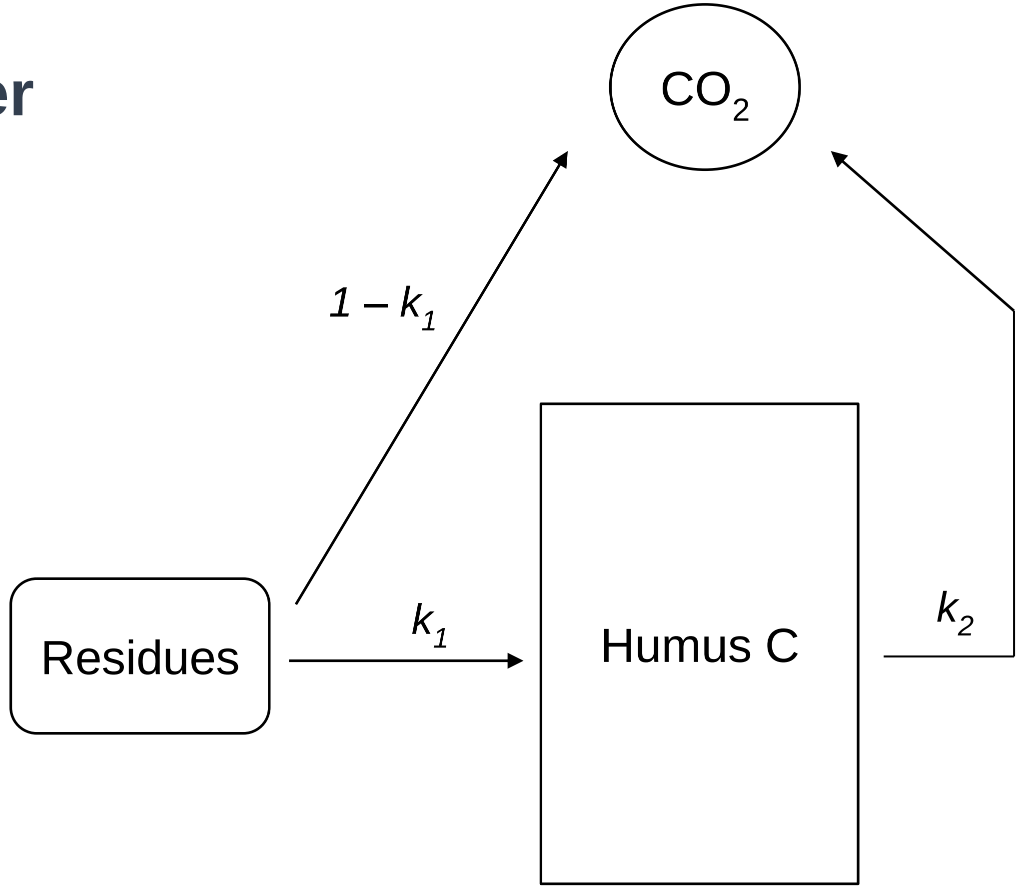
# Cropped soils over decades, ploughed layer

- Soil Organic Phosphorus (SOP): ≈ **30 %** of total phosphorus (P)
- Few long-term studies in field conditions on SOP dynamics
- **No information on SOP gross mineralization**
- Extensive literature on soil organic carbon speciation, dynamic and modeling (Andriulo et al 1999, Clivot et al 2019, Hénin and Dupuis 1945)

➔ **model adaptation to SOP:**
→Annual time step
→Simulation over decades
→Cropped field conditions




*Conceptual diagram of the Hénin-Dupuis model in Andriulo et al 1999: consider two C pools. $k_1$ = humification rate of crop residues, $k_2$ = mineralization rate of soil organic matter*

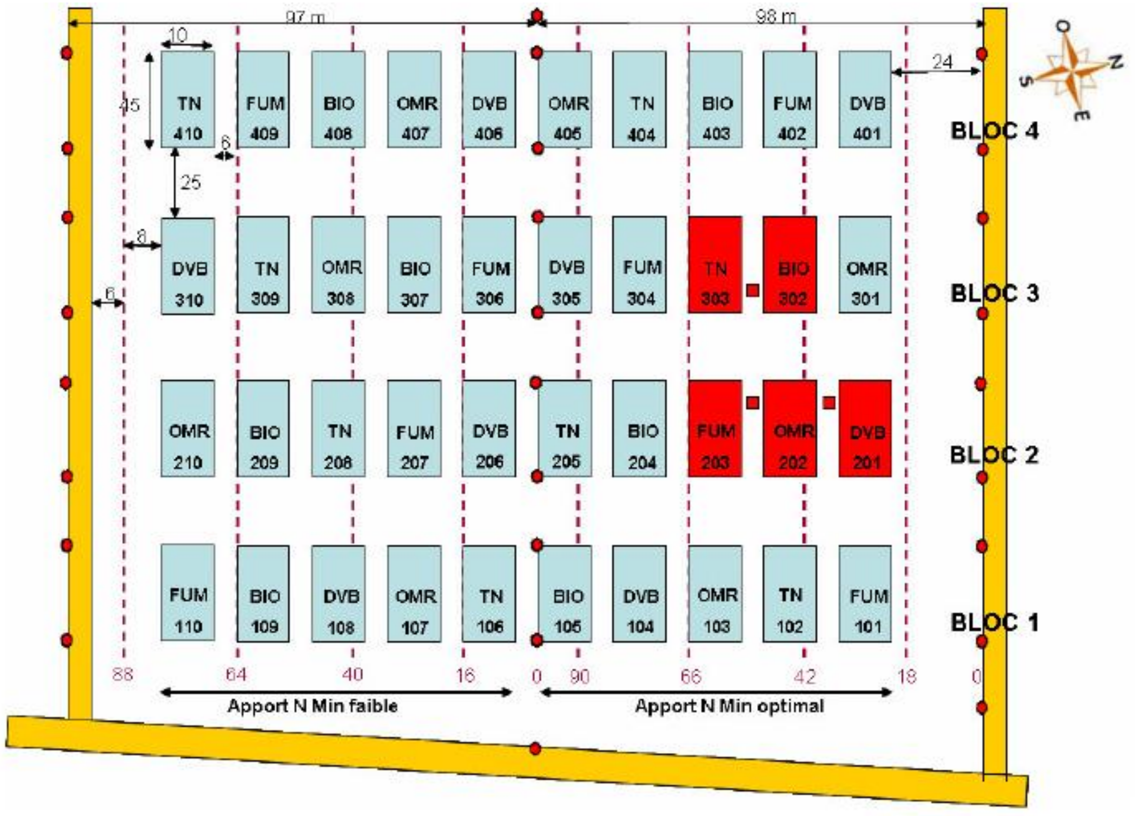
## Study aims

- **Quantification of SOP annual gross mineralization rate**

  →Modeling on time series data
  →Over several decades
  →3 long-term field experiments (4 replicates per treatments)
  →Different field conditions

- **Assessment of fertilization practices effects on SOP gross mineralization**

  →Organic waste products fertilization (OWP)
  →Mineral fertilization




*Qualiagro field map*

# Long-term field experiments

**S2**

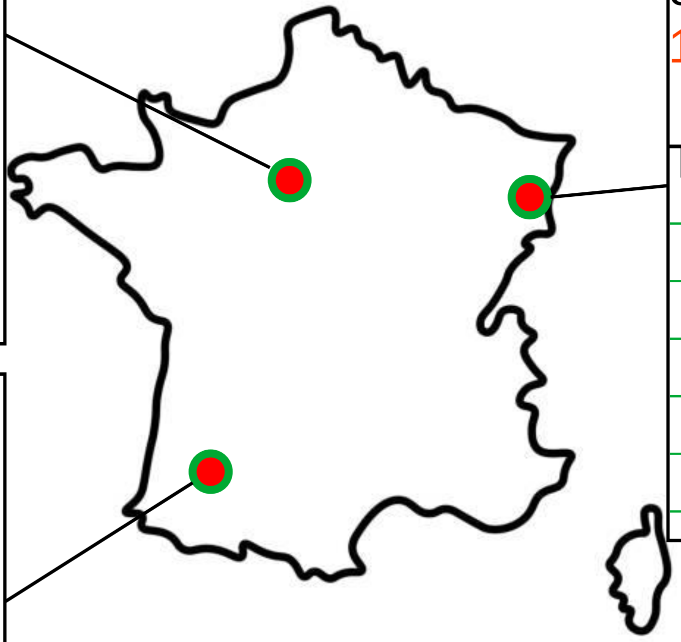
Oceanic ; luvisol; corn-wheat;
18 years; 7 soil samplings; pH = 7.1

Treatments and P inputs (kg P $ha^{-1}$ $an^{-1}$):
→ Control (5)
→ Municipal solid waste (24)
→ Farm yard manure (28)
→ Biowaste (44)
→ Green waste and sewage sludge (106)

**S1**

Oceanic ; sandy soil ; maize monoculture
17 years ; 4 soil samplings; pH = 7.3

P inputs as tripe superphosphate :
0, 27, and 76 kg P $ha^{-1}$ $yr^{-1}$



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**S3**

Continental; eutric brunisol;
corn-wheat-sugar beet-barley ;
14 years; 6 soil samplings; pH = 8.3

Treatments and P inputs (kg P $ha^{-1}$ $an^{-1}$):
→ Control (8)
→ Farm yard manure (21)
→ Composted farm yard manure (21)
→ Biowaste (17)
→ Urban sewage sludge (36)
→ Green waste and sewage sludge (45)

## Sampling and measures

- **Soils and Organic waste product**
  - →**TotP**: HF extraction (AFNOR 1999)
  - →**Organic P**: Saunders and Williams (1955)
- Crops
  - →Annual yield
  - →P concentration in grains
  - →Aboveground residues biomass (S2, S3 and some years in S1)
  - →P concentration in aboveground residues

| | **Cumulated sum total P applied** (kg P ha$^{-1}$) | | **Cumulated sum organic P applied** (kg P ha$^{-1}$) | | $C_{org}/P_{org}$ | $N_{org}/P_{org}$ |
|---|---|---|---|---|---|---|
| | **S2** | **S3** | **S2** | **S3** | | |
| **BIO** | 834 | 327 | 58 | 17 | 725 ±142 | 59 ±11 |
| **FYM** | 714 | 362 | 257 | 114 | 174 ±57 | 11 ±2 |
| **FYMC** | | 373 | | 114 | 133 ±37 | 10 ±2 |
| **MSW** | 436 | | 39 | | 1012 ±313 | 55 ±11 |
| **SLU** | | 588 | | 92 | 73 ±9 | 12 ±1 |
| **GWS** | 2020 | 715 | 323 | 107 | 134 ±51 | 12 ±3 |

## Model description

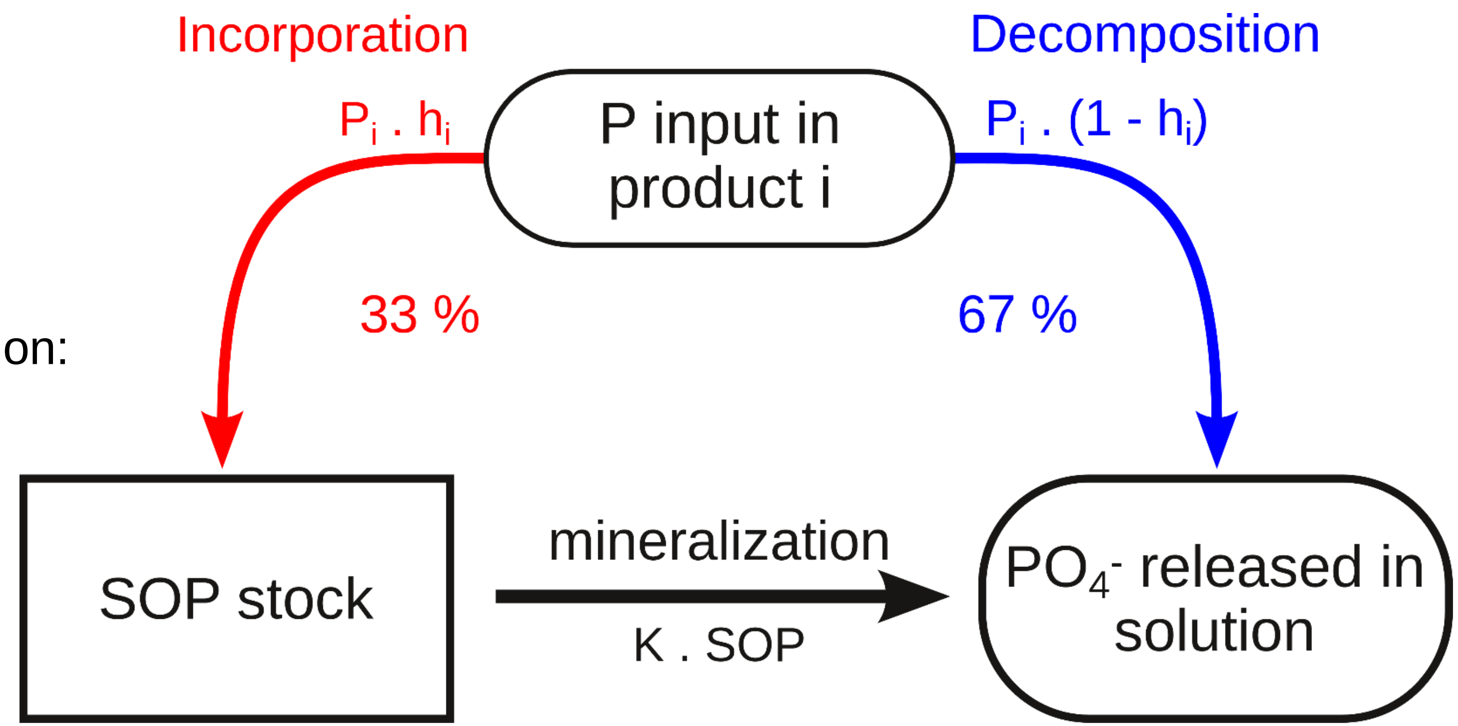
- SOP dynamic = balance between:
  1) **P incorporation** to SOP
  2) **SOP mineralization**
  →Annual time step

- Products P inputs the year following fertilization:
  →$PO_4^-$ (decomposition)
  →SOP (incorporation)

- Derivative equation:

$$\Delta SOP = \sum (P_i \times h_i) - K \times SOP$$

with :
*i*: P input source (3 types of crop residues, OWP)
**Pi** (kg ha$^{-1}$ y$^{-1}$): amount of organic P input within *i*
**hi**: incorporation coefficient of Pi to SOP during 1 year
**K** (y$^{-1}$): gross mineralization coefficient of SOP



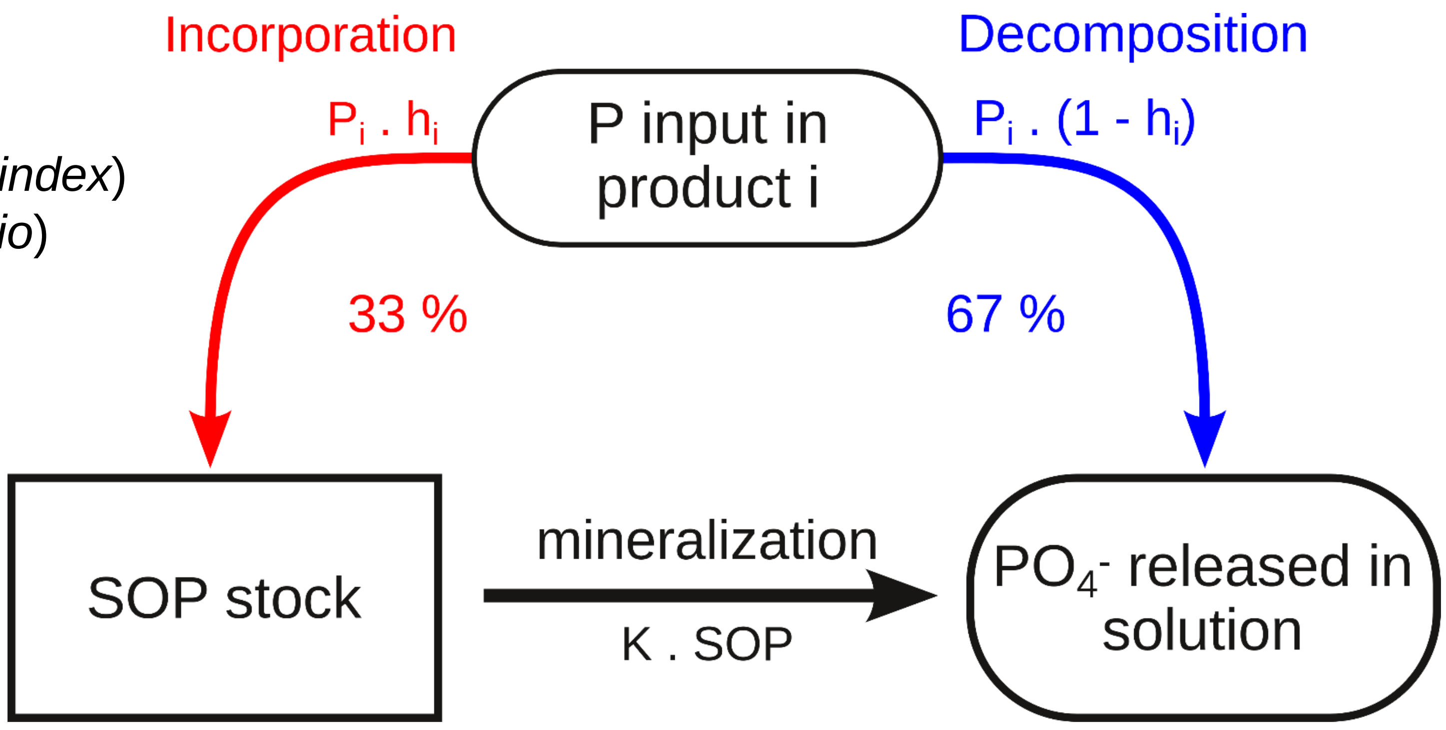

*Conceptual diagram of the model*

## Model calculation

- **Known parameters:**
  →**Pi** : measured in OWP and calculated for:
    - S1 aboveground residues (*use P harvest index*)
    - Belowground residues (*use root-shoot ratio*)
    - Harvest losses (≈ *3% P exported*)
  →**hi** *(based on published values)*
  →SOP stock

- **Unknown parameter: K**
  →Optimized (reduce the sum of square)

- gross annual rate of mineralization =
  **K x SOP** (kg P ha$^{-1}$ y$^{-1}$)




*Conceptual diagram of the model*

## Other calculation

- Net SOP stock variation evaluated with **linear regression**

## Sites main characteristics

| | S1 | S2 | S3 |
|---|---|---|---|
| **Mean annual yield** (t ha$^{-1}$ y$^{-1}$) | 8.3 ±2.0 **a** | 8.2 ±1.3 **a** | 9.1 ±3.9 **b** |
| **Mean annual P exportation** (kg P ha$^{-1}$ y$^{-1}$) | 26.5 ±6.5 **b** | 23.5 ±7.2 **a** | 22.5 ±8.5 **a** |
| **Mean annual organic P applied in OWP incorporated to SOP** (kg P ha$^{-1}$ y$^{-1}$) *include years without fertilization* | | 6.6 ±11 | 4.7 ±6.5 |
| **Mean annual P return in crop residues incorporated to SOP** (kg P ha$^{-1}$ y$^{-1}$) | 2.5 ±0.7 | 3.2 ±1.5 | 4.0 ±2.5 |
| **Initial total P stock** (kg P ha$^{-1}$) | 1508 ±116 | 2440 ±155 | 4296 ±142 |
| **Initial SOP stock** (kg P ha$^{-1}$) | 446 ±43 | 595 ±127 | 1145 ±108 |

## SOP stocks variation between sites and treatments

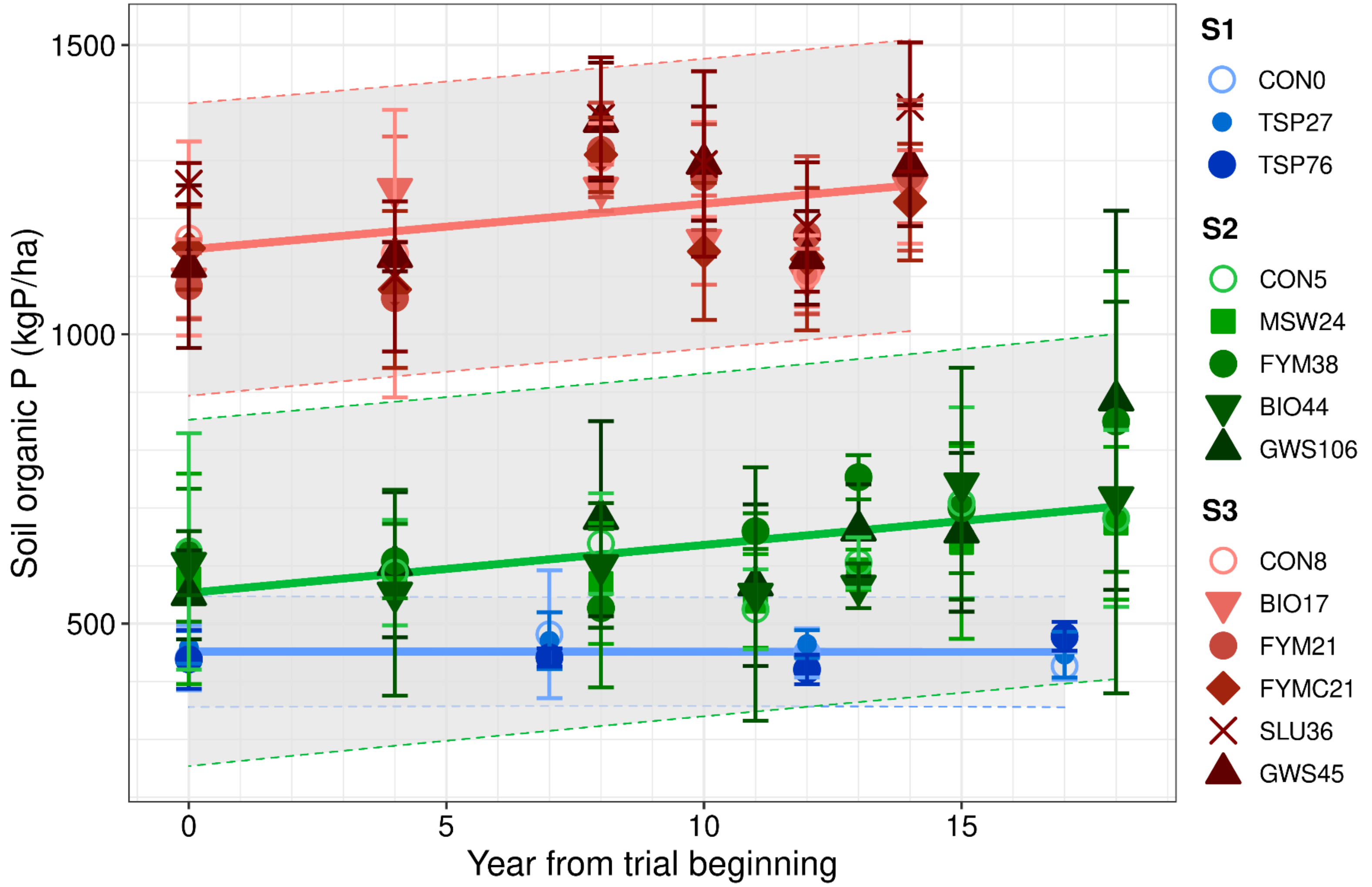
- Variations (= slope) (kg P ha$^{-1}$ y$^{-1}$):

  → S1: -0.04 ±1.06
  → S2: 8.3 ±2.2
  → S3: 7.9 ±2.2

- **Significant site effect on slope and initial SOP stock**

- In all sites:

  →no significant difference between treatments




*Measured SOP and each site linear regression on SOP stocks in the ploughed soil layer as affected by P fertilization along all three sites.*

## Model results

- Gross mineralization coefficient:

  →**Significant differences between treatments in S2**
  *(P-value = 0.02)*

  →highest coefficient for manure and green waste + sludge

  →OWP with highest P incorporation to SOP

- In S1 and S2, **release of $PO_4^-$** from residues + OWP decomposition over 1 year is **greater than annual rate of SOP gross mineralization**

| | S1 | S2 | S3 |
|---|---|---|---|
| **K** ($y^{-1}$) | 0.0046 ±0.0038 | **0.017** ±0.016 * | 0.0047 ±0.0049 |
| **Residence time** (y) | 217 | **59** | 213 |
| **Gross mineralization** (kg P $ha^{-1}$ $y^{-1}$) | 2.1 ±1.7 | 10.8 ±10.1 | 5.7 ±5.8 |
| **Crop residues + OWP $PO_4^-$ release** (kg P $ha^{-1}$ $y^{-1}$) | 12.5 ±3.6 | 10.6 ±4.2 | 9.4 ±4.3 |
| **P incorporation to SOP** (kg P $ha^{-1}$ $y^{-1}$) | 2.5 ±0.7 | 9.8 ±11.8 | 8.7 ±6.9 |

## OWP fertilization and SOP mineralization

1) P in OWP is mainly as **inorganic P form** (≈ 80%)
   →High difference in P applied as OWP due to **$C_{org}$:$N_{tot}$:$P_{org}$ stoichiometry** and **reasoning based on C or N**
   →Organic P amounts applied in OWP are **much smaller** than SOP stock ➔ small impact

2) SOP annual gross mineralization rate is **not affected** by fertilization treatment

3) **$PO_4^-$ released by P inputs decomposition** ≥ SOP gross mineralization

## Further research needed

- Study more long-term field experiments to highlights SOP mineralization drivers
- Look at OWP and soil P speciation to investigate a SOP mineralization driver
- Compare SOP mineralization and $PO_4^-$ diffusion at solid-to-solution interface
  →Quantify SOP mineralization contribution to plant nutrition

# Thanks for listening


## Thanks to

The QualiAgro and PROspective field experiments form part of the SOERE-PRO (network of long-term experiments dedicated to the study of impacts of organic waste product recycling) integrated as a service of the ‘‘Investment for future’’ infrastructure AnaEE-France, overseen by the French National Research Agency (ANR-11-INBS-0001). The QualiAgro experiment was founded and is still supported by INRAE and Veolia R&I.

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# Supplementary

| | Total P concentration (g P kg$^{-1}$) | Organic P (%) | C/P | N/P |
|---|---|---|---|---|
| **BIO** | 4.7 ±1.4 | 7 | 51 ±10 | 4.1 ±0.8 |
| **FYM** | 6.0 ±1.4 | 36 | 62 ±20 | 4.0 ±0.9 |
| **FYMC** | 7.8 ±1.6 | 36 | 48 ±13 | 3.5 ±0.9 |
| **MSW** | 3.6 ±0.7 | 9 | 91 ±28 | 4.9 ±1.0 |
| **SLU** | 30 ±2 | 17 | 12 ±2 | 2.0 ±0.3 |
| **GWS** | 14 ±4 | 16 | 21 ±8 | 1.9 ±0.5 |