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

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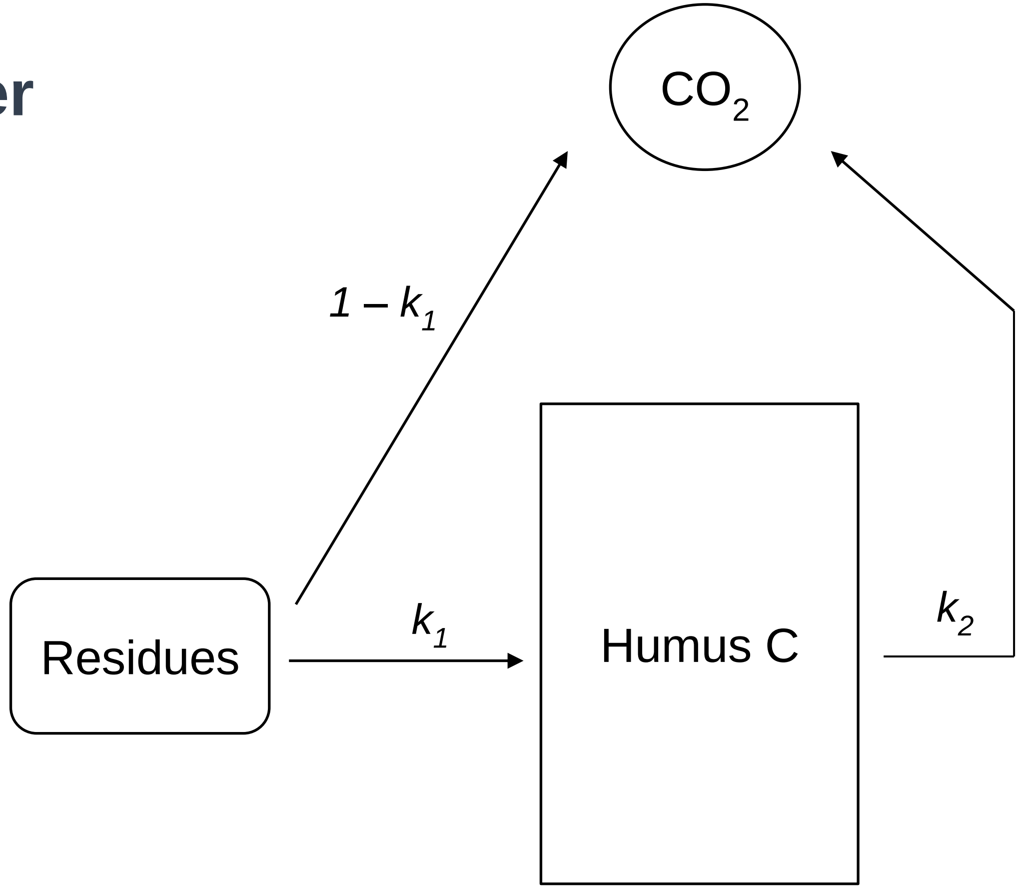
Cropped soils over decades, ploughed layer

- 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

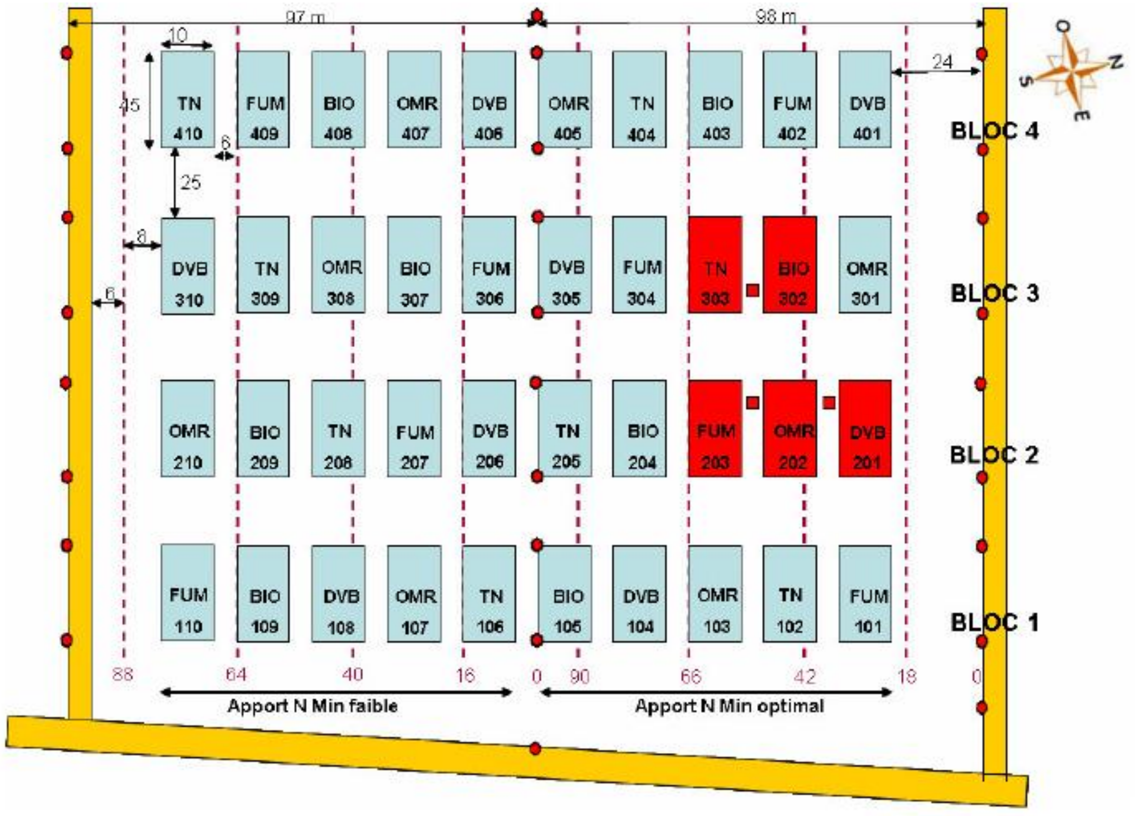
Study aims

- **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

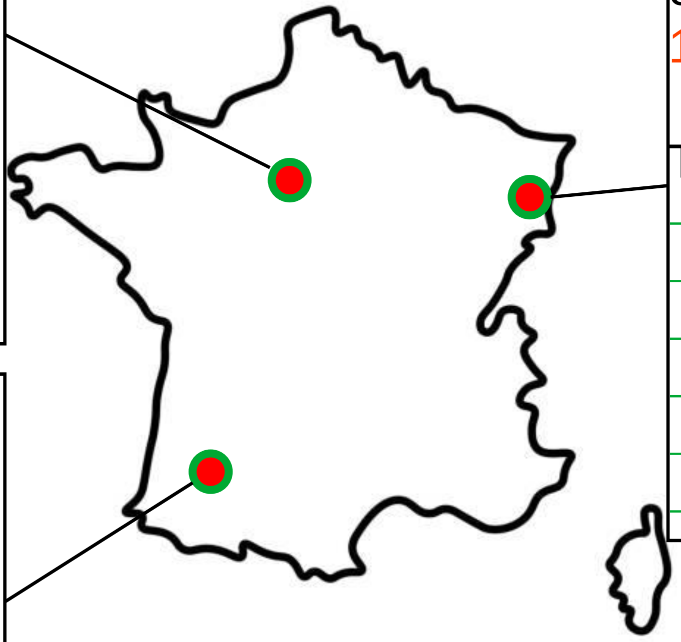
Oceanic ; luvisol; corn-wheat;
18 years; 7 soil samplings; pH = 7.1

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}



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

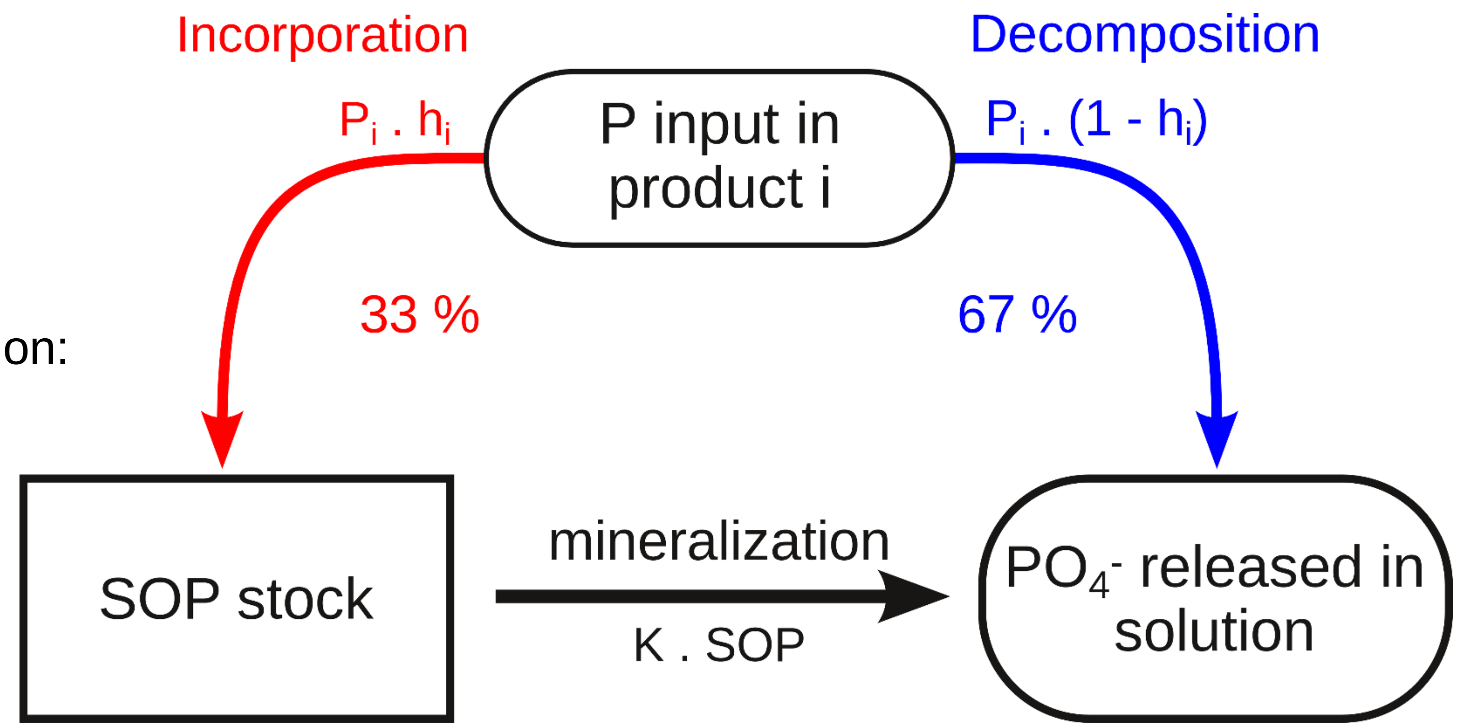
- SOP dynamic = balance between:
  1) **P incorporation** to SOP
  2) **SOP mineralization**
  →Annual time step

- 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



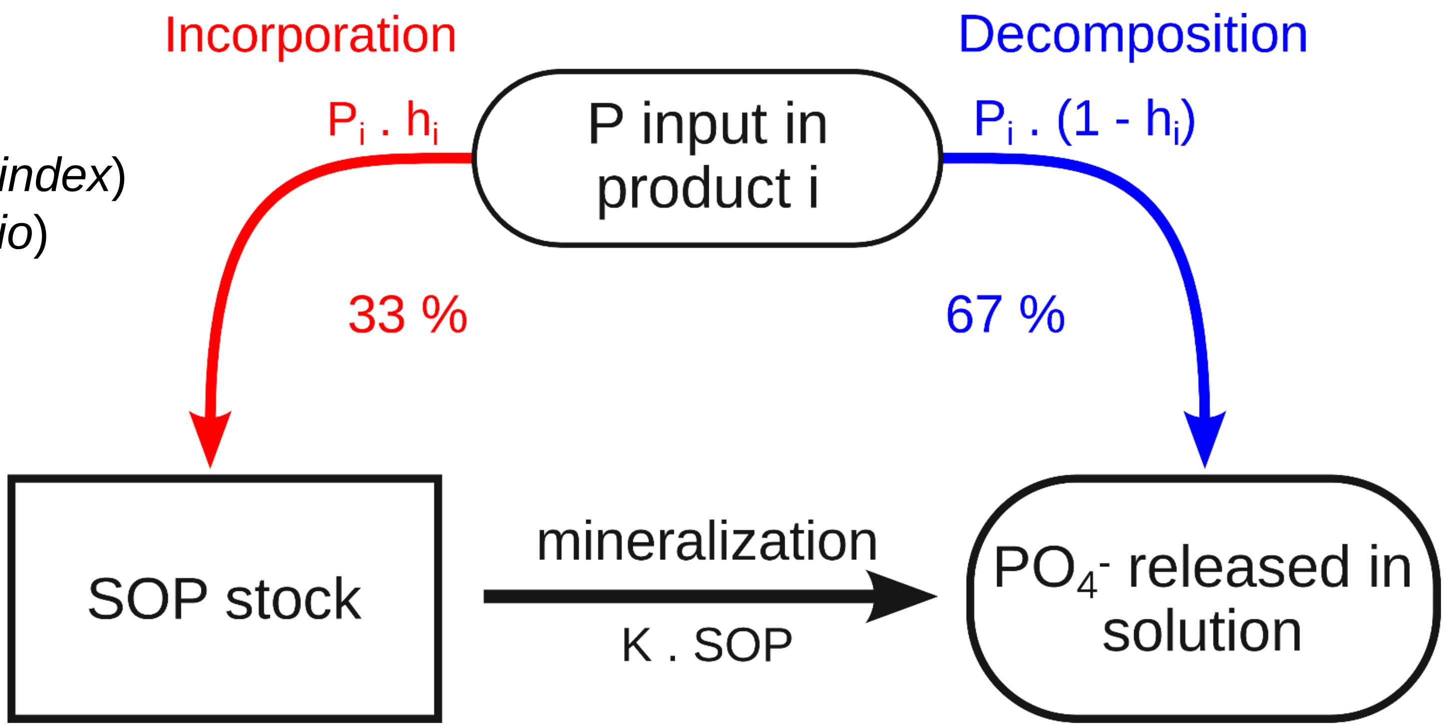
Conceptual diagram of the model

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

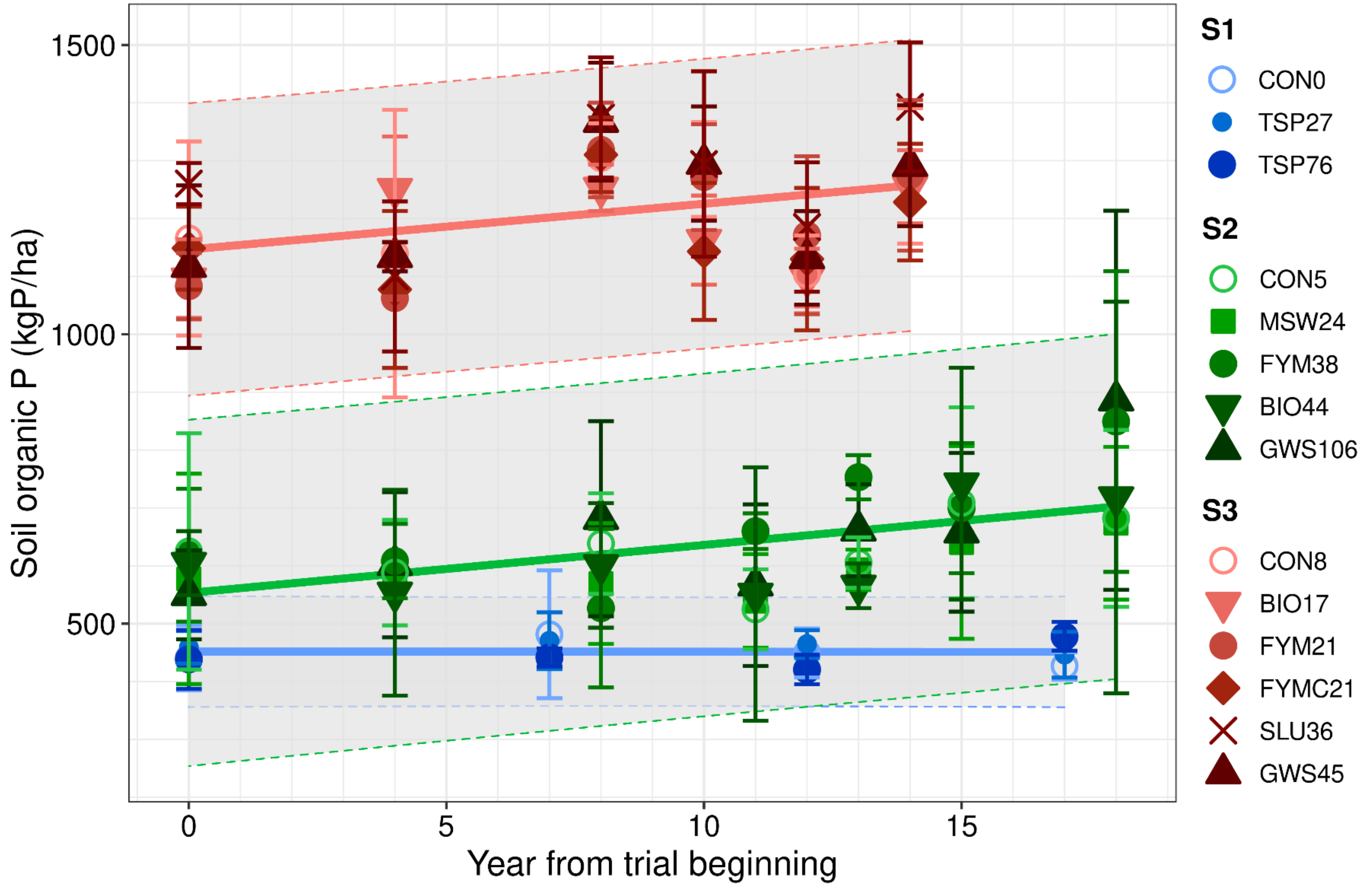
- Variations (= slope) (kg P ha^{-1} y^{-1}):

  → 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