Phosphate fertilizer value of sludge incinerated ashes (SIA)

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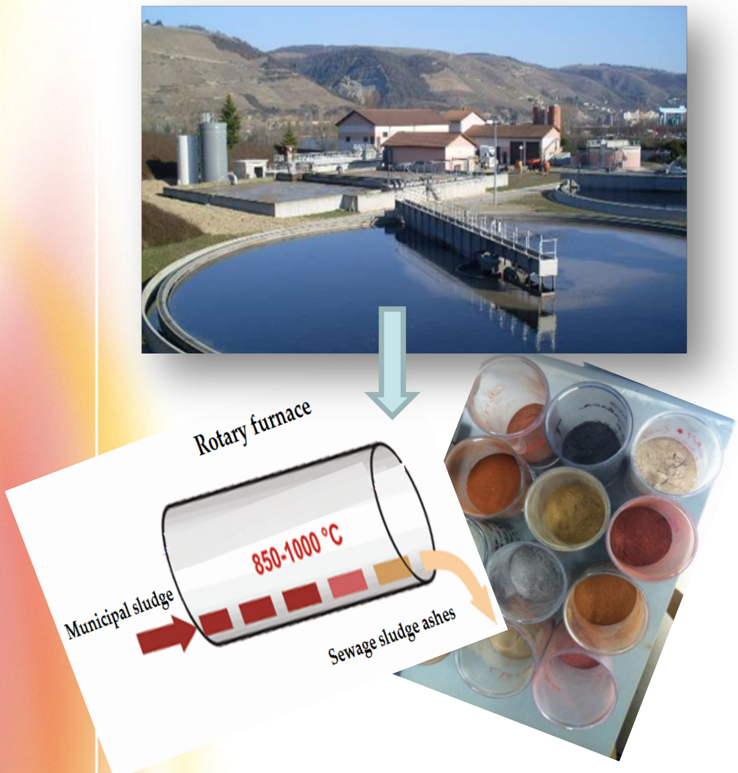
Outline



- Overview;
- Objectives;
- Experimental design;
- Results and
- Conclusion.

Biosolids recycling in agriculture

❖ **Biosolids:** Valuable sources of nutrients (N, P) and organic matter;

1. The regulatory restrictions for land application;

2. The challenge to manage large amounts of sludge produced by major cities;

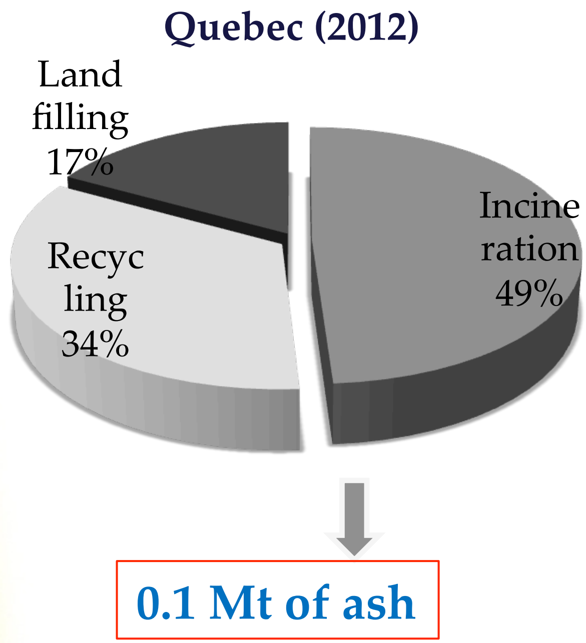
↓

❖**The incineration**: a major management option for larger cities;

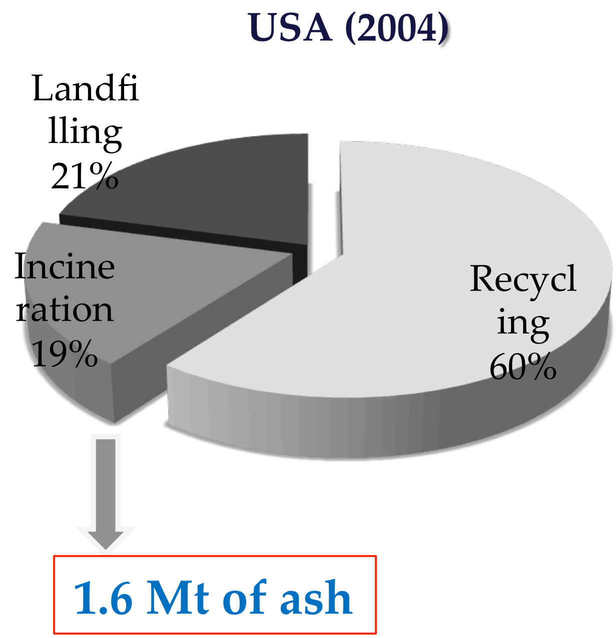
❖**Recycling of nutrients (particularly P) from sludge ash is a possibility to be explored.**

Sewage sludge management

- 0.7 Mt / year in Quebec
  (MDDEFP, 2014)



- 28 Mt / year in the USA
  (CWWA/ACEPU, 2014)



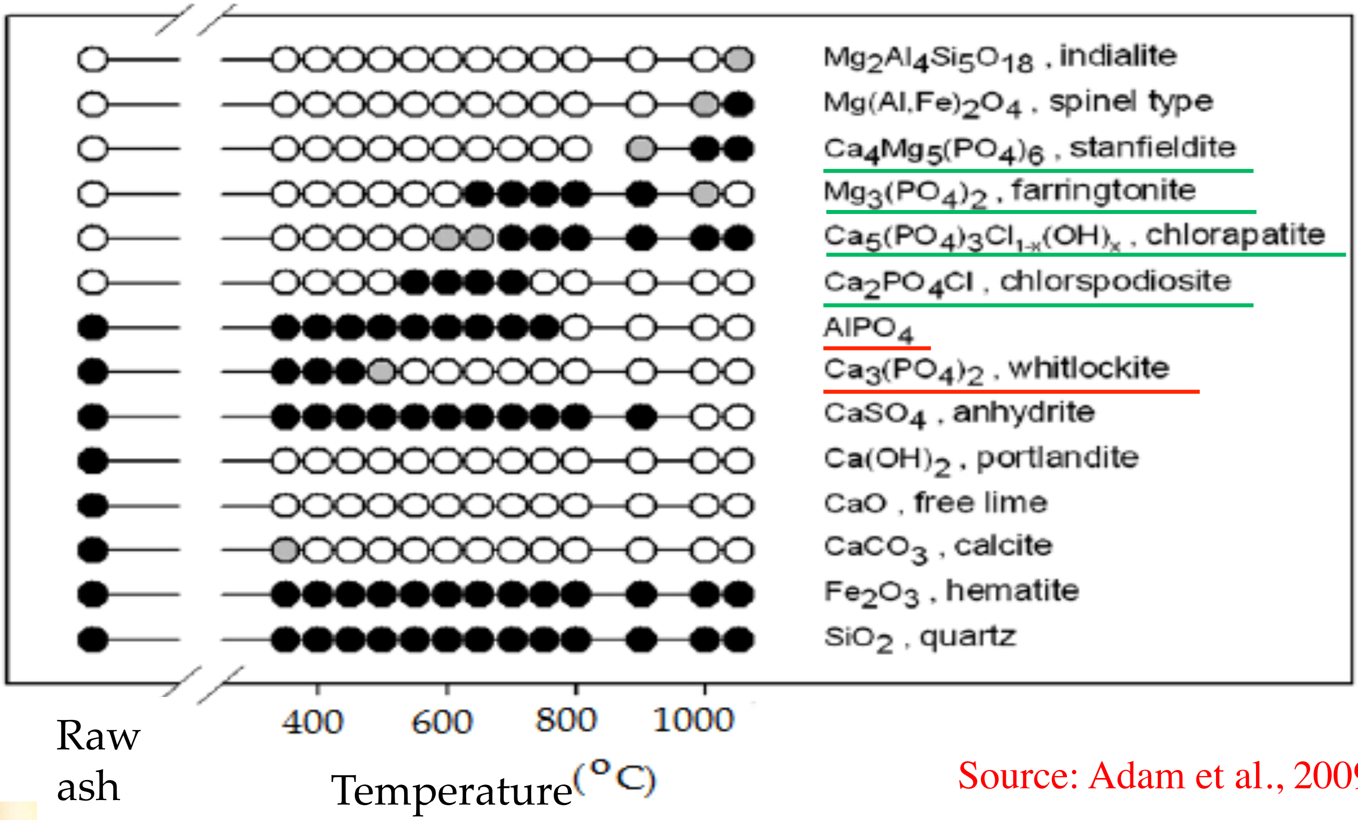
Actual sludge incinerated ashes (SIA) management

- Landfilling (Kruger et al., 2014; CCME, 2012);
- Cement plants and
- Spreading on the agricultural land (CCME, 2012; Vogel et al., 2010; Franz, 2008).

At Quebec: Fertili-cendres


Source (CCME, 2012)

Phosphorus forms in the sludge ashes

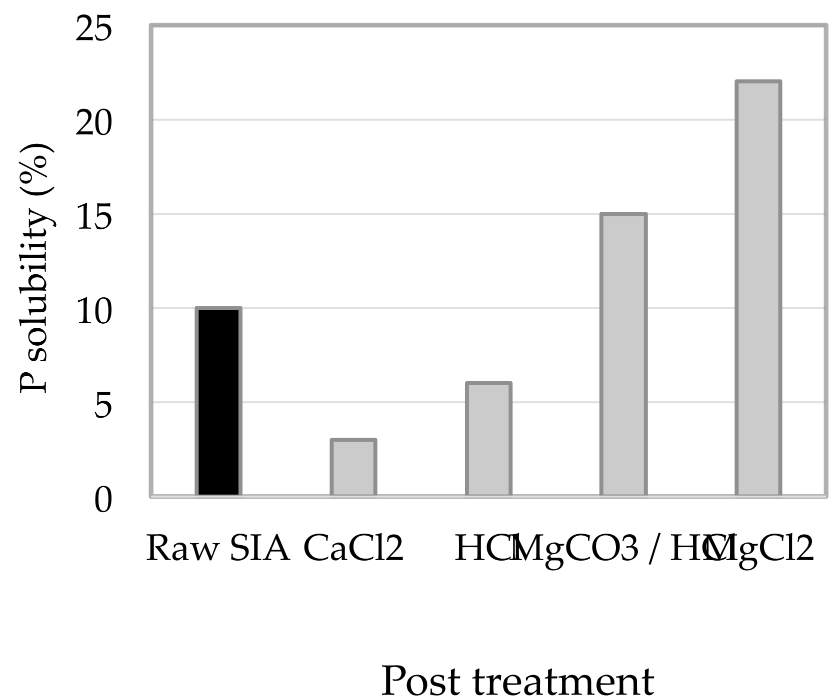


Source: Adam et al., 2009

● = phase detected by XRD, ○ = phase not detected by XRD, ◉ = phase just (dis)appearing.

Factors influencing the bioavailability of ash P

- Soils properties (texture, pH) (Weinfurtner and Waida, 2014);
- Coagulants (Fe, Al) (Ottosen et al
- Size of the particles;
- Temperature of combustion;
- Post treatment type
  (Vogel et al., 2011; Vogel and Adam, 2010; N



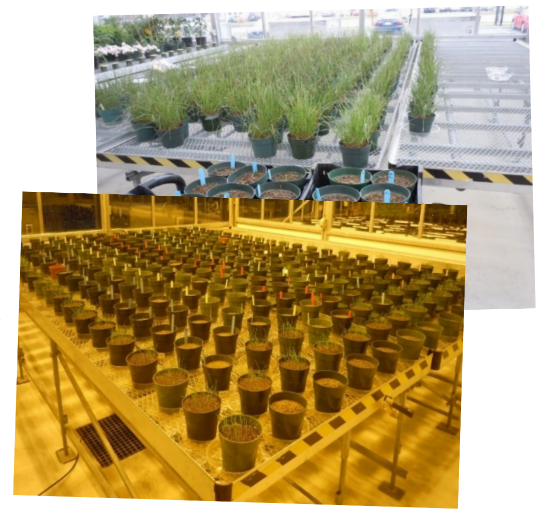
Source: Vogel and Adam., 2011

Aim of the project

The main objective of this project is to determine the relative effectiveness of SIAs compared to water-soluble fertilizers, in order to develop a predictor of the P bioavailability.

Greenhouse experiment

- **29 treatments:**
  - 14 P sources;
    - 12 sludge incinerated ashes (SIA);
    - 1 triple super phosphate (TSP) and
    - 1 rock phosphate (RP).
  - 2 levels: 20 and 60 kg/ha of P_2O_5 and
  - 1 control without any P fertilization.
- **2 soils**: clay and sandy loam;
- **1 Culture:** Annual Rye Grass *var Maris Ledger* (~50 seeds/pot);



Greenhouse experiment

- Randomized complete block design (3 replications);
- N (NH_4NO_3) and K fertilizers;
- Three cuts (6, 9 and 12 weeks after sowing);
- Analytical parameters
  - Sludge ashes:
    - P (total, NAC, oxalate) and other analyses
  - Soils :
    - Mehlich-3 standard characterization (P, K, Ca, Mg, Al, Fe);
    - N, pH_{water}, pH_{SMP}, OM.
  - Crops

    Yield, P uptake, apparent P recovery, relative P efficiency.

The apparent P recovery (APR) and the relative P effectiveness (RPE) calculation

$$APR(\%) = P_{SIA} - P_{control} / P_{applied} * 100$$

$$RPE(\%) = APR_{SIA} / APR_{TSP} * 100$$

Where:

: P uptake in the SIAs treatments;

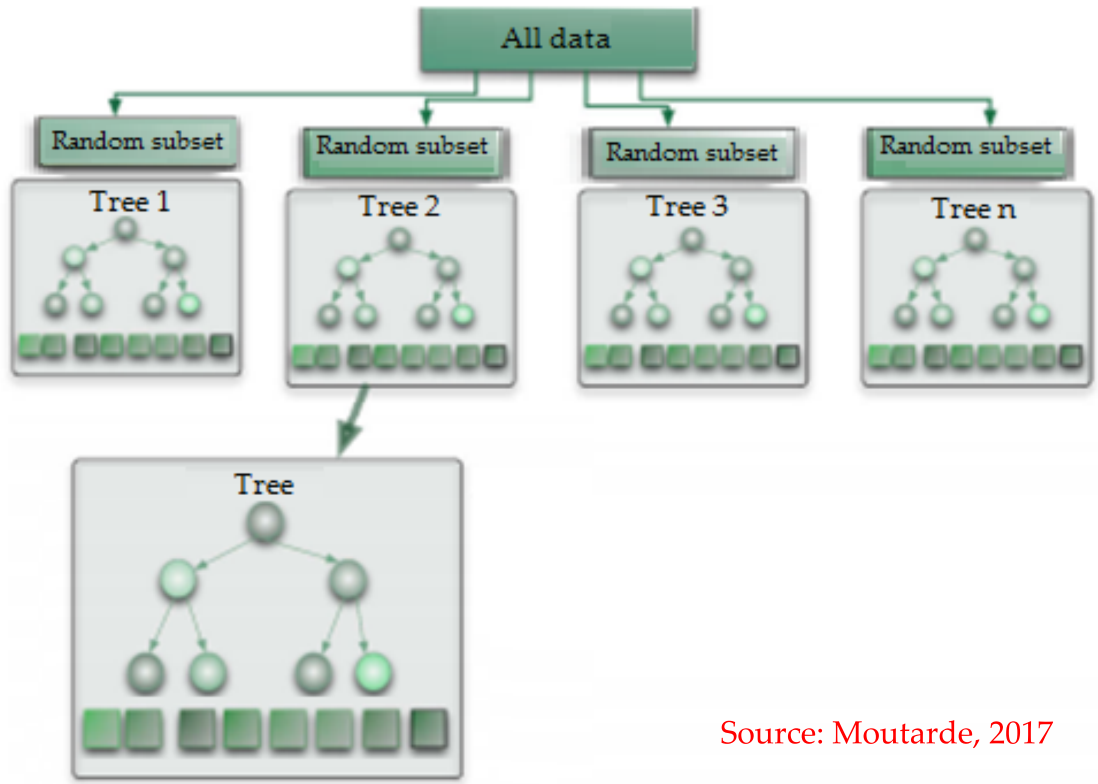
: P uptake in the unfertilized pot;

: P uptake in the TSP treatment;

: Total amount of P applied.

Sludge incinerated ashes (SIA) P availability prediction

Machine learning method: Random Forest



Source: Moutarde, 2017

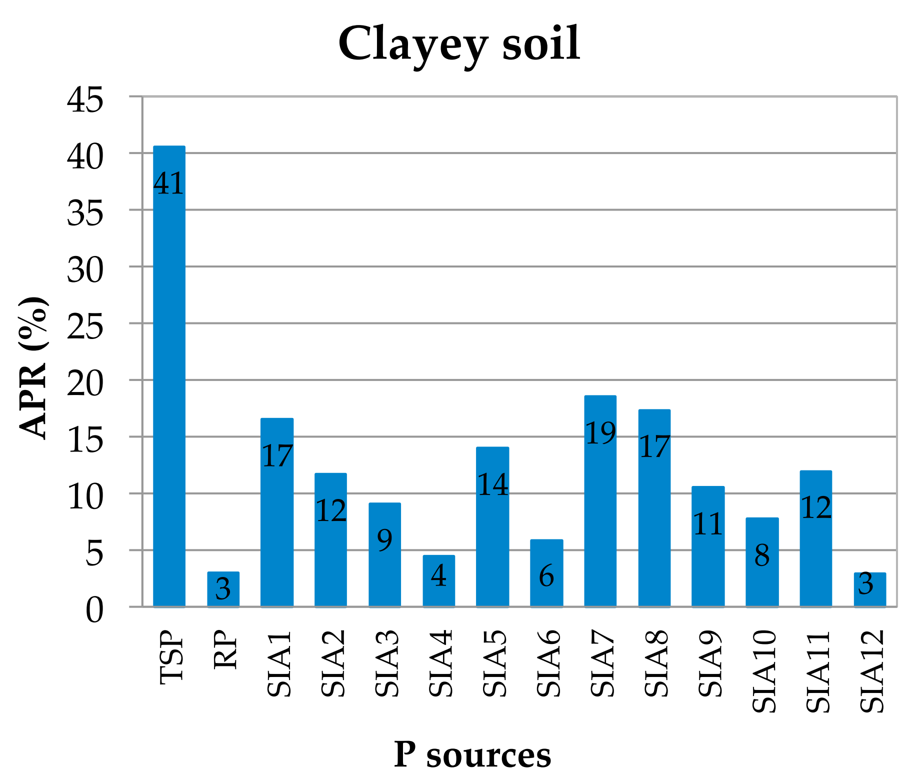
Characterization of the SIA, RP* and TSP**

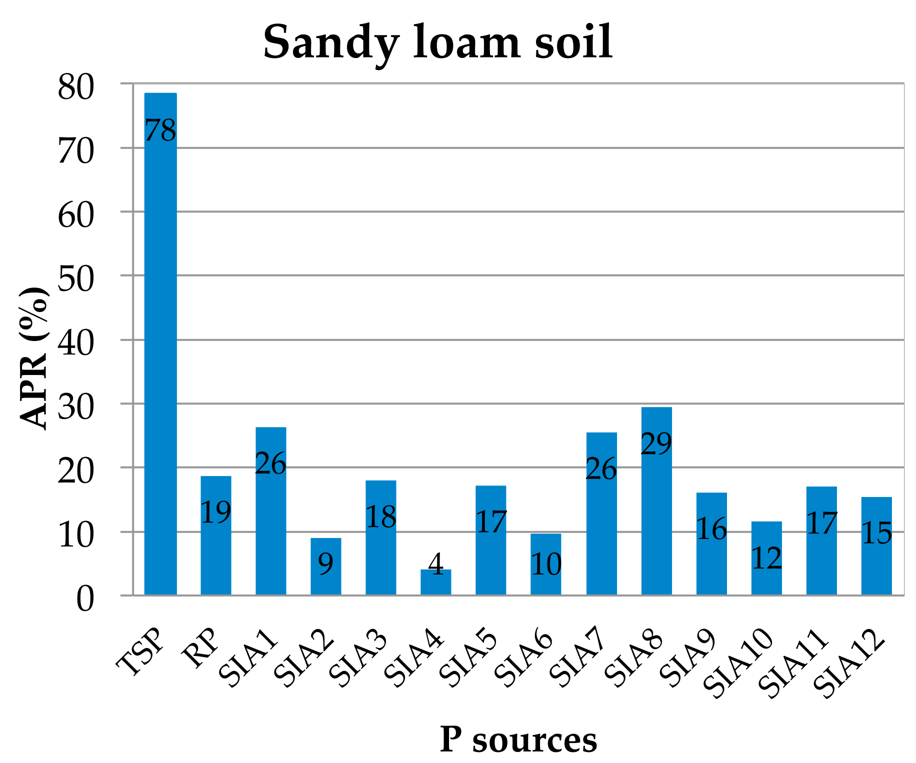
	Min	Max	Average	RP	TSP
$(P_2O_5)_{tot}$ (% DM)	3	32	15	26	47
$(P_2O_5)_{soluble}$ (% of total P)	19	72	42	30	99
$(K_2O)_{total}$ (% DM)	0.2	2.4	1.5	0.4	0.2
Al_{tot} (mg/kg)	2.93	128	42.99	2.54	8.17
Fe_{tot} (mg/kg)	10.5	129	51.54	2.02	7.56
Ca_{tot} (mg/kg)	7.53	225	79.01	272	118
Mg_{tot} (mg/kg)	1.29	17.7	9.184	5.46	4.51
Mn_{tot} (mg/kg)	0.154	5.77	1.068	0.024	0.292
$Fe_{oxalate}$ (mg/kg)	0.06	30.09	9.335	0.12	2.97
$Al_{oxalate}$ (mg/kg)	0.86	34.68	12.24	0.08	4.71
$P_{oxalate}$ (mg/kg)	0.46	11.98	2.852	2.59	100
Neutralising power (%)	3	35	16	21	NA
Particle size (%)	8	100	55	Gran.	Gran.
pH_{water}	6.8	11.6	8.8	7.9	1 to 3

* rock phosphate

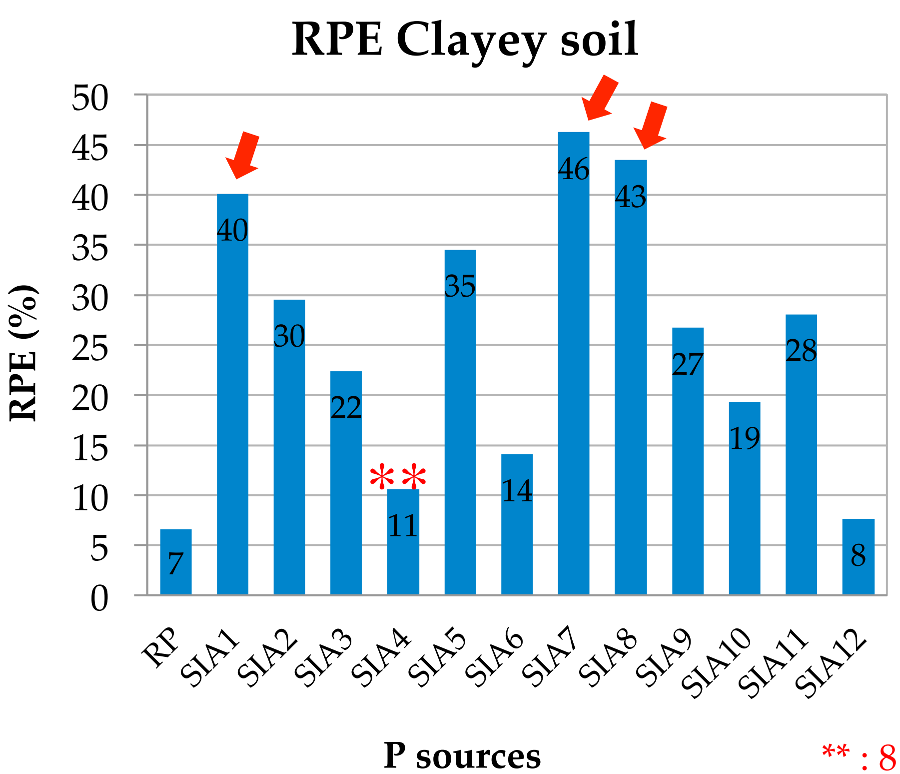
** triple super phosphate

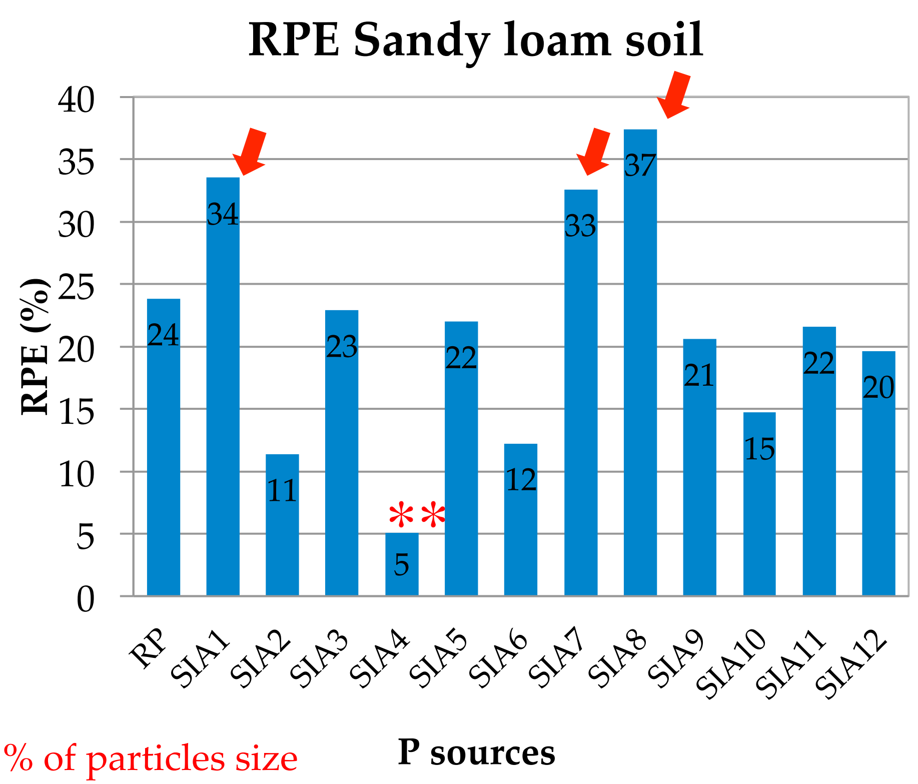
SIA Apparent P recovery





SIA relative P effectiveness





** : 8 % of particles size <0,150 mm and the lower P solubility (19% of total P)

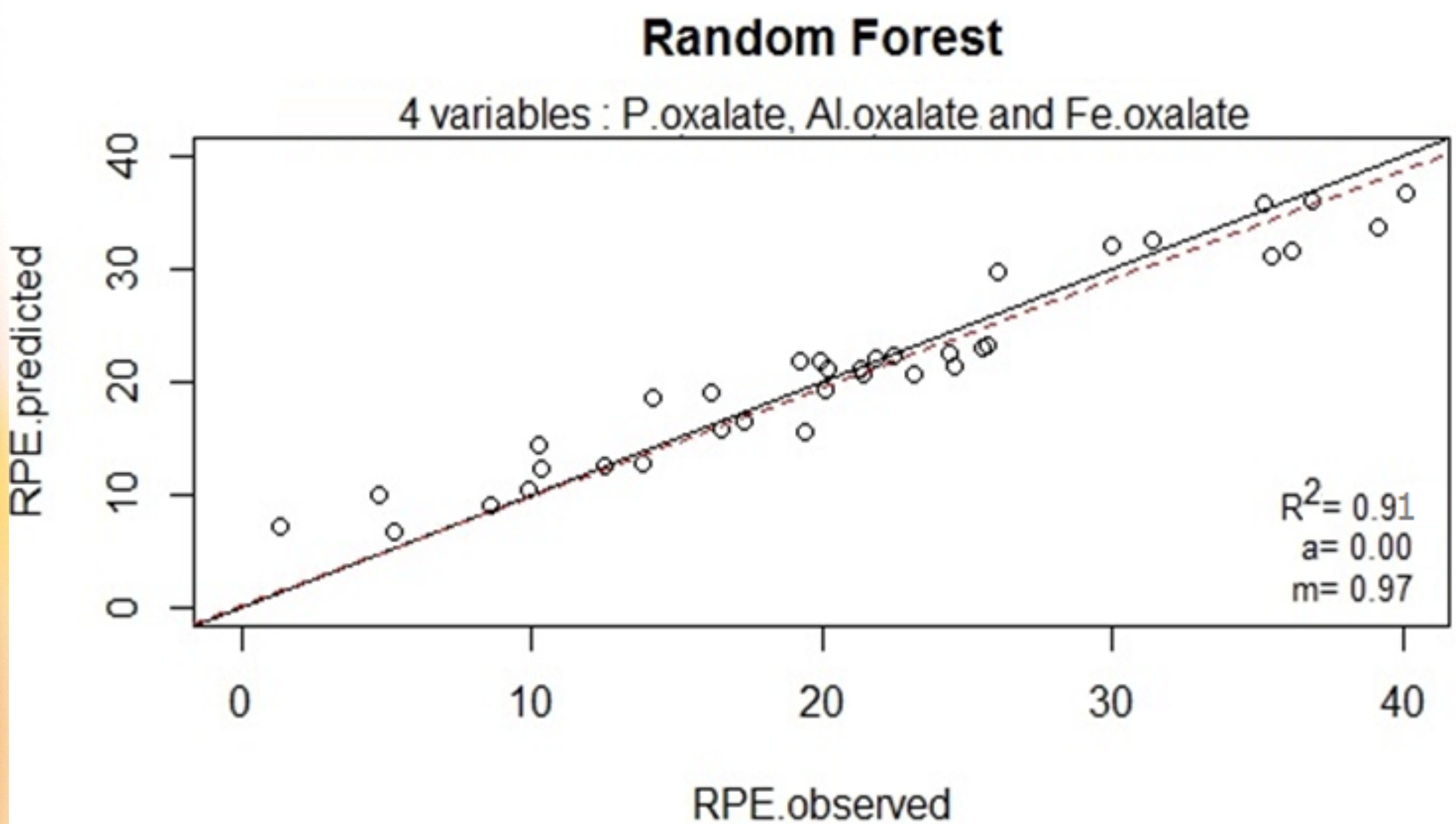
SIA P availability prediction

- Machine learning method: Random Forest

Variables	Importance order	R^2	RSE
Fe_{EDTA}, Al_{EDTA}	Al, Fe	0.87	3.185
Fe_{Ox}, Al_{Ox}, Mn_{Ox}, P_{Ox}	**Al, P, Mn, Fe**	**0.91**	2.632
P_{tot}, Al_{dith}, Fe_{dith}	**Al, Fe, P**	**0.92**	2.535
Fe_{tot}, Al_{tot}, Mn_{tot}, P_{tot}, Ca_{tot}	Al, Fe, Mn, Mg, Ca, P	0.87	3.097
P_{NAC}	P_{NAC}	0.81	3.724
P fractions	NaOH, $NaHCO_3$, H_2O, HCl, Residual	0.82	3.274

RSE: residual standard error, Ox: oxalate, dith: dithionite, NAC: neutral ammonium citrate

SIA relative P availability prediction



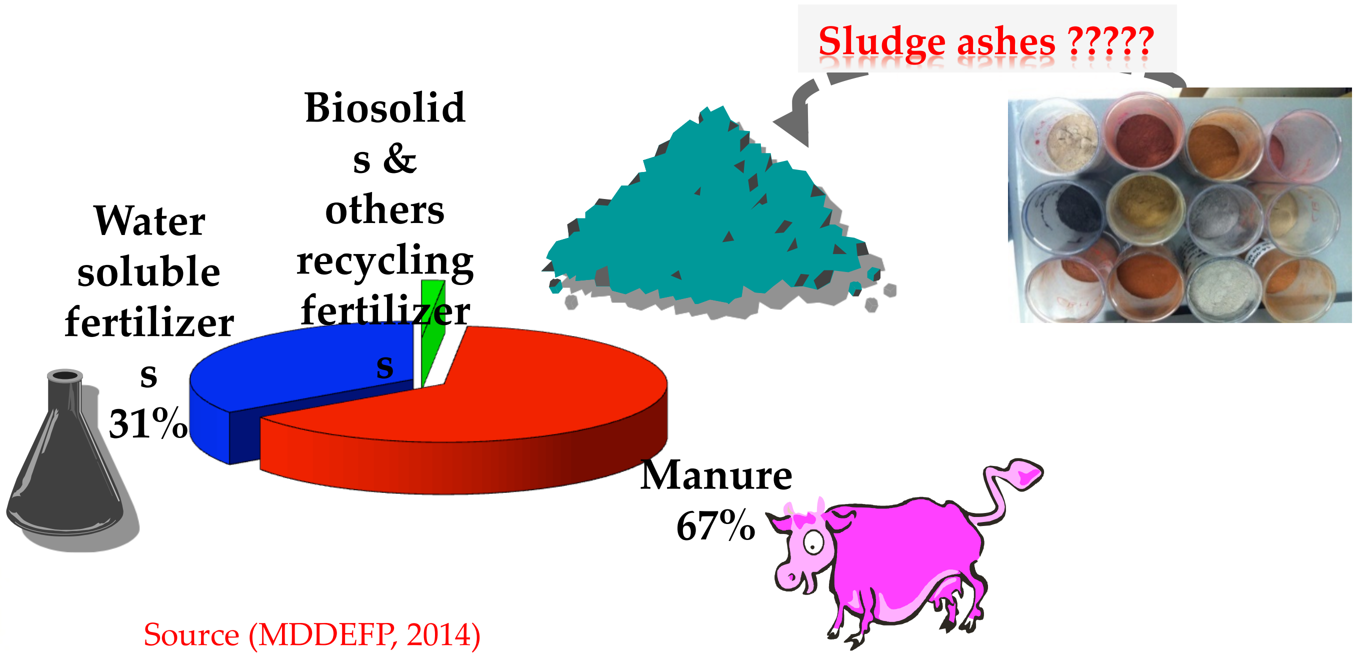
Summary

- ❖The SIA should be used for P fertilizers;
- ❖P efficiency depends on SIA types and soil properties;
- ❖Fe content ➔ low influence on P availability ;
- ❖Al content ➔ the most important for the prediction of SIA P availability and the use of Al coagulants appears to favor greater efficiency;
- ❖Finer particles ➔ better P availability;
- ❖Oxalate extraction➔ good and practical indicator to estimate the SIA P bioavailability
- ❖A better knowledge of the incineration parameters (combustion time, furnace, coagulants) is needed , in order to optimize the ash fertilizer efficiency.


Thank you!

Phosphorus sources in Quebec

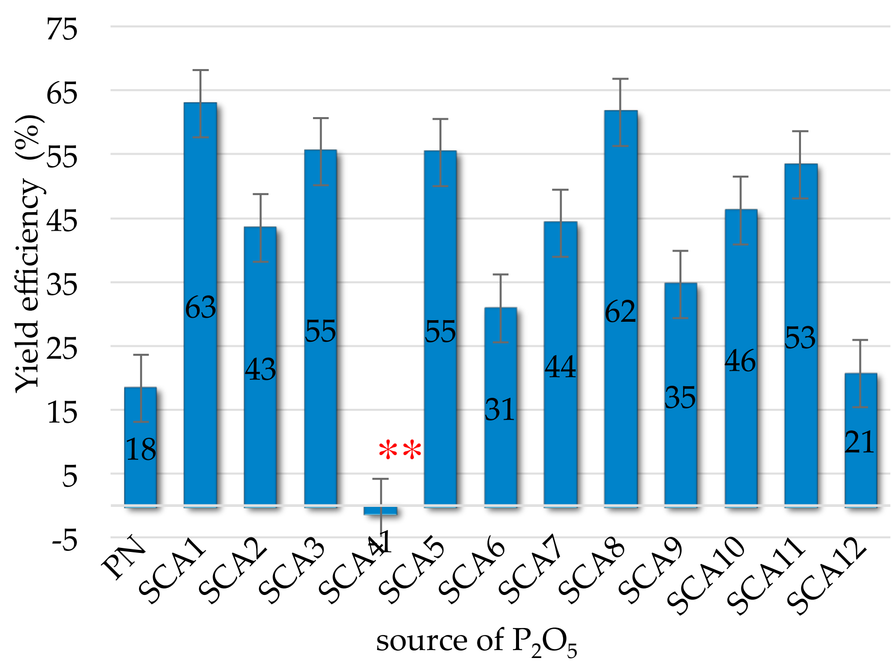
Quantity of P spreading in Quebec: **103 275** tonnes of P_2O_5 /year (MDDEFP, 2014).



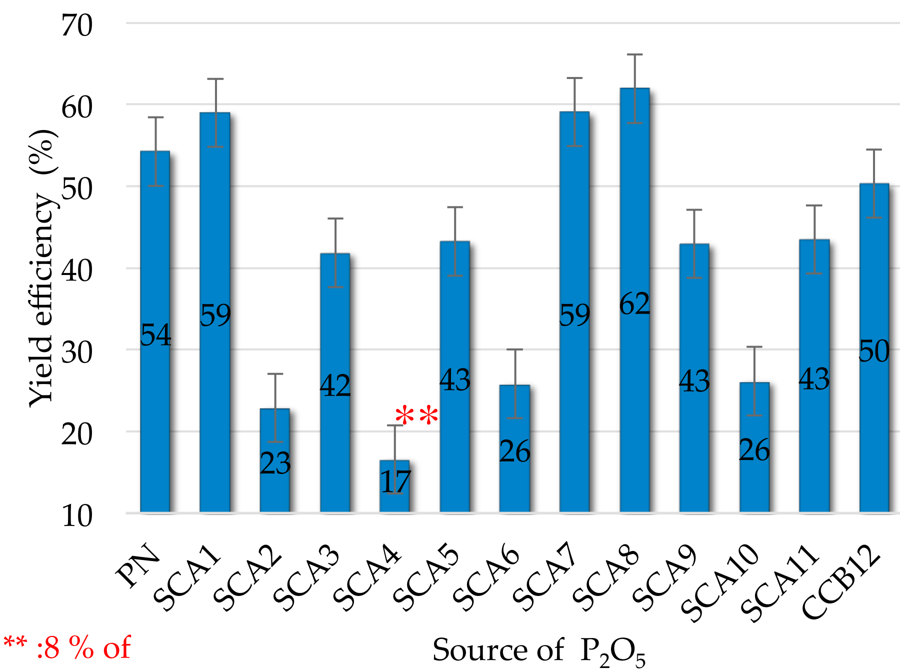
Source (MDDEFP, 2014)

SIA efficiency in clayey and sandy loam soil

SIA efficiency in clayey soil



SIA efficiency in sandy soil



** :8 % of particles size <0,150 mm

Caractérisation physico-chimique des CCB

	P_{total}	P_{NAC}*	K_{tot}	Ca_{tot}	Mg_{tot}	Al_{tot}	Mn_{tot}	Fe_{tot}	pH_{water}	P size#	$P_{soluble}$
	----------------	----------------	----------------	----------g kg^{-1}	----------------	----------------	----------------	----------------		%	% of total P
SIA 1	39.3	28.2	6.5	67.8	9.7	**128.0**	0.4	25.5	10.67	94	**72**
SIA 2	34.9	12.0	7.5	96.1	13.0	32.9	0.6	103.0	11.64	48	34
SIA 3	26.2	11.5	8.0	121.0	17.7	51.2	0.6	48.4	11.11	54	44
SIA 4	65.5	12.2	9.6	63.3	9.3	43.3	0.5	23.4	8.73	8	**19**
SIA 5	96.1	25.5	10.2	94.3	12.7	21.1	1.2	**129.0**	7.65	100	27
SIA 6	**13.1**	4.1	0.8	**7.5**	1.3	**4.4**	0.2	**10.5**	7.40	64	32
SIA 7	78.6	51.6	8.8	54.4	14.2	32.9	1.1	44.4	7.51	45	66
SIA 8	65.5	35.5	6.4	62.5	8.7	54.1	5.8	50.5	8.04	80	54
SIA 9	74.2	34.5	3.2	45.8	3.7	29.4	1.1	41.7	7.10	72	46
SIA 10	91.7	25.0	4.0	47.5	5.3	40.0	0.9	58.2	6.82	49	27
SIA 11	**135.4**	52.4	6.0	**225.0**	6.2	2.9	0.2	68.0	10.56	21	39
SIA 12	39.3	19.4	4.4	62.9	8.4	75.7	0.3	15.9	7.87	23	49
PR	113.5	34.0	1.8	272.0	5.5	2.5	2.4	2.0	7.88	Gran.	30
TSP	205.2	200.9	0.7	118.0	4.5	8.2	29.2	7.6	1-3	Gran.	99

Caractérisation physico-chimique des CCB

	Oxalate				Dithionite		EDTA		P fractionation			
	---				g kg^{-1}		---					
	Fe	Mn	Al	P	Fe	Al	Fe	Al	H_2O	$NaHCO_3$	NaOH	HCl
SIA 1	1.10	0.01	34.68	1.25	10.67	25.33	0.04	0.02	0.02	0.40	6.33	24.25
SIA 2	30.09	0.05	6.81	1.49	48.41	3.91	0.08	0.01	ND	0.63	0.29	26.84
SIA 3	7.56	0.02	11.44	1.25	9.59	4.41	0.06	0.01	ND	0.64	0.21	20.07
SIA 4	0.06	ND	12.22	2.16	7.60	0.52	0.14	0.15	0.67	0.33	8.79	38.88
SIA 5	20.50	0.17	7.23	2.52	95.37	4.55	0.32	0.43	0.10	0.37	11.95	66.68
SIA 6	1.39	0.03	1.02	0.46	6.95	0.24	0.09	0.04	0.05	0.15	1.88	5.74
SIA 7	13.96	0.28	12.41	4.54	35.15	5.28	0.86	0.39	0.23	0.84	21.87	40.05
SIA 8	4.09	0.78	18.32	3.10	13.97	6.27	0.10	0.49	0.03	0.32	14.09	36.98
SIA 9	7.80	0.31	15.51	1.55	32.58	3.00	0.09	0.19	0.04	0.16	15.74	39.82
SIA 10	13.34	0.32	9.53	2.07	41.57	0.90	0.57	0.10	0.06	0.23	30.76	46.46
SIA 11	10.47	0.01	0.86	11.98	27.06	ND	0.06	0.01	0.02	1.63	0.03	120.91
SIA 12	1.66	0.01	16.89	1.85	7.65	7.27	0.27	0.24	0.04	0.32	5.13	27.96
PR	0.12	ND	0.08	2.59	1.28	0.22	0.03	ND	0.04	0.49	0.01	103.27
TSP	2.97	0.03	4.71	100	8.82	5.62	4.76	0.30	185.15	2.15	8.81	11.96