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Soil properties and not inputs control the carbon, nitrogen, phosphorus ratios in cropped soils

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Introduction

- All organisms need C, N and P for growth; they differ in nutrient acquisition and use
- CNP ratios of **soil microorganisms** provide information about their capacity to immobilize or release nutrients and to adapt to existing resources
- CNP ratios in **soil organic matter** provide information on the role of microorganisms & plants in determining soil organic matter composition and on nutrient limitations to C sequestration
- A lot of data are available on C and N **but we lack information on P**
- A lot of data are available on semi-natural systems **but we lack information on how agricultural practices impact CNP ratio in cropped soils where elements are added, removed, stored and lost**

Questions

- Do long-term inputs with similar CNP ratio into cropped soils, leave an in-print on the CNP ratio of soil microbial biomass and ultimately on soil organic matter

- Or will we find the Redfield ratio everywhere CNP: 106:16:1 (Cleveland and Liptzin, 2007)

Material

- **Three long-term experiments**:
  - the **Saria** trial in Burkina Faso (Pieri, 1989)
  - the **Wagga Wagga** trial in Australia (Heenan et al., 1994)
  - the **DOK** trial in Switzerland (Mäder et al., 2002)
- For each trial, we estimated the yearly C, N and P inputs to the soil, the N and P soil system budget and compared them to the C, N, P contents and molar ratios of soil pools

The Saria Trial (Pieri, 1989)

- **Goal:** Maintenance of soil fertility, since 1960
- **Location**: Burkina Faso, 800 mm rainfall/yr, mean temperature 30° C
- **Soil:** ferric Acrisol, 12% clay (quartz), weak aggregate stability
- **Treatments**: **CON** (no nutrient input), **MIN1** (37 N, 10 P, 11.6 K kg/ha yr), **MINFYM1** (MIN1 plus 5 t manure/ha every 2nd year), **MIN2** (60 N, 10 P, 36.5 K kg/ha yr), **MINFYM2** (MIN2 plus 40 t manure/ha every 2nd year)
- **Rotation**: sorghum, cowpea

Photos INERA September 2011

The Wagga Wagga Trial (Heenan et al., 1994)

- **Goal:** crop rotation, stubble and tillage management, since 1979
- **Location**: NSW Australia, 570 mm rainfall/yr, mean temperature 16° C
- **Soil:** chromic Luvisol, 29% clay (Q, K, I, H), stable structure
- **Treatments**: **WL-M-C** wheat/lupin with mulch and cultivation; **WL-B-C** wheat/lupin with burning and cultivation; **WW-B-C** continuous wheat with burning and cultivation; **WS-M-D** wheat/subterranean clover with mulch and direct drilling ; **WS-M-C** wheat/ subterranean clover with mulch and cultivation
- **Fertilization**: no N & K, 20 kg P/ha yr as super triple P

Photos E.K. Bünemann

The DOK trial (Mäder et al., 2002)

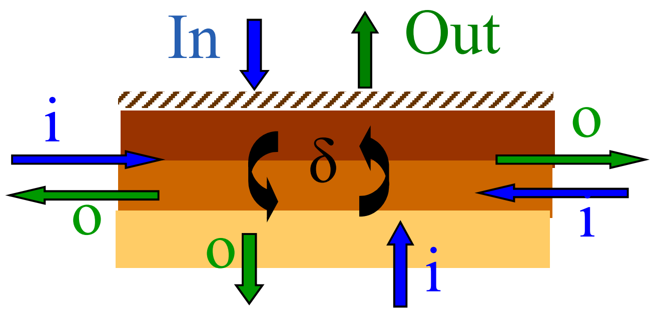
- **Goal:** comparison between conventional and organic cropping systems, since 1978
- **Location**: Therwil NW Switzerland, 790 mm rainfall/yr, mean temperature 10° C
- **Soil:** haplic Luvisol, 15% clay (interstratified clays, mica), weak aggregate stability
- **Treatments**: **NON** no fertilizer input; **MIN** exclusively mineral fertilizers; **ORG** bio-organic, receives slightly aerobically rotted farmyard manure and slurry; **MINORG** conventional system, receives stacked farmyard manure, slurry and mineral fertilizers as supplement
- **Rotation:** silage maize, winter wheat, soybean, potatoes, winter wheat II, and two years of grass-clover ley

Photos A. Oberson

Parameters

- **Estimated C, N, P inputs** = sum of elements added by plant biomass, symbiotic N_2 fixation, seeds, organic and mineral fertilizers, dust and rainfall
- **Estimated N, P outputs** = sum of elements removed in exported plant products, and lost to water, the atmosphere and deep soil horizons
- **Soil system budget** = Inputs – Outputs
- **Soil data**: pH; total C, N, P; organic and inorganic P; resin P (available); microbial C, N and P

Soil system budget



Oenema et al., 2003

Results Saria I

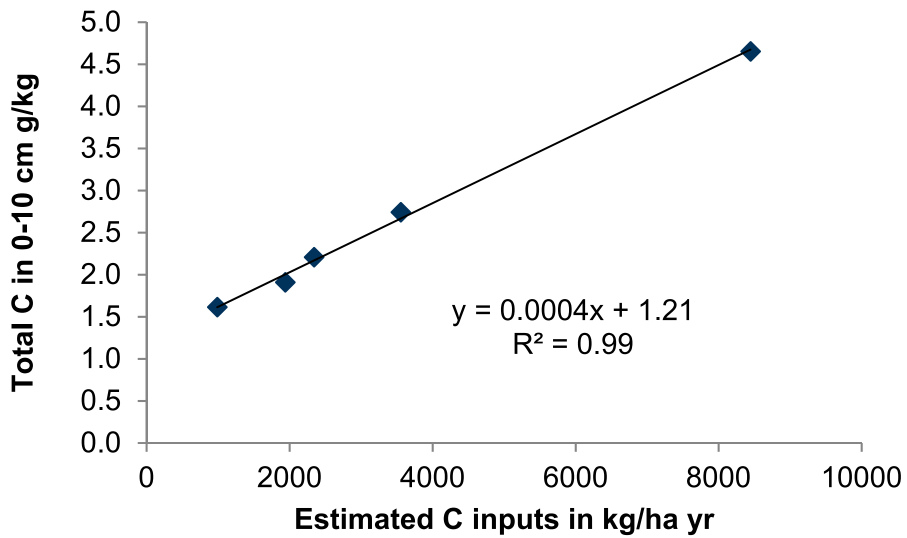
Treatments		CON	MINFYM1	MIN1	MINFYM2	MIN2
Inputs	C t/ha yr	**1.0**	3.6	1.9	**8.9**	2.3
	N kg/ha yr	**11.5**	90.9	55.4	**388.1**	77.0
	P kg/ha yr	**0.8**	17.6	10.8	**69.9**	10.8
Molar ratio	C:N:P	**3280:33:1**	522:11:1	465:11:1	**312:12:1**	561:16:1
Budgets	N kg/ha yr	**-31**	-18	-27	**189**	-30
	P kg/ha yr	**-2.1**	5.7	3.8	**49.4**	2.4

- **Inputs** = large variability due to manure production; large variations in CNP ratios (factors 10 for CP and 3 for NP)
- **Budgets** = large variations in N and P

Results Saria II

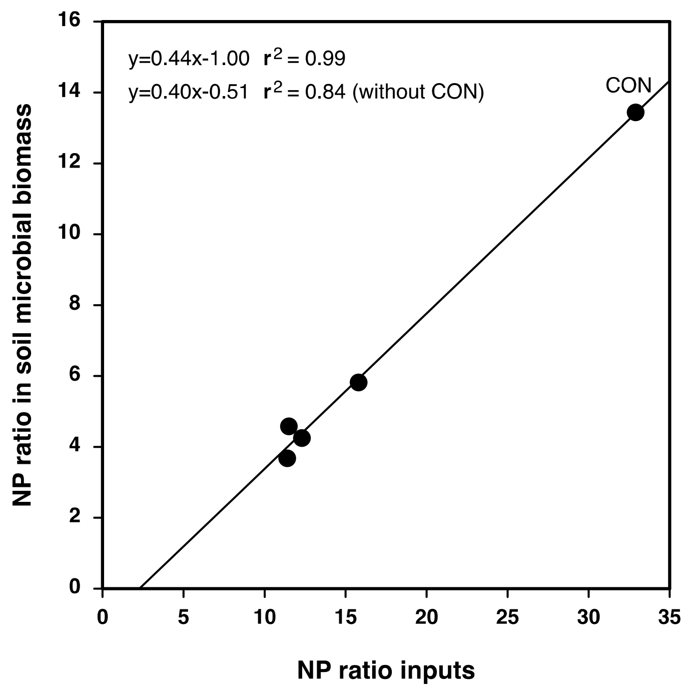
- **Effects on soil pools**

- Treatments affect highly significantly soil C, N and P concentrations in all pools



- **Effects on soil CNP ratios**

- The relation NP in inputs vs NP in microbial biomass is the only significant one in this data set



- **Saria's microbes feed on inputs and sequester P**

Results Wagga Wagga I

Treatments		WL-M-C	WL-B-C	WW-B-C	WS-M-D	WS-M-C
Inputs	C t/ha yr	6.1	5.7	**5.4**	**7.1**	7.1
	N kg/ha yr	85	85	**7**	**129**	129
	P kg/ha yr	21	21	**21**	**21**	21
Molar ratio	C:N:P	764:9:1	713:9:1	**673:1:1**	**892:14:1**	891:14:1

Budget	N kg/ha yr	-29	-42	**-51**	**9**	-6
	P kg/ha yr	12	22	**11**	**15**	15

- **Inputs** = large C inputs, large variability in N due to N_2 fixation (factor 18)
- **Budgets** = very large differences in C and N budgets

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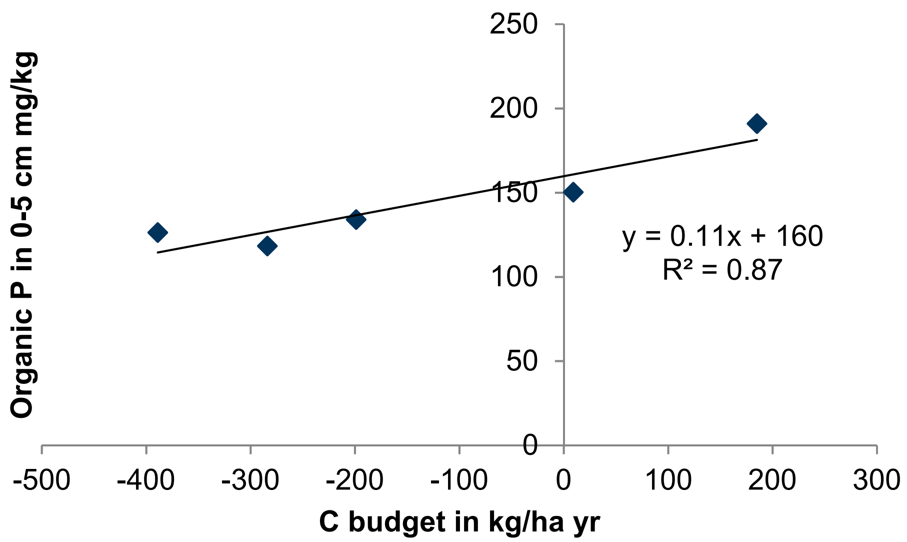
Results Wagga Wagga II

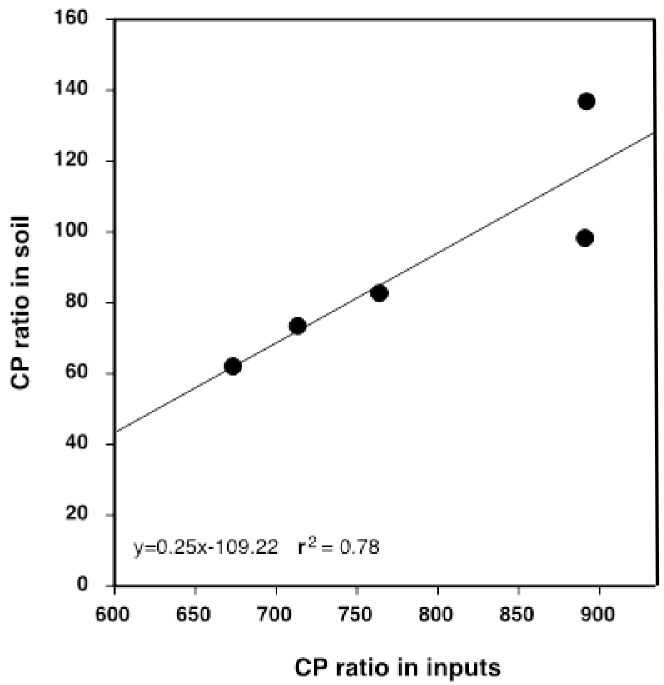
- **Effects on soil pools**

- Positive relationships between total C, total N, organic P, microbial C, microbial N and C budget



- **Effects on soil CNP ratios**

- Positive relation between CP, CPo; NP in soil organic matter and CP in inputs



- **No relation between microbial CNP and inputs CNP; increased C budget leads to organic nutrient storage (P storage)**

Results DOK I

Treatments		NON	MIN	ORG	MINORG
Total inputs	C t/ha yr	**1.0**	1.4	2.4	2.8
	N kg/ha yr	**81.7**	184.4	219.5	250.5
	P kg/ha yr	**0.8**	30.8	27.8	41.8
Molar ratio	CNP	**3162:230:1**	118:13:1	223:17:1	174:13:1

Budget	N kg/ha yr	**-72.3**	-81.6	-49.5	-59.5
	P kg/ha yr	**-19.0**	-3.0	-5.0	3.0

- **Inputs** = large variability in C inputs due to manure; in N inputs due to N_2 fixation, and in P inputs due to nutrient inputs, leading to large variations in CNP ratios (factors 26 for CP and 17 for NP)
- **Budgets** = strong differences in P budgets

Results DOK II

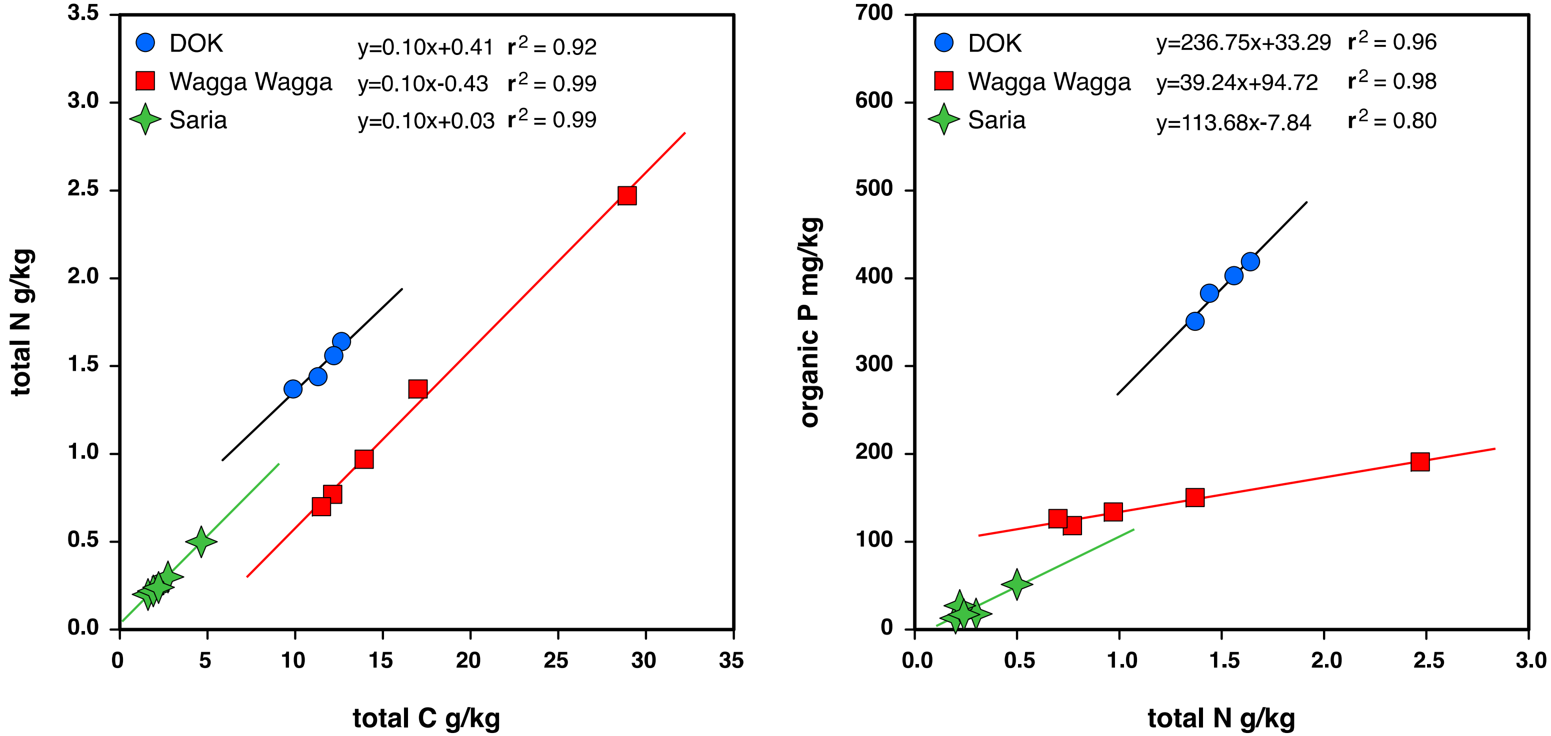
- No relation between CNP in inputs and CNP in soil microorganisms; while NP ratio in soil microbes is related to total N: total P ratio in soil → **microbes feed on soil nutrients**

- No relation between CNP in inputs and CNP in soil organic matter/total pool → **the interplay between degradation and stabilization has erased the CNP ratio of inputs**

The soil rules

- The CNP ratio of inputs has little impact on the CNP ratio of soil pools, while the different treatments often modified element concentrations

- The changes induced by treatments were controlled by soil properties



Summary/Conclusions

- The CNP ratio of agricultural inputs and the N, and P budgets have limited impacts on the CNP ratio of soil pools.
- Changes in management lead to changes in elements concentration in soil following trajectories controlled by soil properties (organic matter, mineralogy, biological activity)
- Stiochiometric approaches are challenging in soil because of soil capacity to sequester either molecules containing a single element (P or C), two (protein, IHP) or CNP (plant and microbial products)
- Subsequent works will need precise estimations of elements inputs/outputs and balance
- **Multiple isotope tracing is necessary to follow the fate of C, N and P added to the soil/plant system (→ Poster Oberson *et al.* 2017)**

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