Are dual goals of increasing P availability to crops and increasing soil C mutually exclusive?

UK soil organic P consortium

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Soil ecosystem functions

A direct role in 13 out of the 17 defined by Costanza et al.

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Ecosystem function	Examples	Role of soil P	Role of soil C
1. Gas regulation	Regulation of atmospheric gases		✓
2. Climate regulation	Regulation of global temperature, biologically-mediated climate processes, GHG		✓
3. Disturbance regulation	Storm protection, flood control, drought recovery, habitat stability		✓
5. Water supply	Water storage and retention in catchments, aquifers		✓
6. Erosion control	Prevention of soil loss by water, wind etc		✓
7. Soil formation	Rock weathering and organic matter accumulation		✓
8. Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients	✓	✓
9. Waste treatment	Recovery of mobile nutrients or breakdown of excess compounds	✓	✓
11. Biological control	Trophic-dynamic regulations of populations		✓
13. Food production	The portion of GPP extractable as food	✓	✓
14. Raw materials	The portion of GPP extractable as timber, fuel or fodder	✓	✓
15. Genetic resources	Sources of unique biological material and products		✓
17. Cultural	Providing opportunities for aesthetic, artistic, educational, spiritual and scientific values		✓

Why improve P sustainability?

- Many agricultural soils are P deficient
    - agricultural systems respond significantly to P application
- Efficiency of P fertilizer use is poor
    - 10 to 50% recovery of applied P
    - Fixation of P in soils and accumulation
- Environmental problems with P mismanagement
    - eutrophication of aquatic environments
    - need to reduce the nutrient-load on a landscape scale
- Future trends towards a P-deficit
    - Rock-P is a finite resource; Sulphur to convert to TSP even more
    - agriculture will reach nutrient limited productivity ceilings

Soil P forms and properties in UK soils across different land uses

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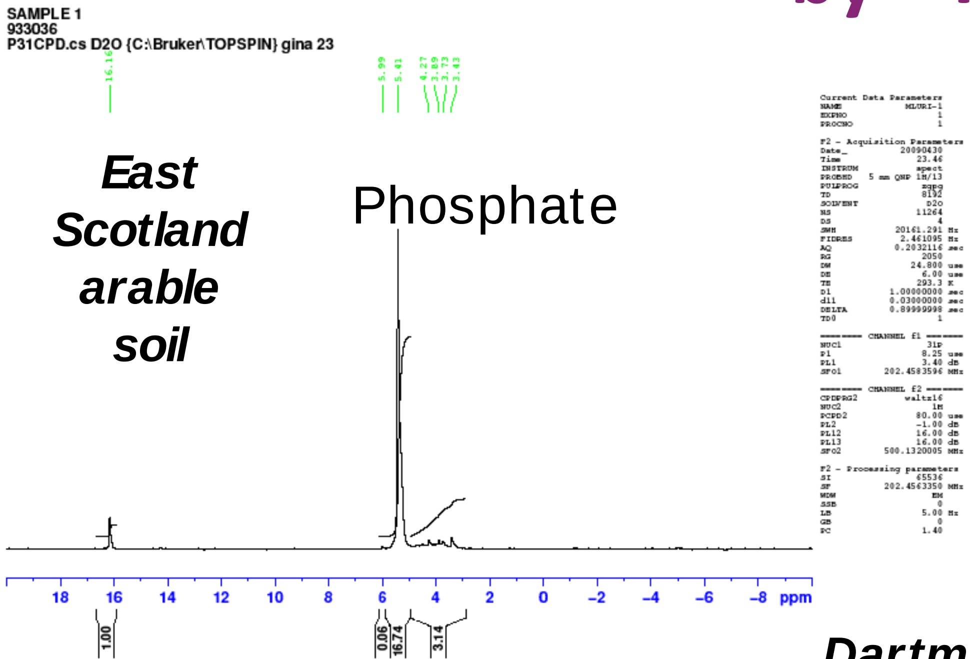
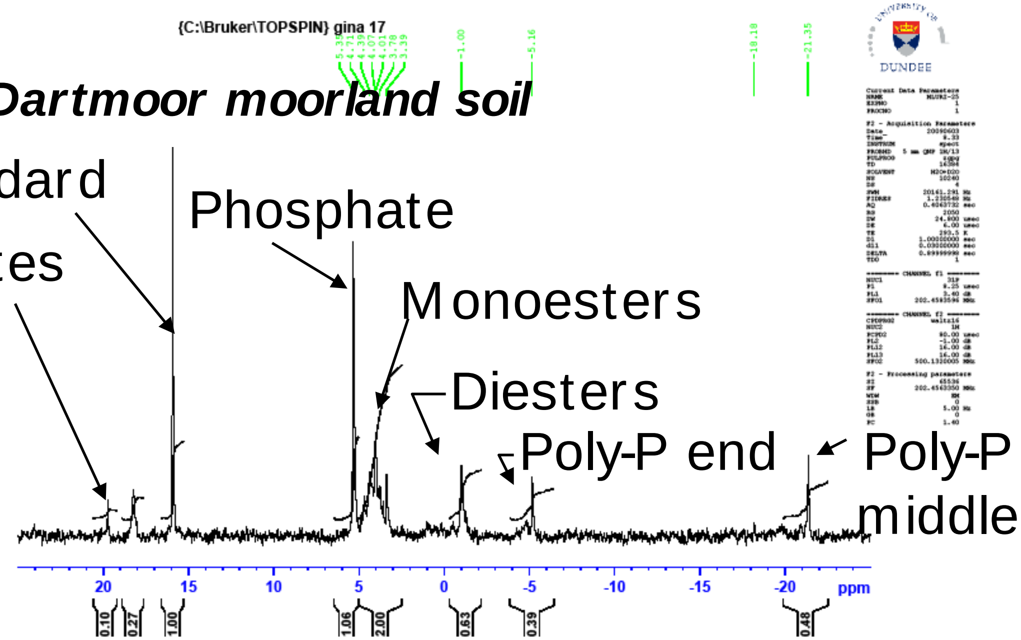
Analysis of P fractions in UK soils by ^{31}P NMR





Using NaOH / EDTA extraction and quantitative ^{31}P NMR spectroscopy

Soil P forms in sampled UK soils

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Means for soil property, P index and P form concentrations according to land use classes with overall differences expressed by ANOVA

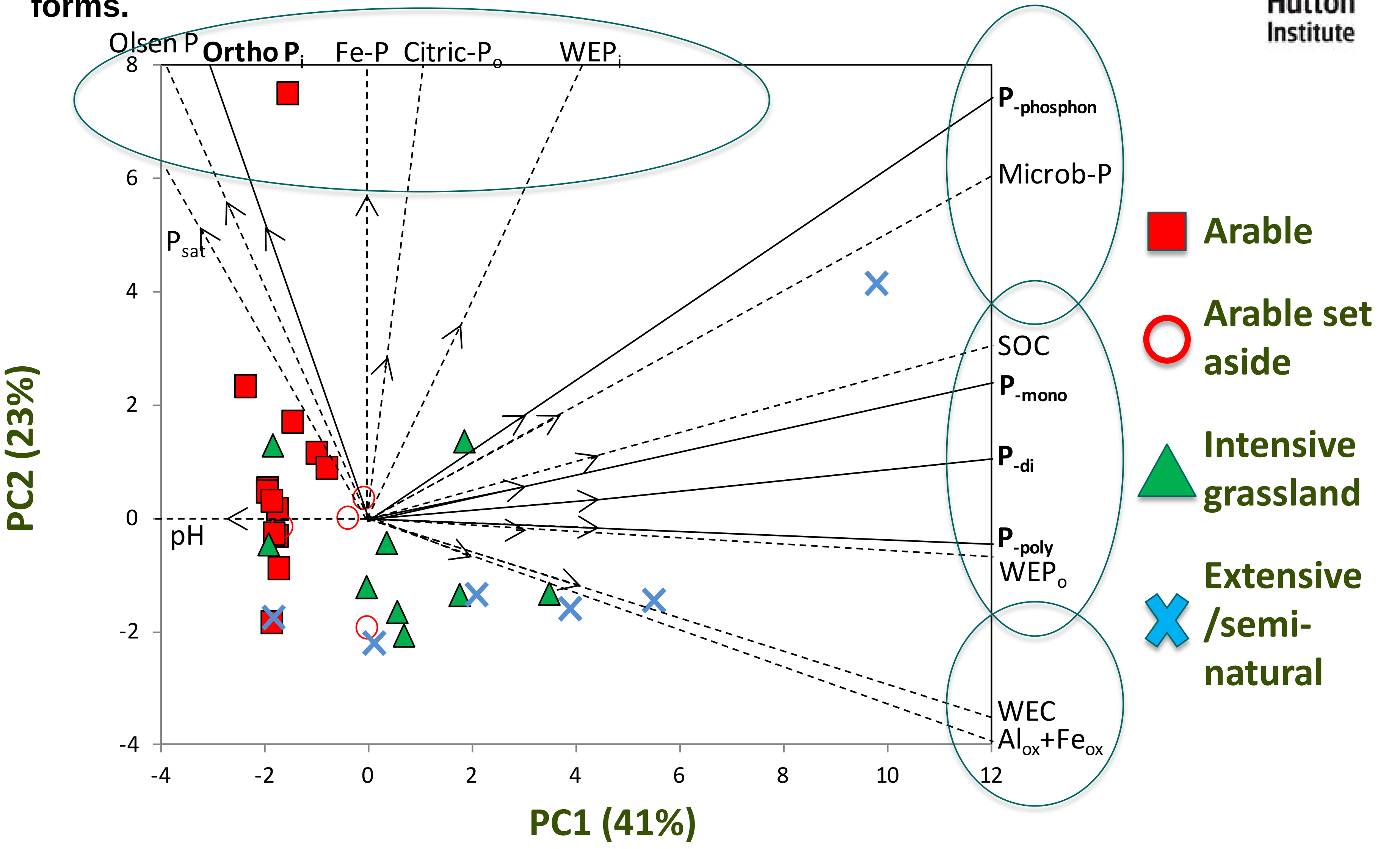
Different letters for classes denote significant differences according to Tukey tests (*p*<0.05).

Values are as mg kg^{-1} soil, except for P_{sat} .

	Arable (n=13)		Arable set aside (n=3)		Intensive grassland (n=10)		Extensive (n=6)		ANOVA
ortho-$P_{inorganic}$	695		356		462		188		ns
$P_{-monoester}$	239		226		393		348		ns
$P_{-diesters}$	4	a	11	a	16	b	55	c	***
$P_{-polyphosphate}$	1	a	11	ab	29	b	51	b	***
$P_{-phosphonates}$	0		0		0		17		ns
P_{sat}	0.17	a	0.11	ab	0.11	b	0.06	b	***
Olsen P	69.4	a	41.5	a	43.3	a	18.5	b	***
SOC	22.4	a	54.0	ab	51.1	b	158.0	b	***
Water extractable OC	0.13	a	0.29	ab	0.41	b	0.75	b	***
Al_{ox}+Fe_{ox}	7.4		7.6		10.8		9.2		ns

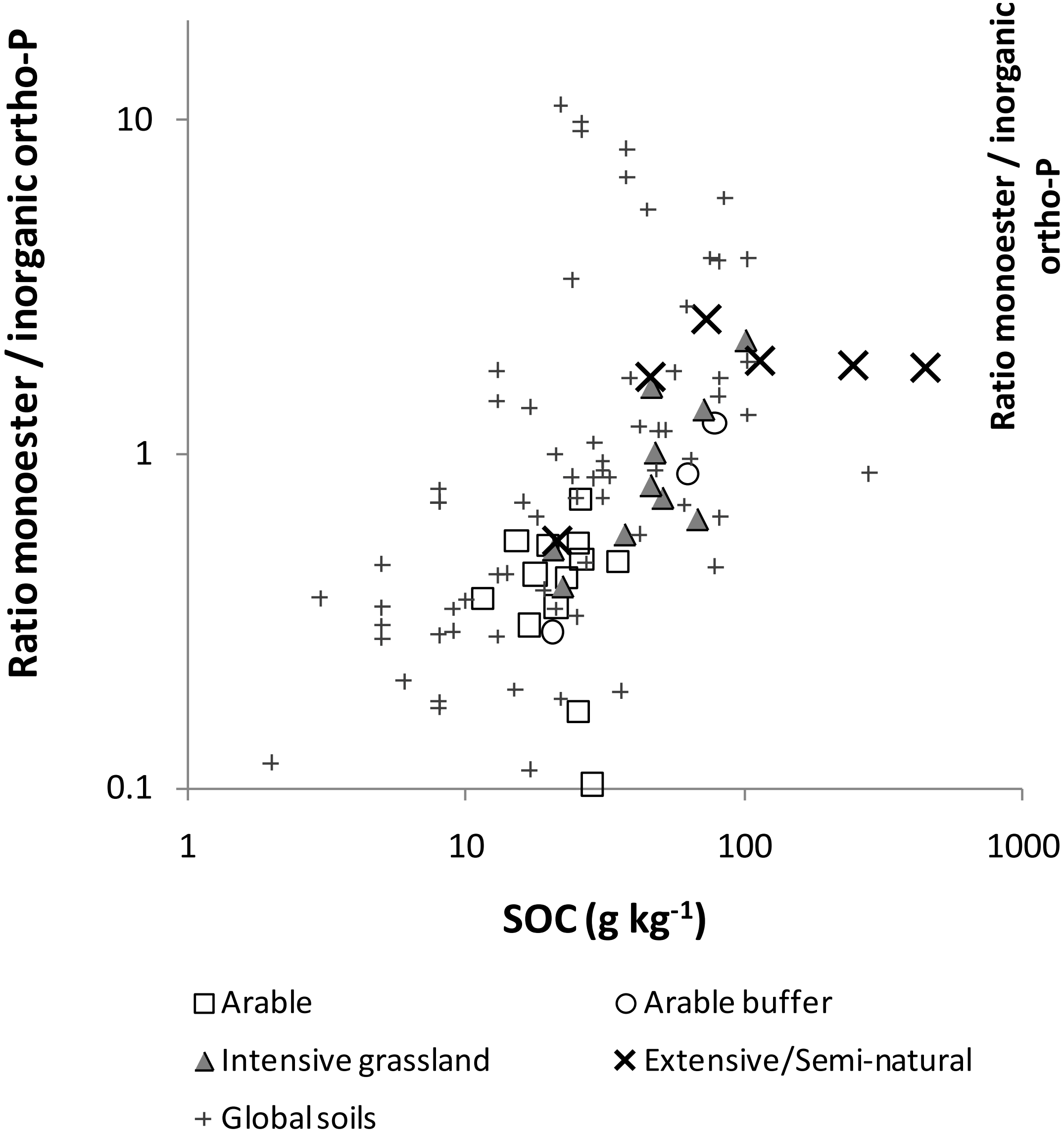
Soil P forms and wider soil properties

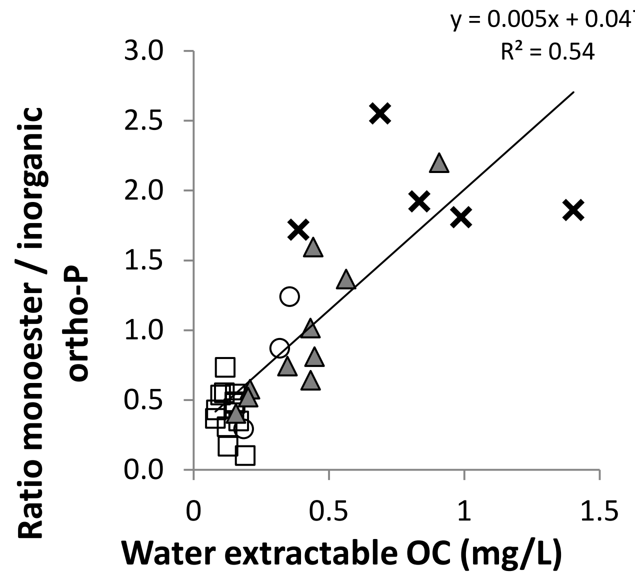
Principal components biplot of soil properties, soil P indices and ^{31}P NMR P forms.



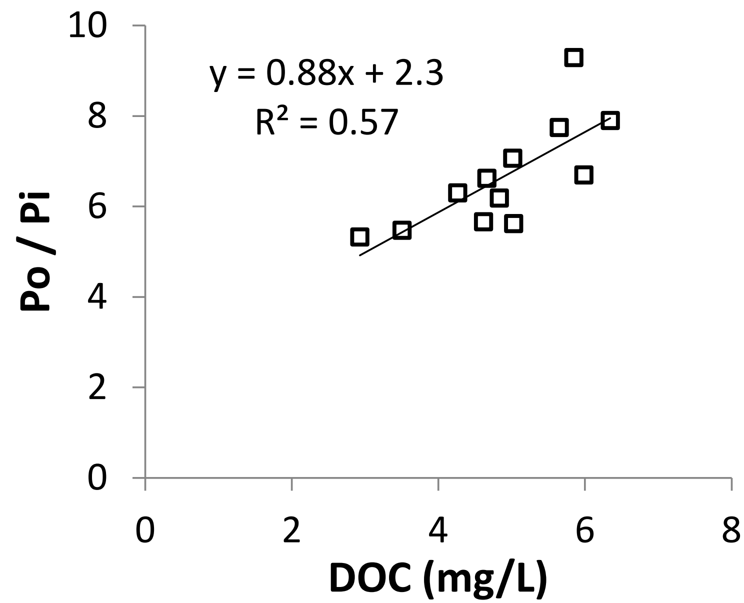
Interactions between soil C and P

Relationships exist between P forms and SOC
For soils…

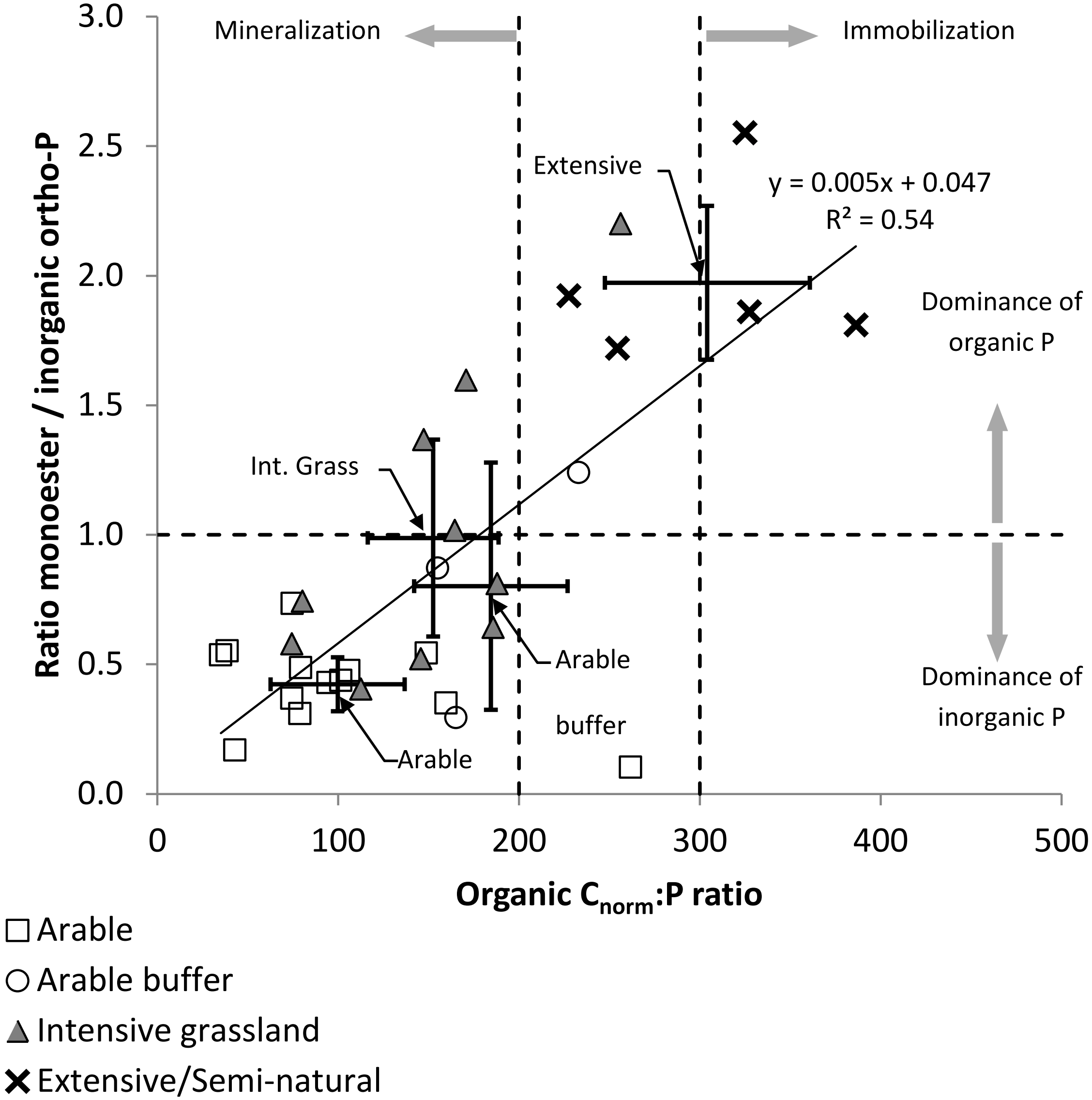




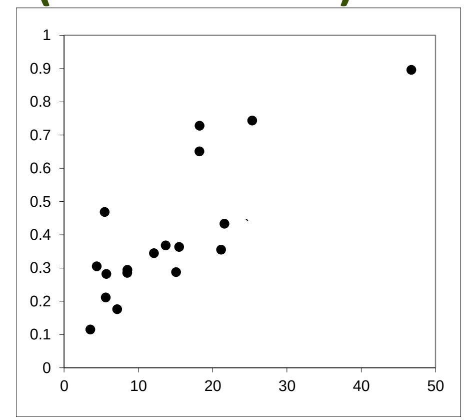
…and for river waters



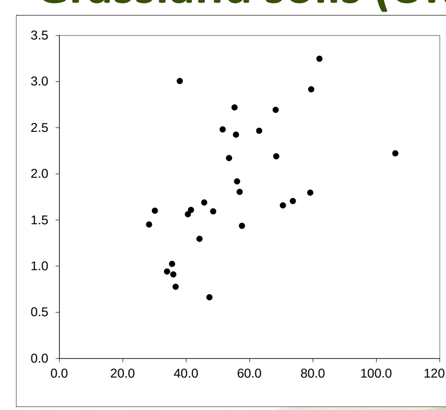
Does P availability compete with storing soil organic C?



Arable soils (Western U.S.)



Grassland soils (UK)



Data: B. Turner

What's going on? *Possibility 1*

Potentially this merely represents the impact of:

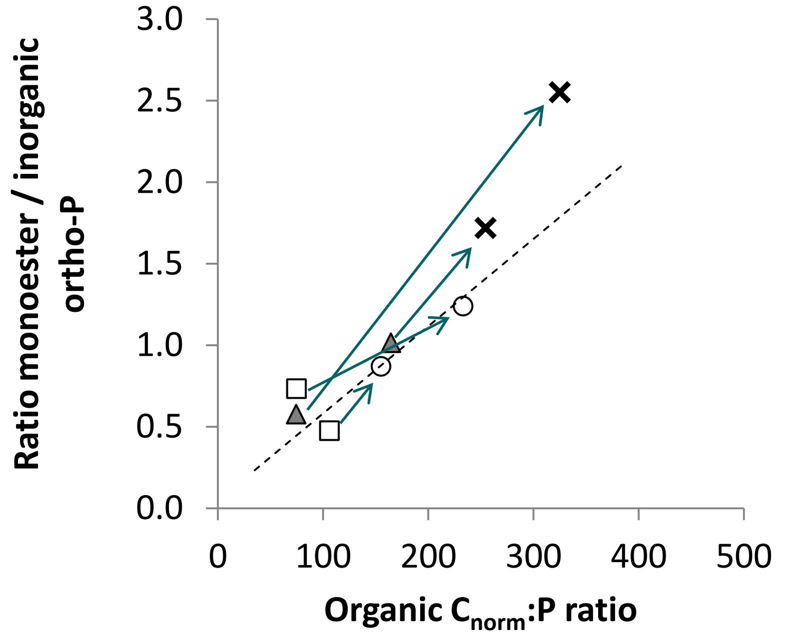
- Greater P fertiliser inputs favouring both lower monoester:Pi (because more Pi) and lower C:P ratio (because more Pi),
- and/or that low agricultural- intensity systems are on soils (or climatic conditions) that favour wide C:P and high Po:Pi (e.g. cold and wet conditions)

What's going on? *Possibility 2*

- A microbial *push*…..Increased labile OC fuels microbial P turnover favouring P immobilisation and accumulation of organic P compounds
- A geochemical *pull*…..At the same time soil stabilisation factors (like Fe, Al surfaces complexes) favour the accumulation of both monoester P and SOC

Some evidence
Space for time substitution of adjacent soils on arable/intensive grassland vs set aside/extensive management

□ Arable
○ Arable set aside
▲ Intensive grassland
✖ Extensive /semi-natural



Theories coupling P and C cycling

1. McGill & Cole (*Geoderma*, 26: 1981) suggest that "while N is mineralized in SOM decomposition by microbial need for C/energy, P mineralization is driven by microbial need for P"……"so C and P mineralization are decoupled"

2. However, Kirkby et al. (*SBB*, 60: 2013) showed that adding excess inorganic P (and N) to soils increased humification rates of litter, suggesting that "inadequate nutrient supply limits C sequestration" and that "soil C sequestration also sequesters P"

3. Furthermore, Spohn & Kuzyakov (*SBB*, 61: 2013) for German forest soils showed "microbes used phosphorylated organic compounds as a C source….but incorporated only a small amount of the mineralized P….facilitating P acquisition for plants"

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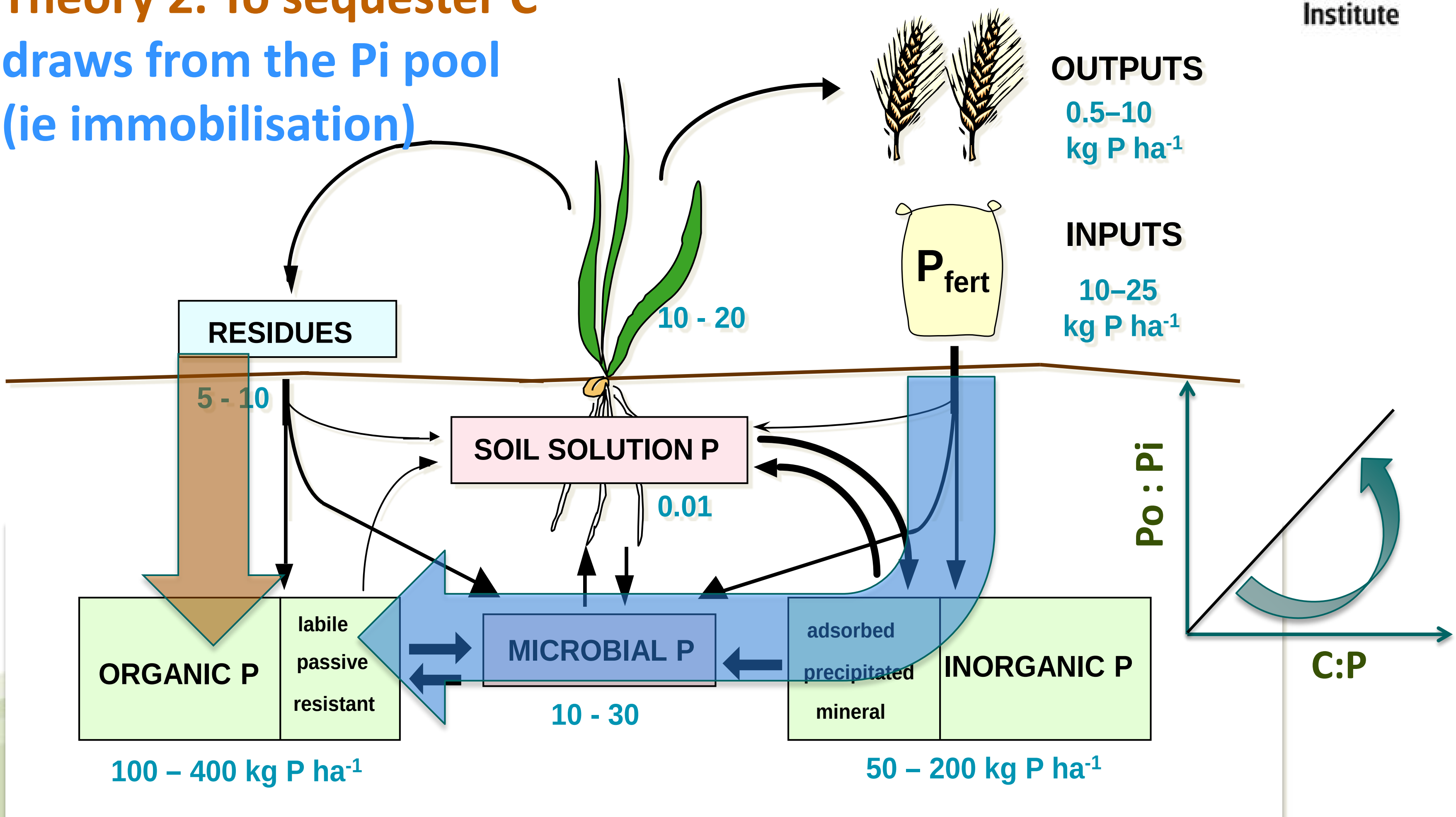
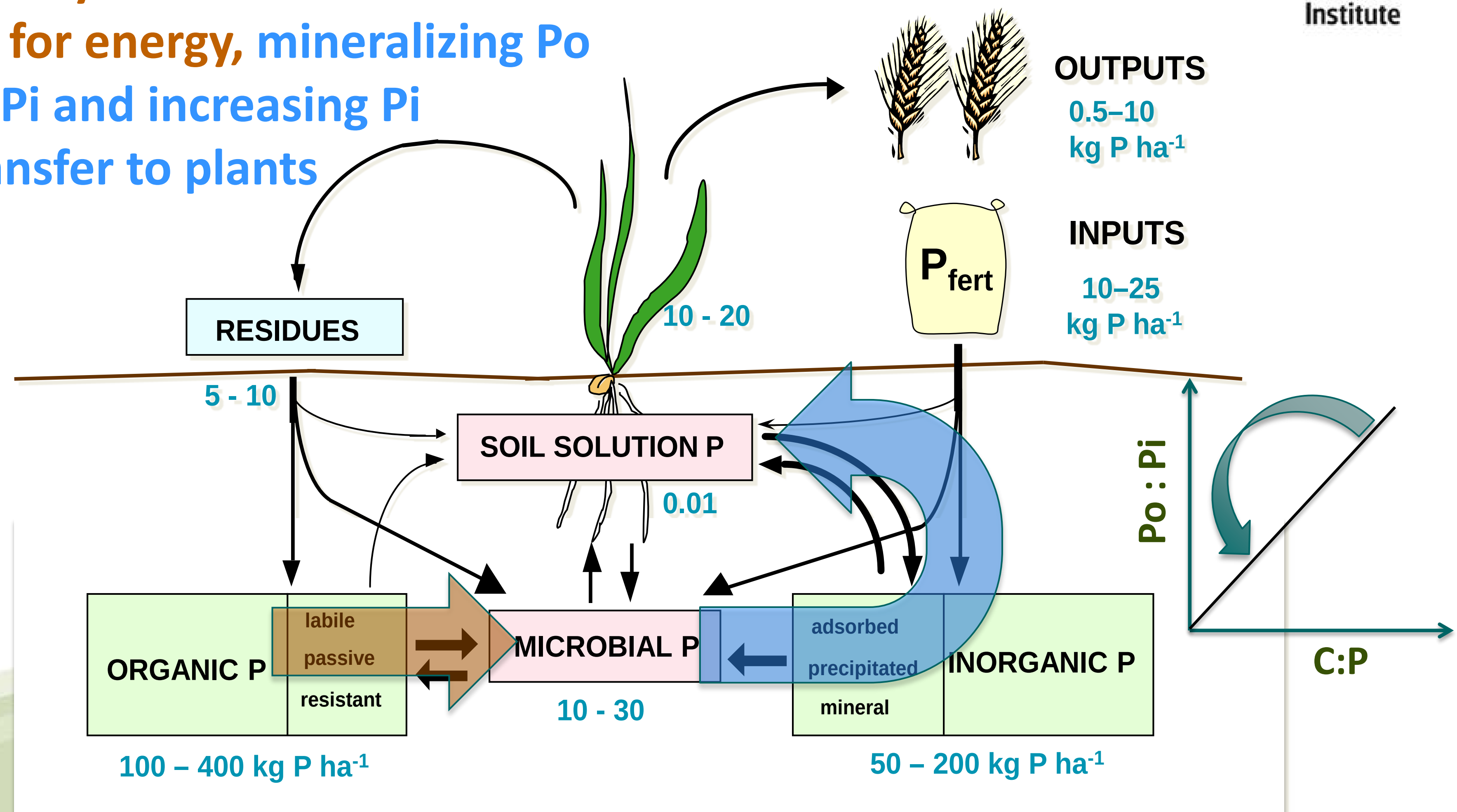
A dynamic system of P turnover

Theory 2. To sequester C draws from the Pi pool (ie immobilisation)



A dynamic system of P turnover

Theory 3. Microbes can utilise Po for energy, mineralizing Po to Pi and increasing Pi transfer to plants



What are the ways towards more sustainable systems for both P and C?

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Improving P acquisition from a range of soil P forms

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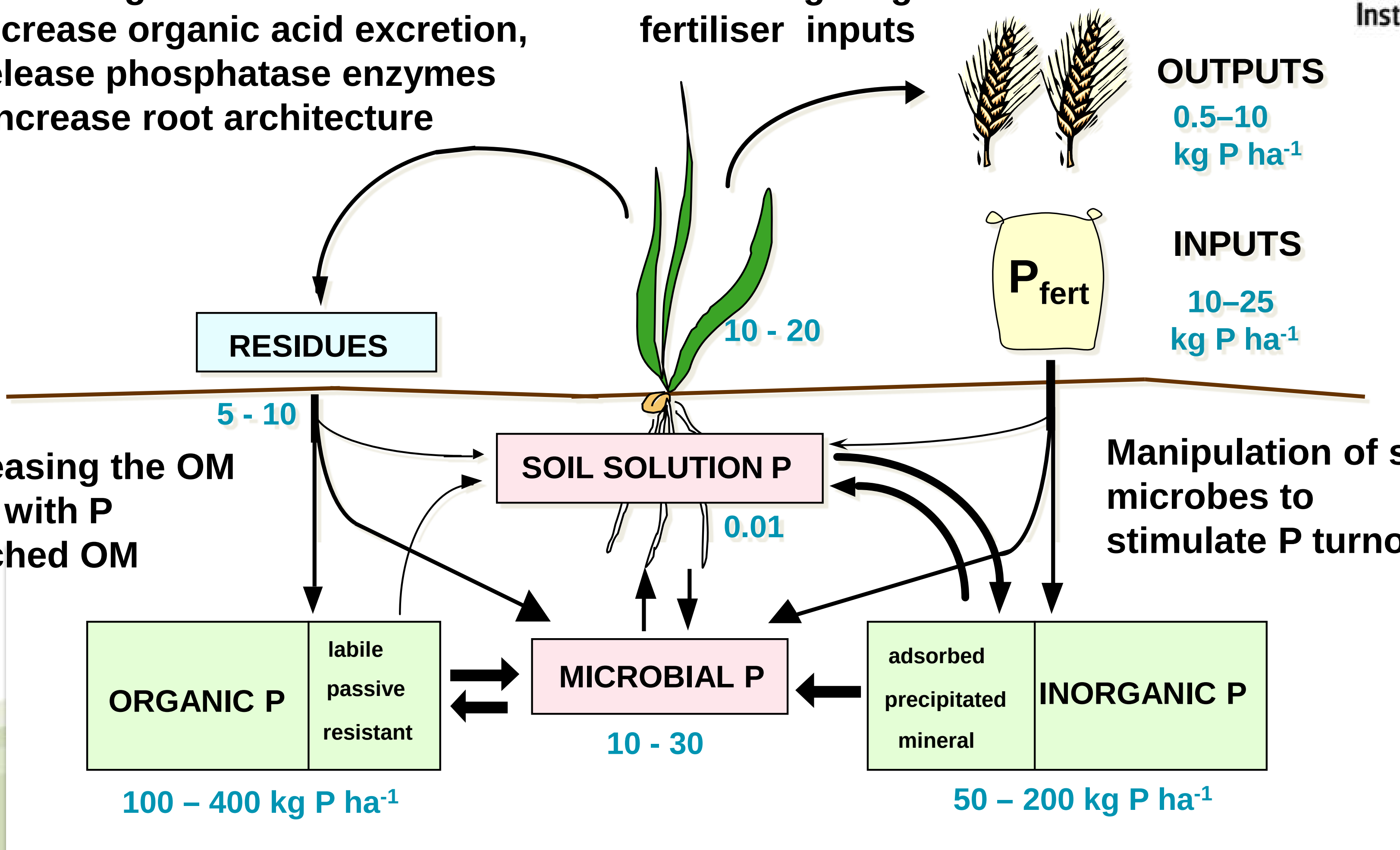
Utilising crop breeding and biotechnologies to
(i) increase organic acid excretion,
(ii) release phosphatase enzymes
(iii) increase root architecture

Better targeting of fertiliser inputs



Increasing the OM pool with P enriched OM

Manipulation of soil microbes to stimulate P turnover

Reducing losses of leached and eroded P

Using microbial innoculants in the rhizosphere

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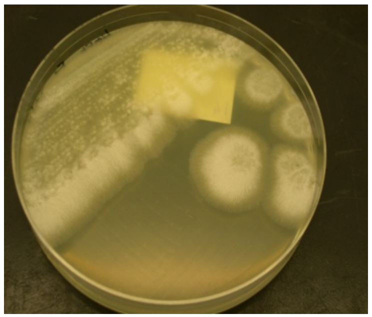
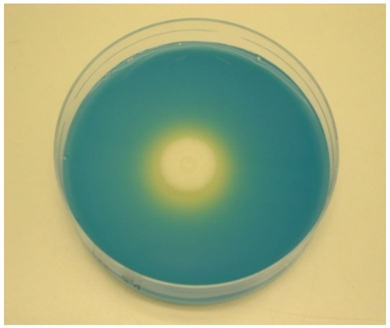
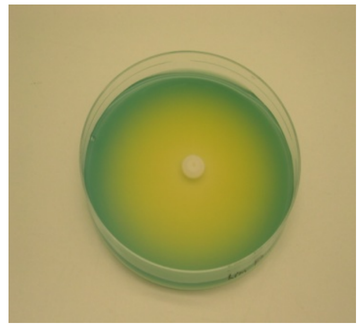


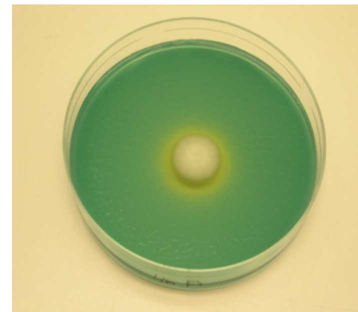
Fungal Colony



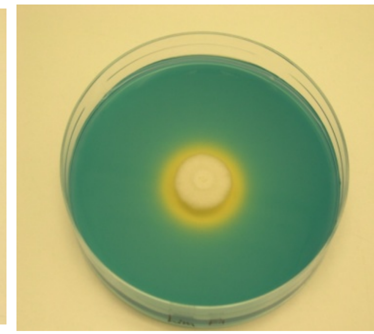
Ca-P



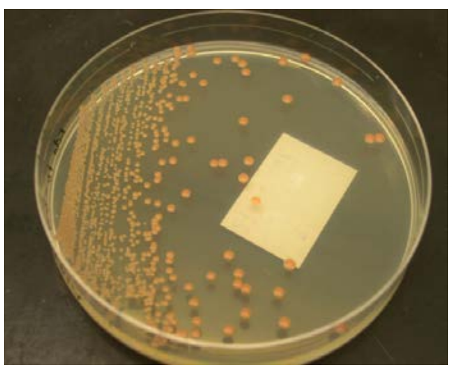
Al-P



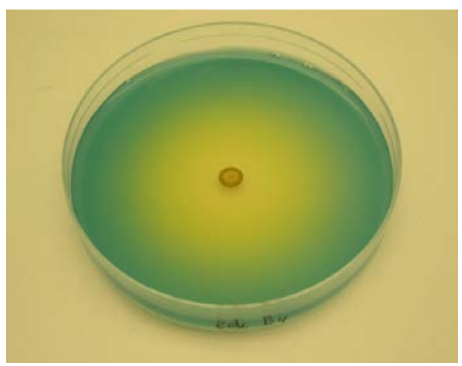
Fe-P



Inositol-P



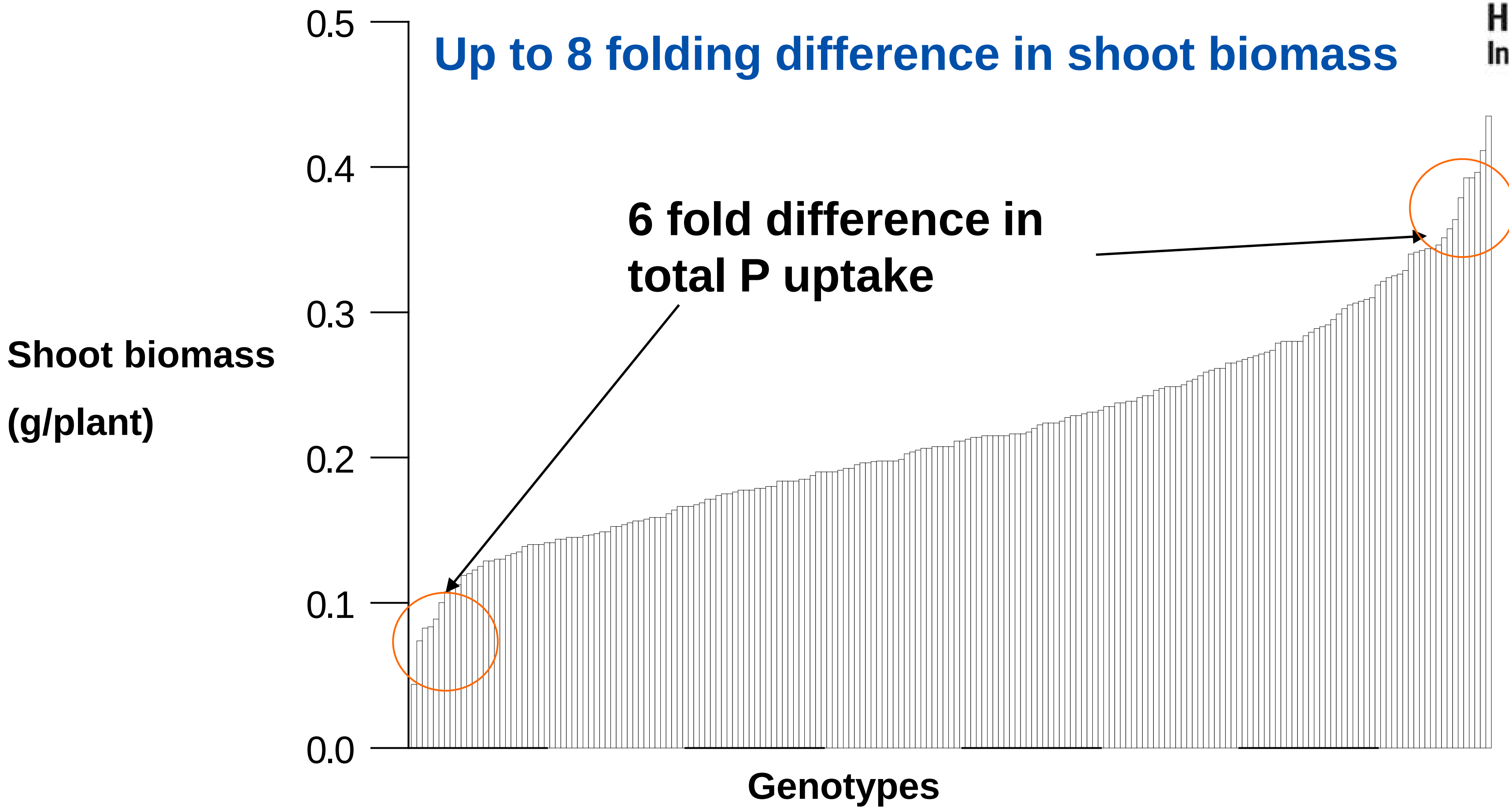
Bacterial Colony



Al-P

Slide courtesy of T. George

Screening for P efficiency



200 wheat genotypes screened on unamended, highly P-fixing Ferrosol

Slide courtesy of T. George

Better using root exudation in single and mixed cropping systems

- **Cluster roots**
- **Exudation of**
  - **Protons**
  - **Organic anions**
  - **Acid phosphatases**

Slide courtesy of T. George

Summary

- Many soil physical and biogeochemical functions depend on adequate amounts of available C and P
- Organically-complexed P forms are major components of total soil P that cannot be ignored for crop nutrition
- Potentially it is not so much *direct competition* between maintaining P availability and increasing SOC. We just need to ensure appropriate soil-crop-microbial conditions to ensure all parts of the dynamic P system are present.
- Potentially a mixed approach is best to: (i) incorporate plant residues and OM into soils (increasing SOM, but at the expense of Pi), (ii) stimulate microbes in the rhizosphere (to mineralize Pi, and promote excess Pi availability to crops) and (iii) breed traits into crops to make best use of wider soil P cycles, (iv) use chemical P sparingly as a top up.