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Storing C in agricultural soils

Does it have a role in C-trading?

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CSIRO Plant Industry



Composition of Soil

Soil organic matter
0.1 – 10%

Soil Minerals
>90%



Non-living 85%

Living 15%



Roots
5-15%



Fauna
5-10%



Microorganisms
75-90%

Break up
organic matter

Soil
turnover

Biopore
formation

Degrade
chemicals

Nutrient
Cycling

Aggregate
stabilisation

There are many good reasons to increase soil organic matter & C

Farming systems that increase soil organic C are likely to be more productive, profitable & sustainable

Increasing soil organic C enhances:

- Nutrient storage & supply
- Water infiltration & soil water holding capacity
- Soil buffering capacity
- Erosion control
- Food & habitat for biodiversity

What potential is there to store more C in agricultural soil?

Is there a role for soil C storage to assist farmers' to profitably engage in C-trading?

Options for increasing soil C reserves

Either management &/or land use needs to change so that :

- *CO₂ capture by photosynthesis*
- *Net inputs of C to soil*

**Greater than
current levels**

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Options to increase C inputs

- Maximise water use efficiency - *kg total dry matter produced per mm rainfall*
- Maximise stubble retention
- Increase frequency of pasture leys in rotations
- Introduction of perennial vegetation where appropriate - *afforestation, pastures*
- Alternative crops - *lower harvest index*
- Alternative pasture species - *increased below-ground allocation*
- Green manure crops - *legumes also improve N supply*
- Addition of offsite organic materials - *diversion of waste streams*

There are limits to the amount of C that can be fixed by photosynthesis & returned to the soil



Irrigated maize:
Residues = 6 tonnes C/yr

Source: Clive Kirkby, CSIRO PI

Storing Soil Carbon

It is not as straight forward as it seems

Constraints to the rate at which C can accumulate in soil

There are limits to the amounts of C that can be fixed by photosynthesis

30-35 tonnes C/ha from sugarcane

6 tonnes C/ha in residues from irrigated maize

1-8 tonnes C/ha from perennial pastures

Rates of C input will be dependent upon seasonal conditions - *The amount plant dry matter (40-50%C) produced is regulated by water availability & nutrient supply*

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40-90% of C in plant residues & stubble will be lost as CO₂ within 1-2 yrs

It can take decades to achieve significant change

eg Measured changes of soil C over a 20 year period range from:

0.4 tonnes C/ha (low rainfall sandy soils) to

11 tonnes C/ha (high rainfall using minimum tillage)

Increasing soil C content 0-15cm by 1% requires additional inputs of 23 tonnes C/ha over the levels being achieved by current farming practices (assuming bulk density = 1.5)

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Soils differ in their capacity to accumulate C

- Influenced by the nature of soil minerals & CEC
- Regulated by the composition of soil microbes
- There tends to be a natural equilibrium

Storing Soil Carbon

It is not as straight forward as it seems

Soil Organic Carbon (SOC) pool size is large

Most Australian soils contain between 10-100 tC/ha (0-30cm)

It is difficult & expensive to reliably measure changes in soil C

Small net inputs of C in a large background

SOC is much less than 5% of total soil mass & changes in C concentration by <10% are at the limits of measurement

eg Analytically it is not possible to distinguish between 1.49 & 1.50%C

Errors due to changes in soil bulk density over time

Estimates can be greatly overestimated if not corrected for bulk density

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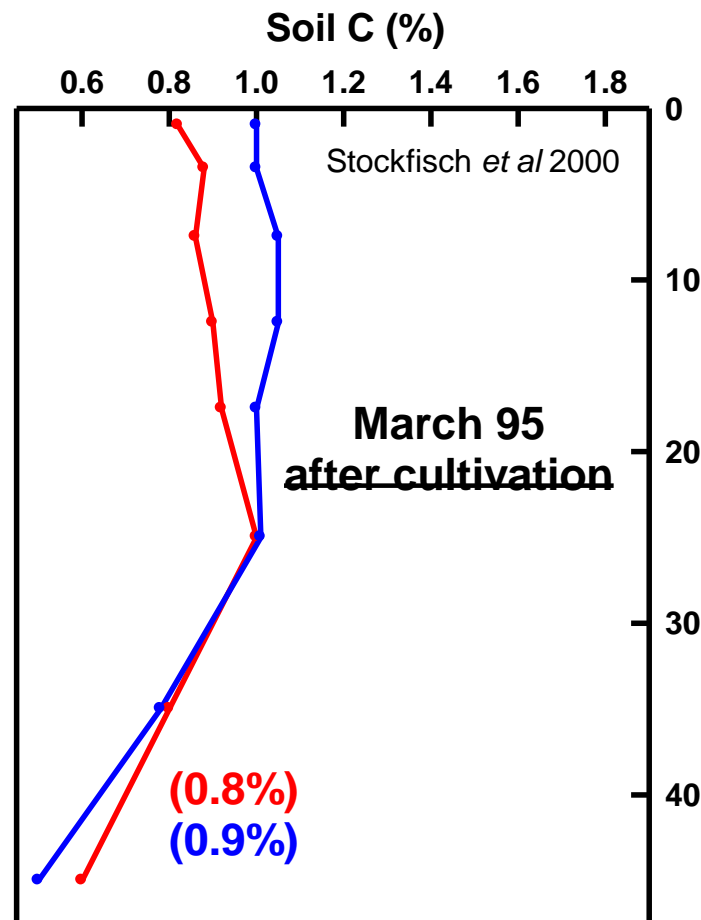
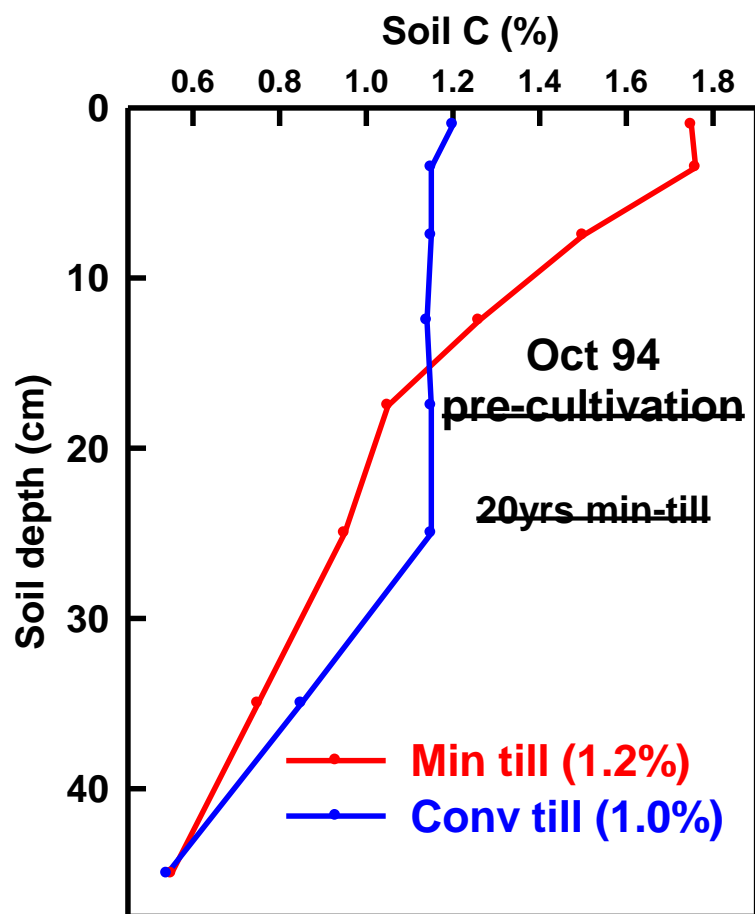
High inherent spatial variability

Variable across the landscape & down the soil profile

Can fluctuate widely from year to year

eg Pools of soil C decline during drought, or in response to cultivation

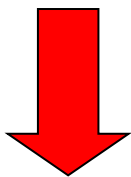
Large losses of soil C in response to changed management



Different pools of C in Soil Organic Matter (SOM)

Fresh residues,
living organisms

**<1-10%
C pool**

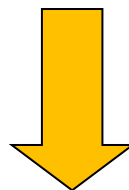


Active (labile) SOM
<1-3 y



'Resistant' residues,
physically protected

**POM
10-20%
C pool**

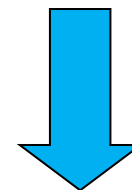


Slow SOM
20-40 y



Protected humus,
charcoal

**Humus
40-60%
C pool**



**Charcoal
0-50%
C pool**

Stable SOM
Up to 1000 y



Change in soil organic C from crop residues to humus

Crop residues on the soil surface

Buried crop residues
(>2 mm)

Particulate organic matter (POM)
(2 mm – 0.05 mm)

Humus
(<0.05 mm)

Extent of decomposition
increases

Vulnerability to change
decreases

Forms of C become
more stable &
nutrient rich



The amounts (kg) of N, P & S per tonne (1,000kg) of C in crop residues

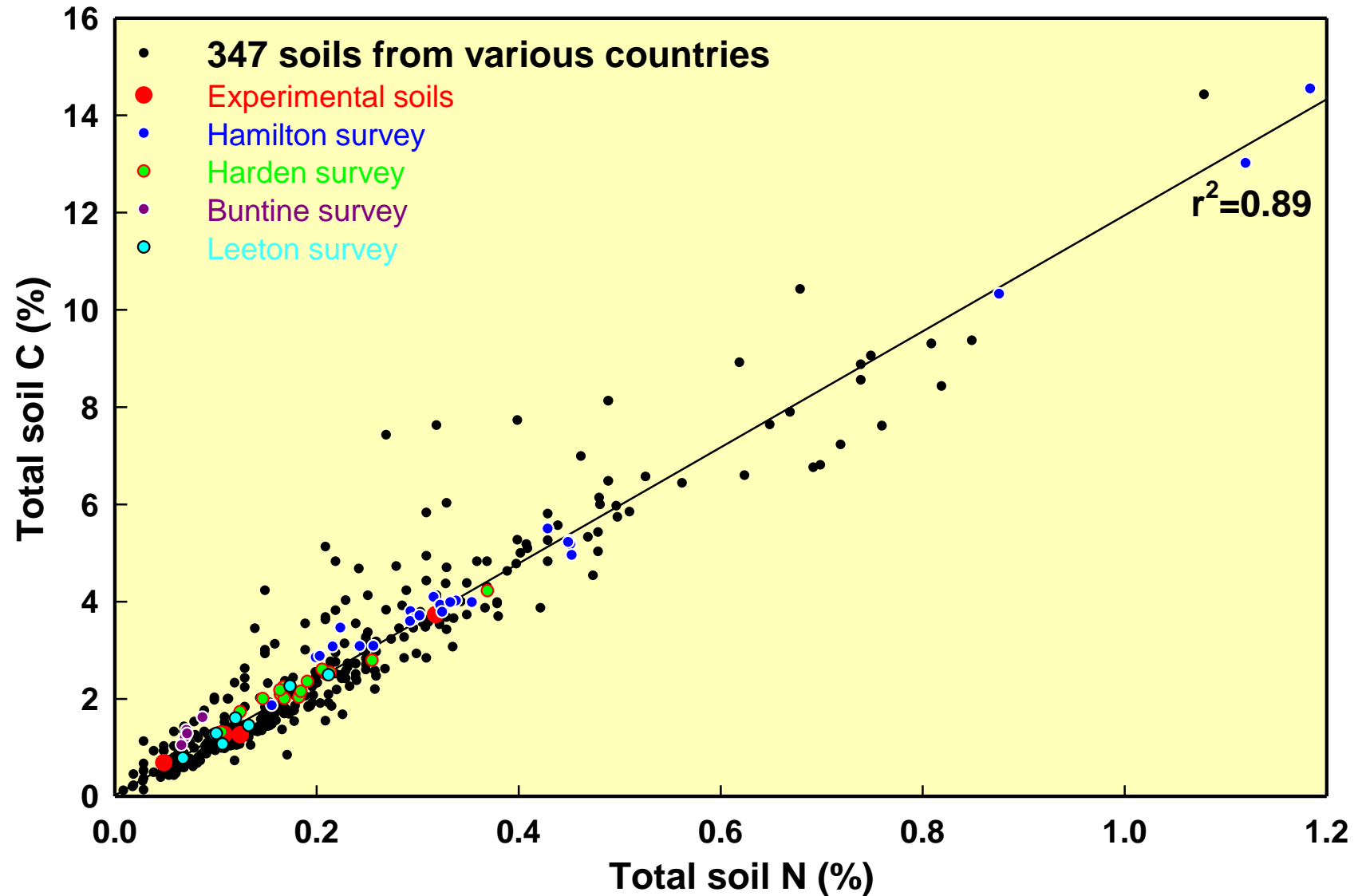
Nutrient	Wheat	Maize	Faba bean
Carbon (C)	1,000	1,000	1,000
Nitrogen (N)	13.4	21.4	49.5
<i>C:N ratio</i>	<i>75:1</i>	<i>47:1</i>	<i>20:1</i>
Phosphorus (P)	1.6	3.6	7.1
<i>C:P ratio</i>	<i>625:1</i>	<i>278:1</i>	<i>141:1</i>
Sulphur (S)	1.7	3.8	2.9
<i>C:S ratio</i>	<i>625:1</i>	<i>263.1</i>	<i>345:1</i>

Source: Clive Kirkby, CSIRO PI

The amounts (kg) of N, P & S per tonne (1,000kg) of C in crop residues, humus, soil fungi or bacteria

Nutrient	Wheat	Maize	Faba bean	Humus	Fungi	Bacteria
Carbon (C)	1,000	1,000	1,000	1,000 kg	1,000	1,000
Nitrogen (N)	13.4	21.4	49.5	83.3 kg	109	240
<i>C:N ratio</i>	<i>75:1</i>	<i>47:1</i>	<i>20:1</i>	12:1	<i>9:1</i>	<i>4:1</i>
Phosphorus (P)	1.6	3.6	7.1	20 kg	10.9	52
<i>C:P ratio</i>	<i>625:1</i>	<i>278:1</i>	<i>141:1</i>	50:1	<i>92:1</i>	<i>19:1</i>
Sulphur (S)	1.7	3.8	2.9	14.3 kg	3.6	10
<i>C:S ratio</i>	<i>625:1</i>	<i>263:1</i>	<i>345:1</i>	70:1	<i>278:1</i>	<i>100:1</i>

C:N ratio is relatively stable across a range of soils



Source: Clive Kirkby, CSIRO PI

Storing Soil Carbon

It is not as straight forward as it seems

Nutrients are required to store stable forms of C in soil

Humus = stable organic matter fraction of soil arising from crop residues
= 40-60% of total soil organic C

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Humus = stable organic matter fraction of soil arising from crop residues
= 40-60% of total soil organic C

Humus has a ratio of C:N = 10-12:1

C:P = 50:1

C:S = 65-70:1

Amount of nutrients tied up every tonne of soil stored C (= 1.7 t humus)

= 80 kg N (value if replaced with fertiliser @ \$1.50/kg N = \$120)

= 20 kg P (value if replaced with fertiliser @ \$5/kg P = \$100)

= 14 kg S (value if replaced with fertiliser @ \$2/kg S = \$28)

Approx total cost for as long as C stored = \$248/tC

Storing Soil Carbon

The value of N, P & S locked up per tonne of C

Australian agriculture is formally unable to trade in C offsets for other industries until at least 2012

In existing markets C trading is based on a tonne of CO₂ equivalent

The value of CO₂ currently ranges from :
\$0.25/tonne (*Australian Soil Carbon Accreditation Scheme – WA*)
5-10/tonne (*Chicago Climate Exchange*)
\$40/tonne (*EU/Kyoto compliance*)

If C-trading was \$40/tonne CO₂, then 1 tonne soil C
(= 3.7 tonne CO₂) would be worth approx \$150

This is considerably less than the estimated value of the nutrients stored in humus

Questioning the assumptions that have led to high expectations for using soil C for C-credits

Only if soils heavily degraded

Much of the C in residues will be lost as CO₂ within 1-2 yrs

Basic Assumptions:

1. It will be relatively easy for farmers to increase the amount of C stored in agricultural soils since all the C in plant residues & crop stubbles contribute to soil C reserves
2. Increases in soil C can be achieved at relatively little or no cost
3. (a) Big \$'s will be on offer for the use of soil C as C credits in a C-trading scheme
(b) Farmers will be paid on the basis of the amount of C stored in the soil

- Changes to farming practices will be required to increase annual C inputs above current levels
- Nutrients tied-up along with the C have a value

Questioning the assumptions that have led to high expectations for using soil C for C-credits

Basic Assumptions

1. It will be relatively easy to store C in agricultural soils and crop residues
stubbles compared to other land uses
2. Increases in soil C can be achieved at relatively little or no cost
3. (a) Big \$'s will be on offer for the use of soil C as C offsets in a C-trading scheme
(b) Farmers will be paid on the basis of the total amount of C present in their soils

• Current trading prices for C may be insufficient to cover the cost of nutrient tie-up
• The compliance costs associated with measuring & monitoring soil C levels could outweigh the financial benefits

No – only the rate of change in soil C over & above standard practice

Take-Home Messages

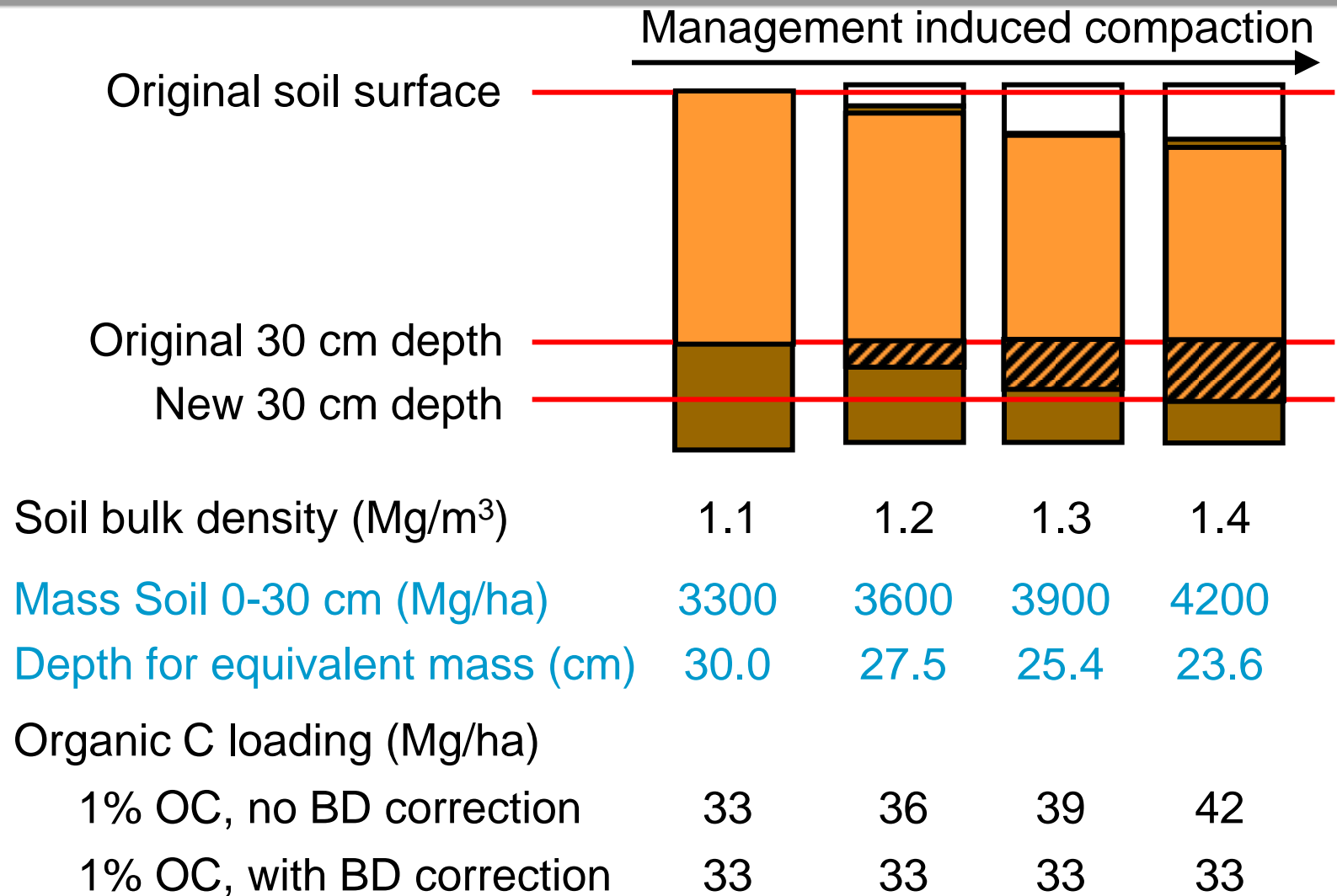
- Australian soils do have the **potential** to store more C
- Current management systems will need to be altered to store more C than presently being achieved

Take-Home Messages

- Australian soils do have the **potential** to store more C
- Current management systems will need to be altered to store more C than presently being achieved
- Need to be cautious if looking to engage in C-trading by storing soil C
 - *The rate of change in soil C reserves is generally slow*
 - *It is difficult to quantify short-term changes in soil C*
 - *Nutrients will be tied up along with C in stable forms of soil organic matter such as humus*
 - *The cost of this nutrient tie-up may be greater than the value of C-trading under current pricing structures*

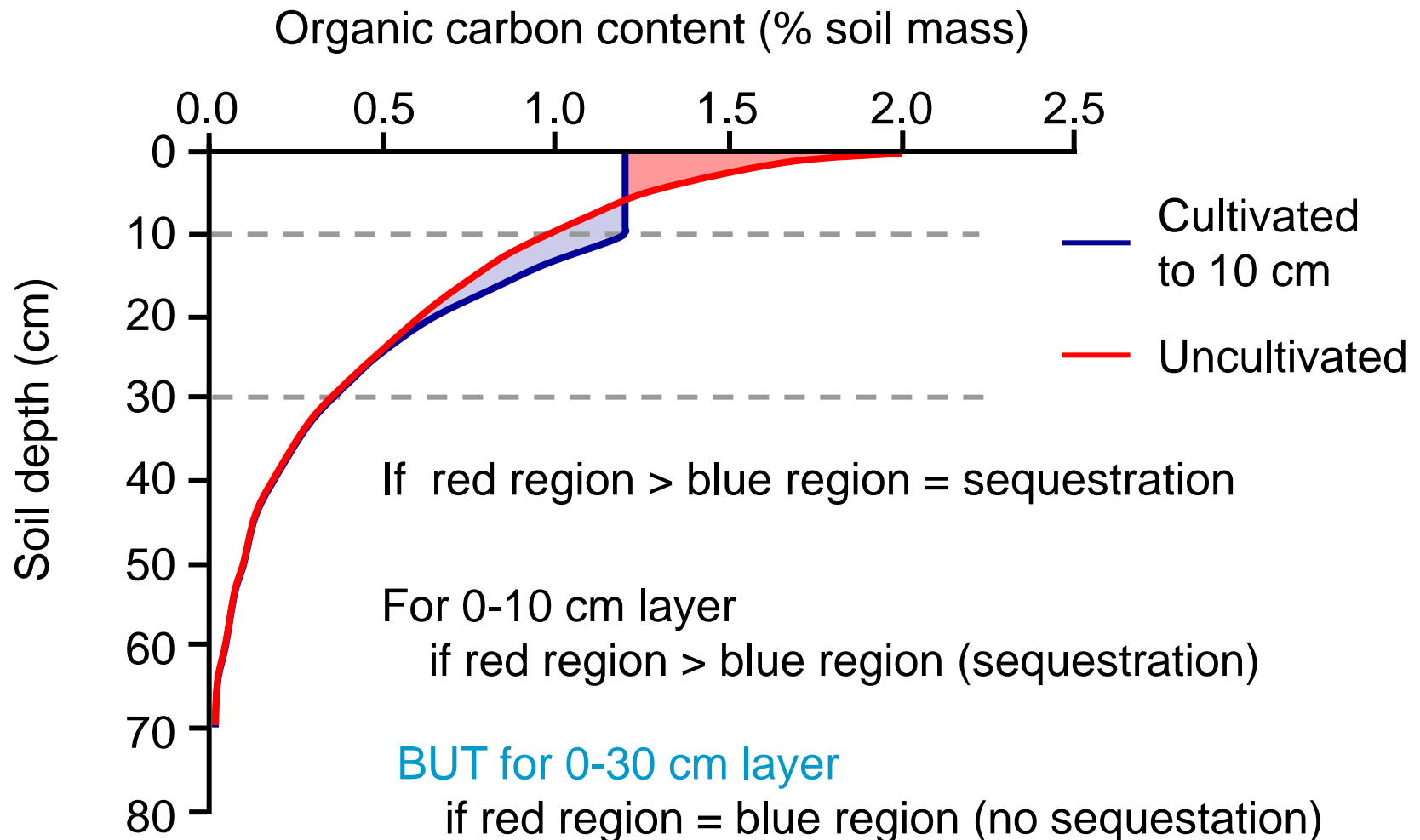
Storing more organic carbon in soils has many benefits for farmers beyond C-trading

Correcting soil carbon for management induced changes in bulk density

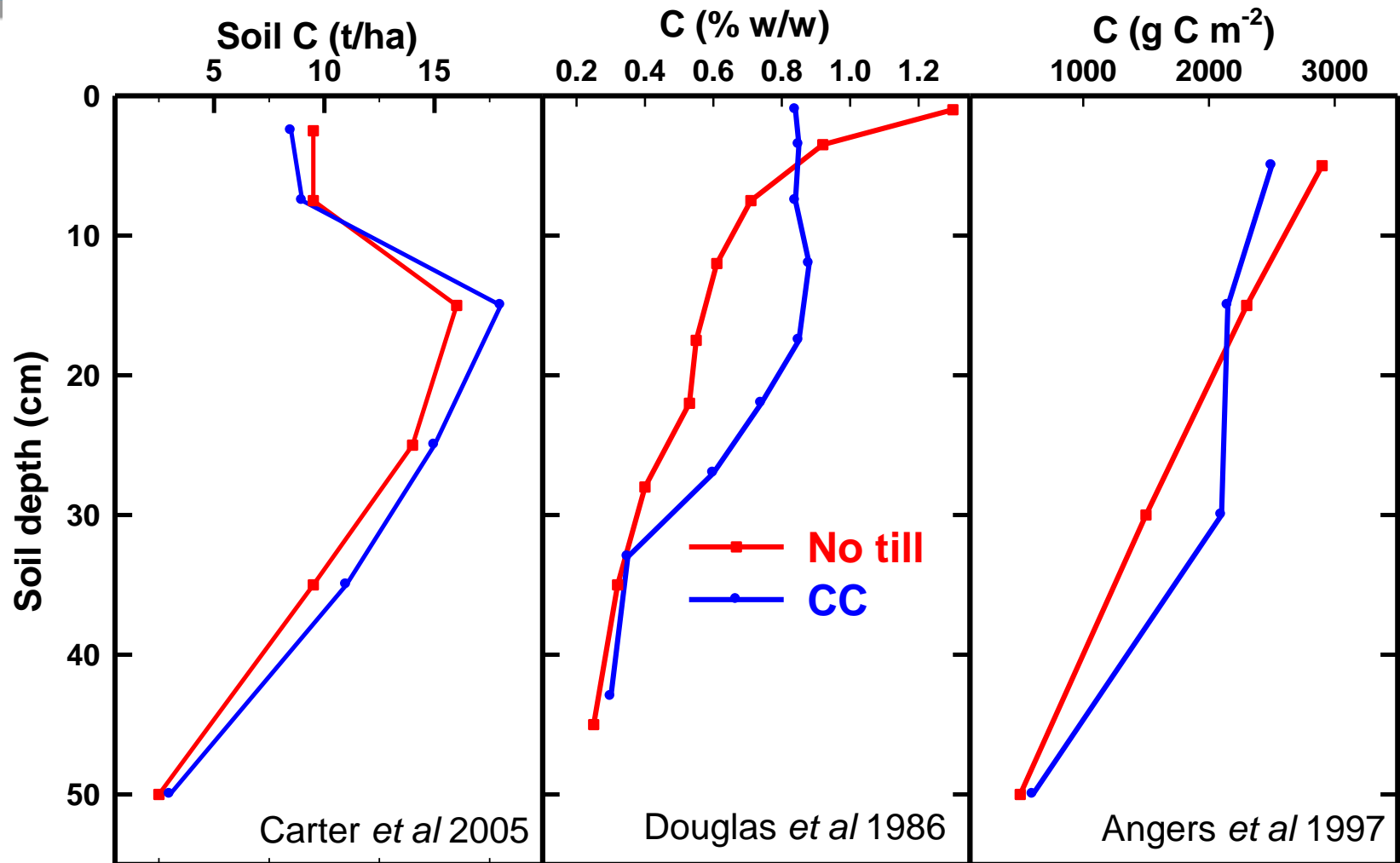


Source: Jeff Baldock CSIRO Land and Water

Influence of tillage on changes in soil carbon with depth



Changes in the topsoil, but overall little difference in the total mass of carbon down the soil profile



**Never Farmed
or fertilised**

118 t/ha

**Long Term
Pasture**

116 t/ha

**Long Term
Cropping**

9 t/ha



Source: Clive Kirkby, CSIRO PI

OM debris



C:N:P:S ratios for Fresh Residues

Stubble	C	N	P	S
wheat	10,000	134	16	36
maize	10,000	214	36	38
rice	10,000	95	12	14
canola	10,000	238	48	119
fababeans	10,000	495	71	29

- Ratios quite variable
- Once fresh residues “hit” soil it is part of SOM

C:N:P:S ratios for Residues & Humus

Stubble	C	N	P	S
wheat	10,000	134	16	36
maize	10,000	214	36	38
rice	10,000	95	12	14
canola	10,000	238	48	119
fababeans	10,000	495	71	29
HUMUS	10,000	833	200	143

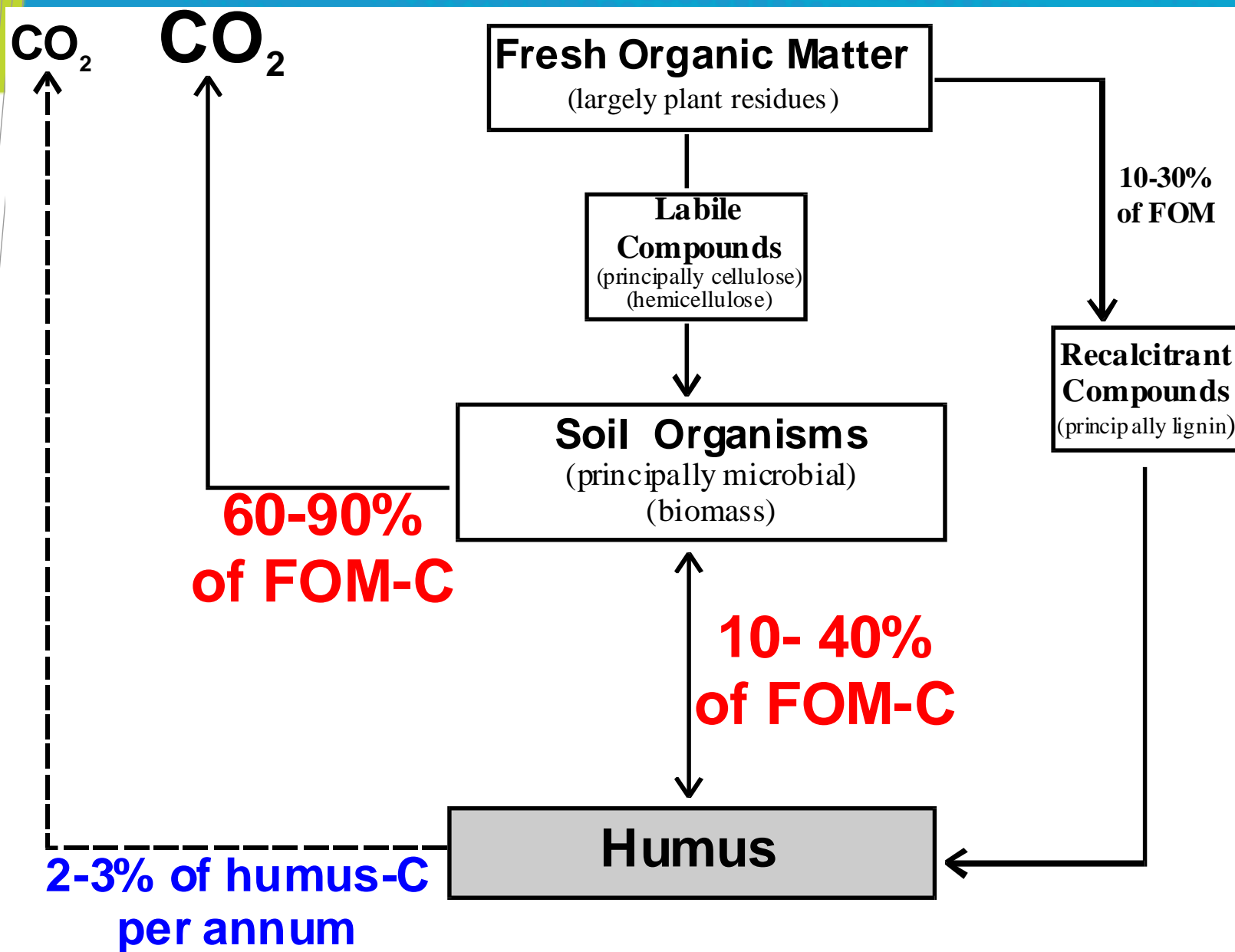
C:N:P:S ratios for Residues, Microbes & Humus

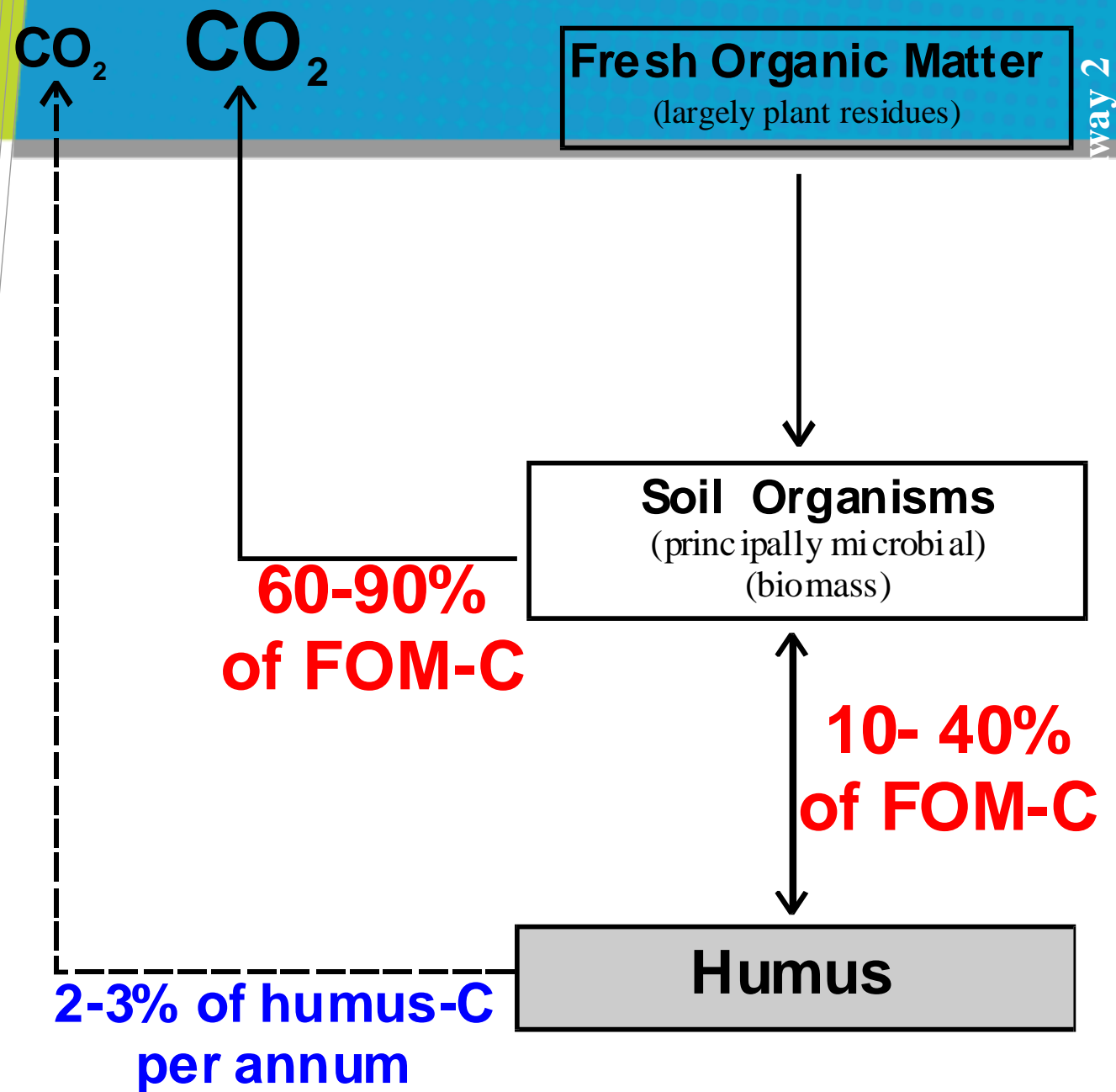
	C	N	P	S
wheat	10,000	134	16	36
maize	10,000	214	36	38
rice	10,000	95	12	14
<i>bacteria</i>	10,000	2,400	520	100
<i>fungi</i>	10,000	1,091	109	36
humus	10,000	833	200	143

**To sequest 10 tonnes of C as humus
one must also sequest**

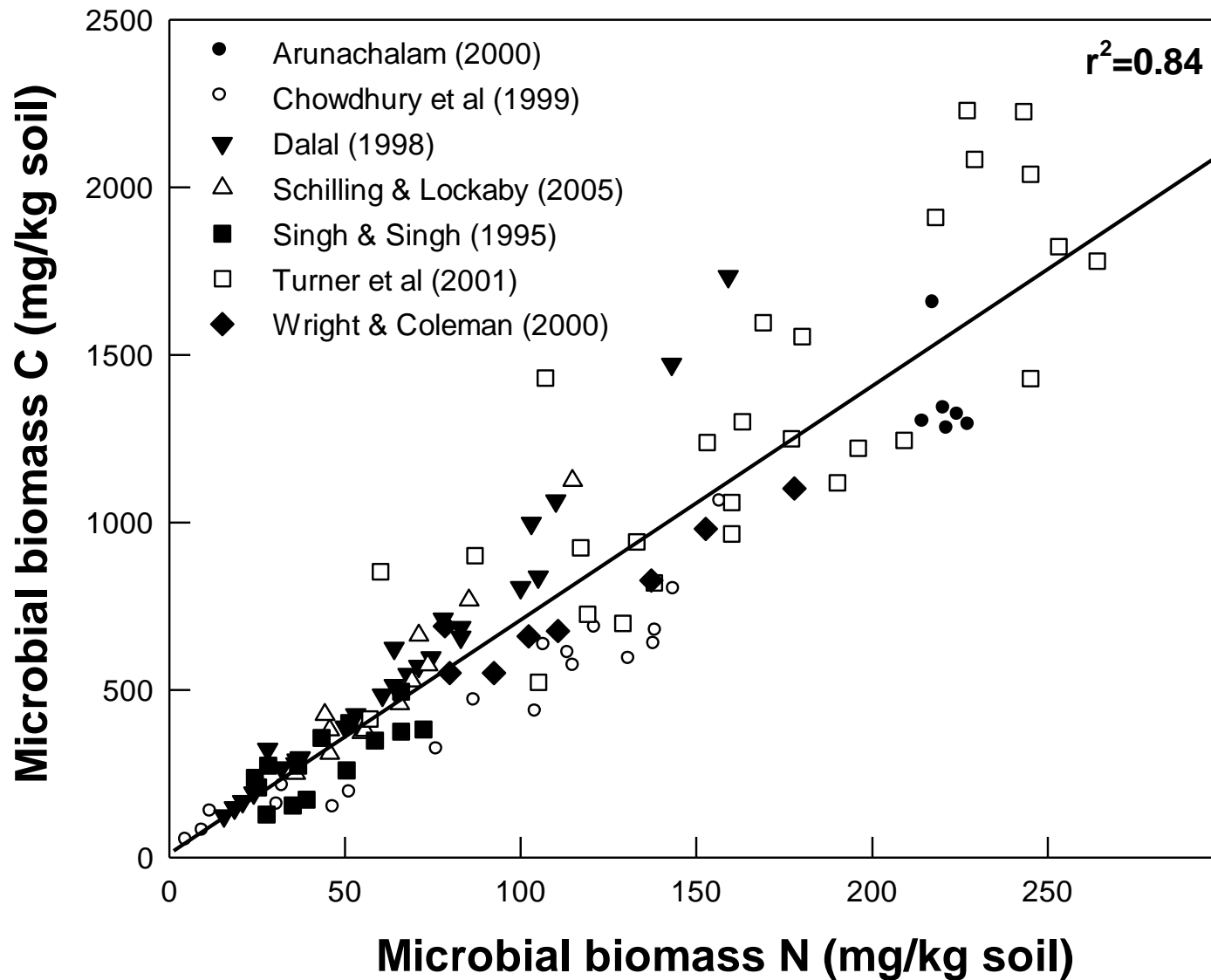
833 kg N, 200 kg P and 143 kg S

(one cannot sequest C in isolation)

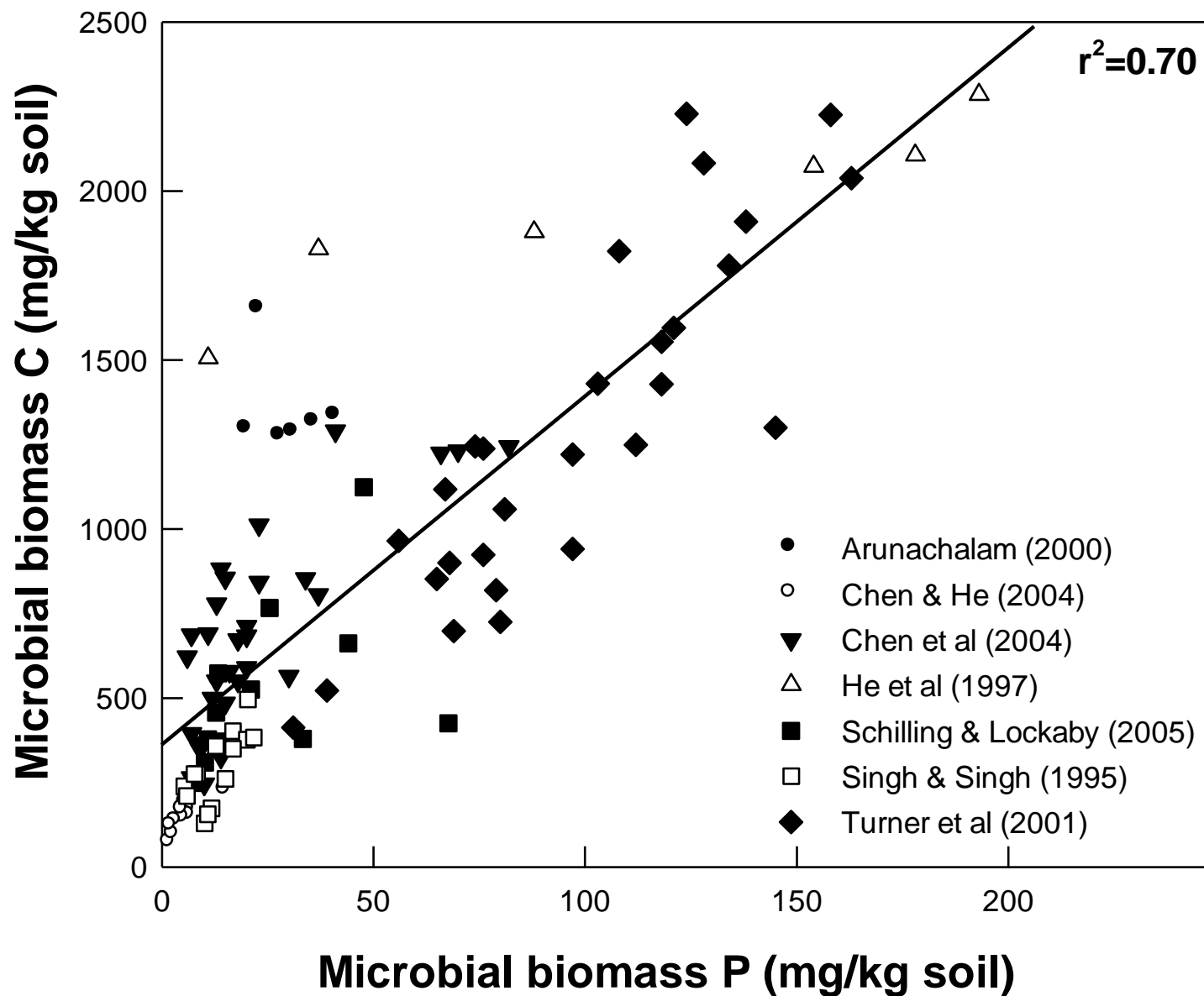




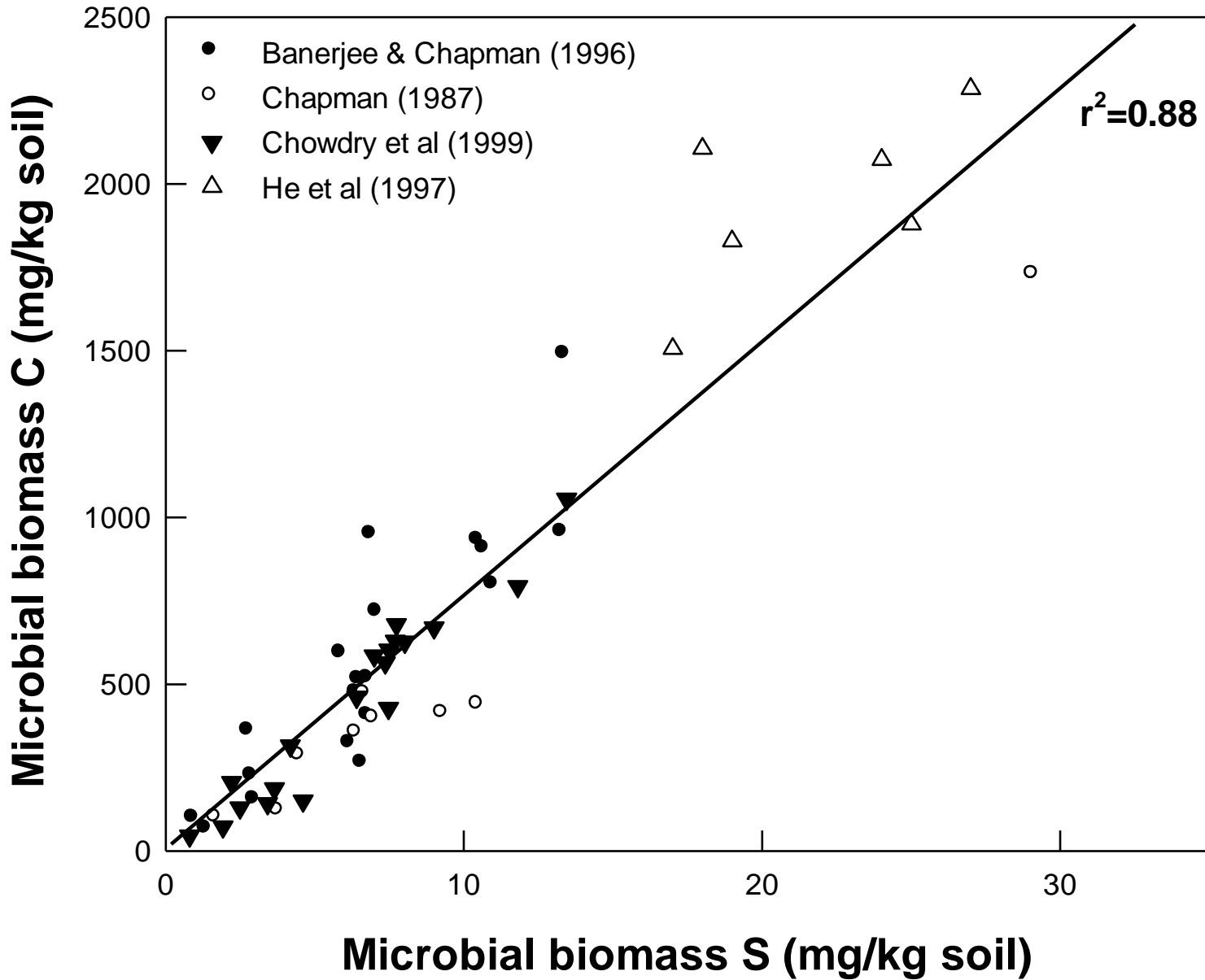
Microbial C:N



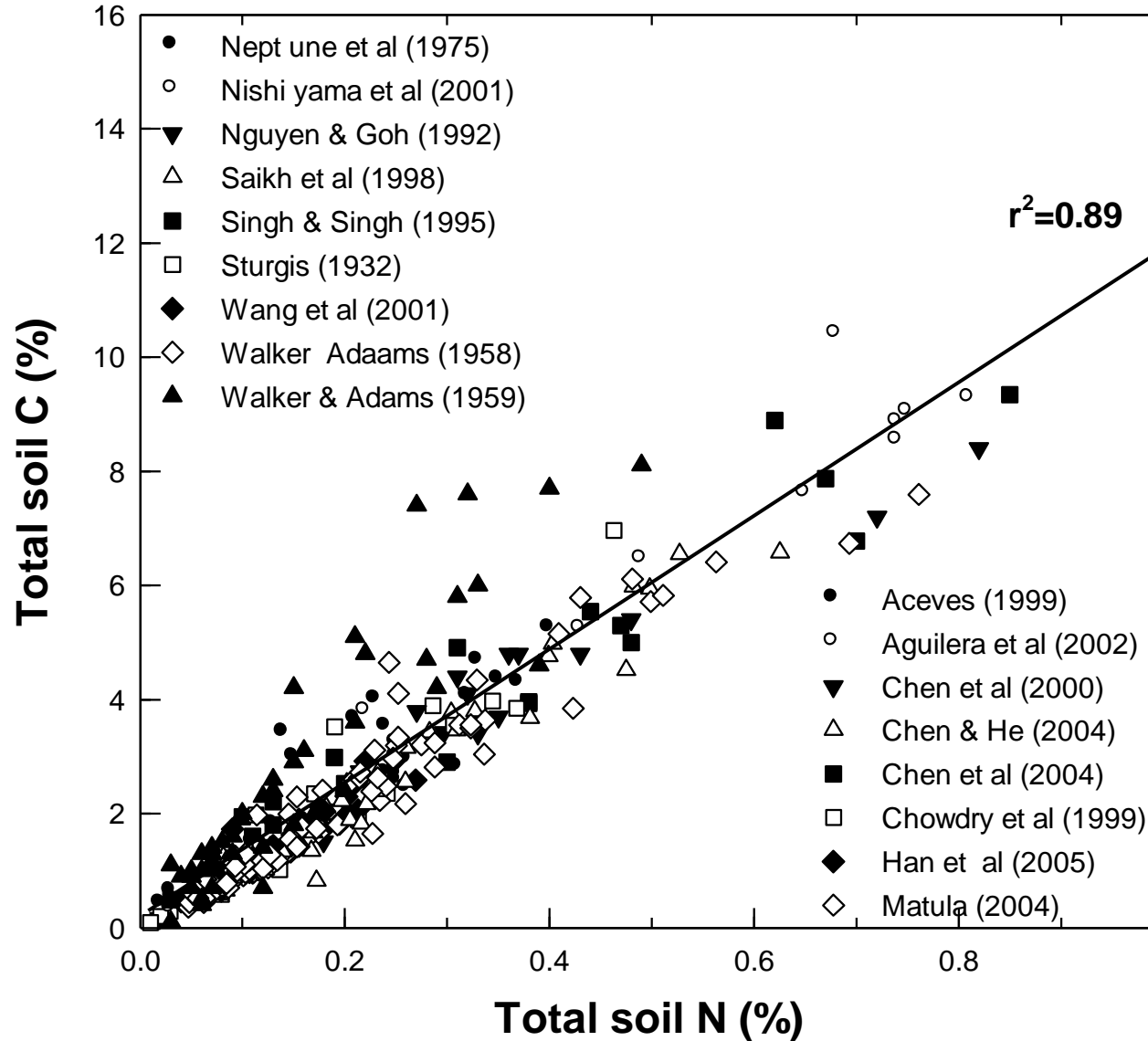
Microbial C:P



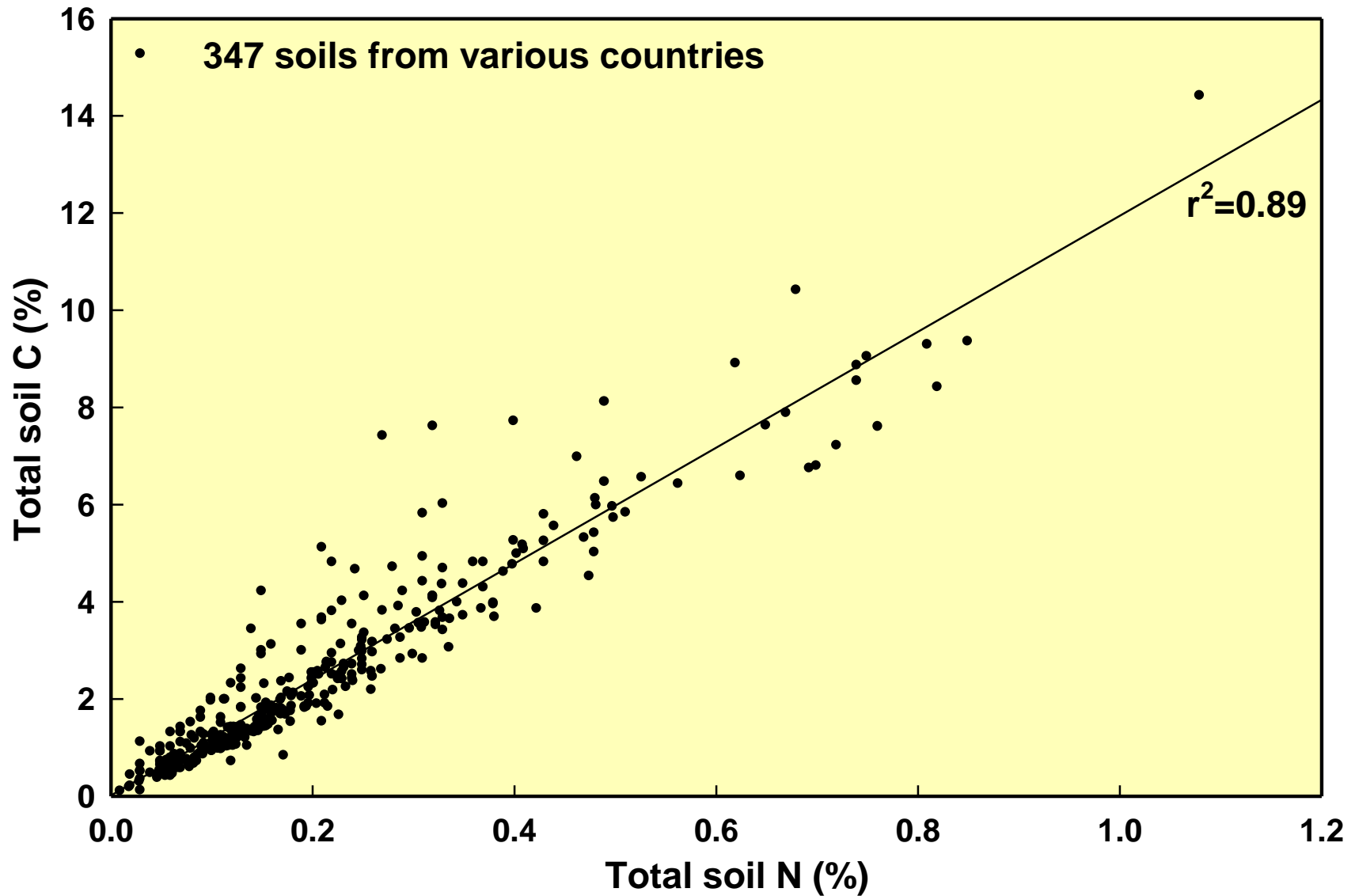
Microbial C:S



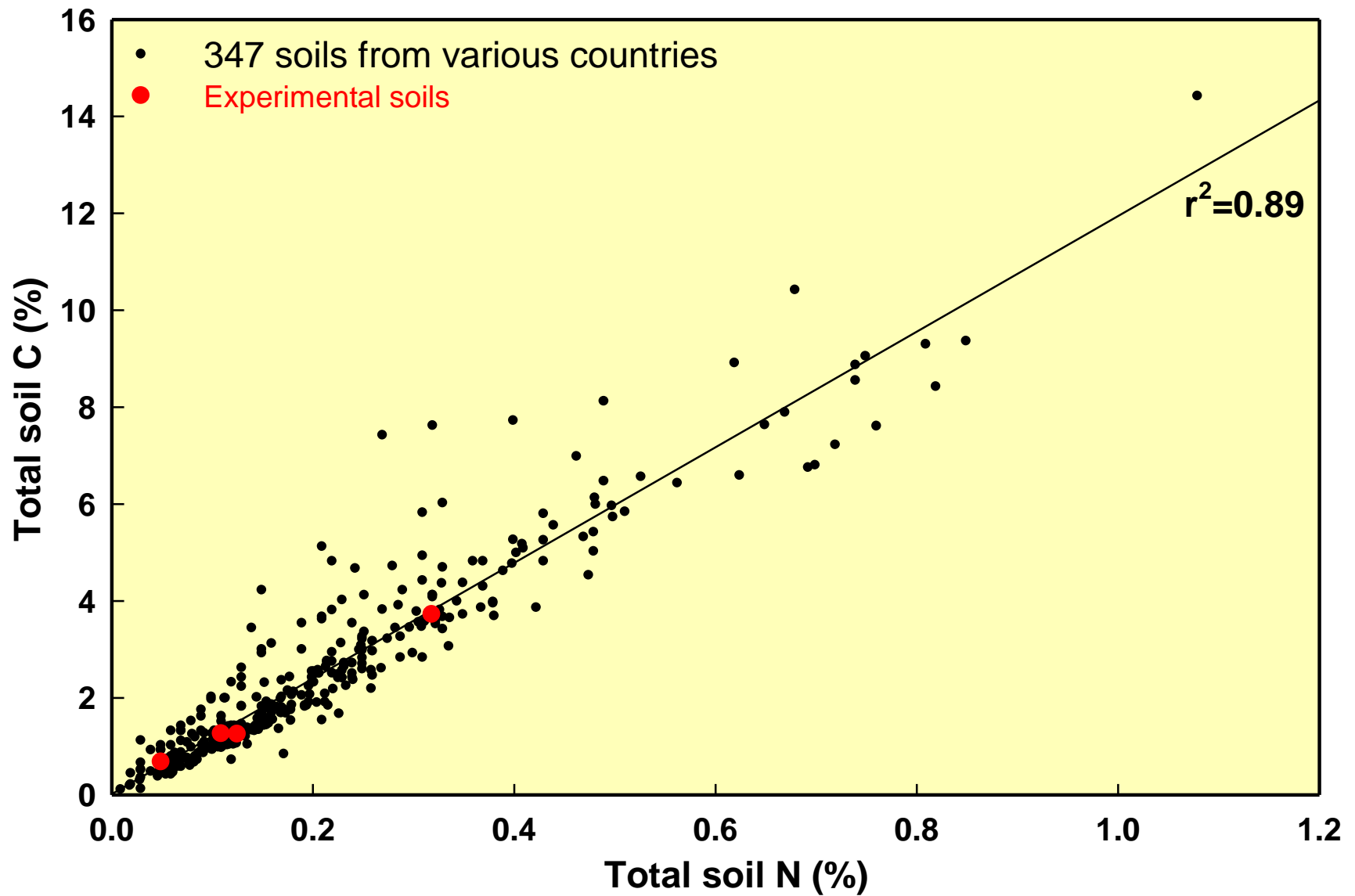
Soil C:N



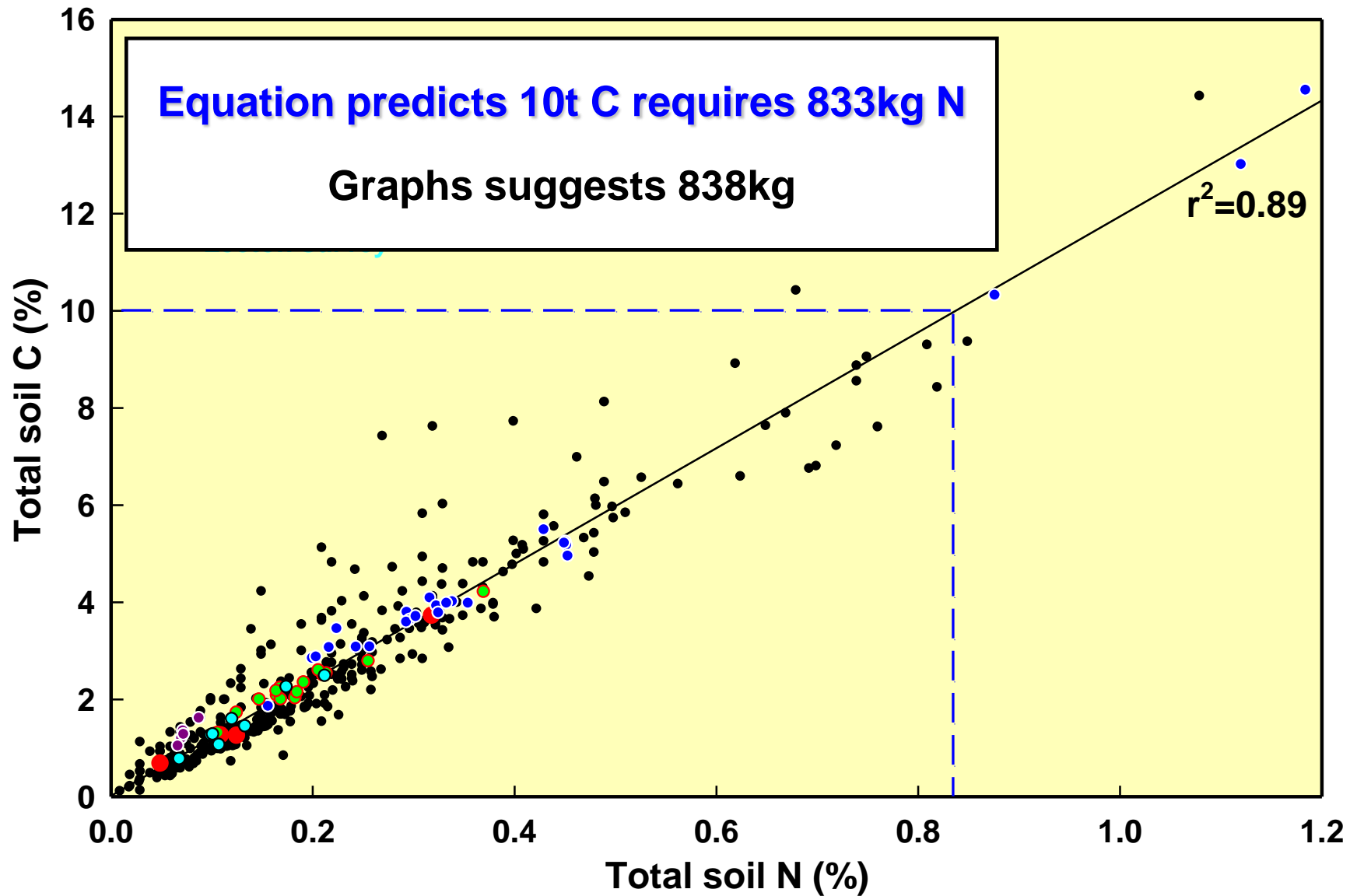
Total soil C:N



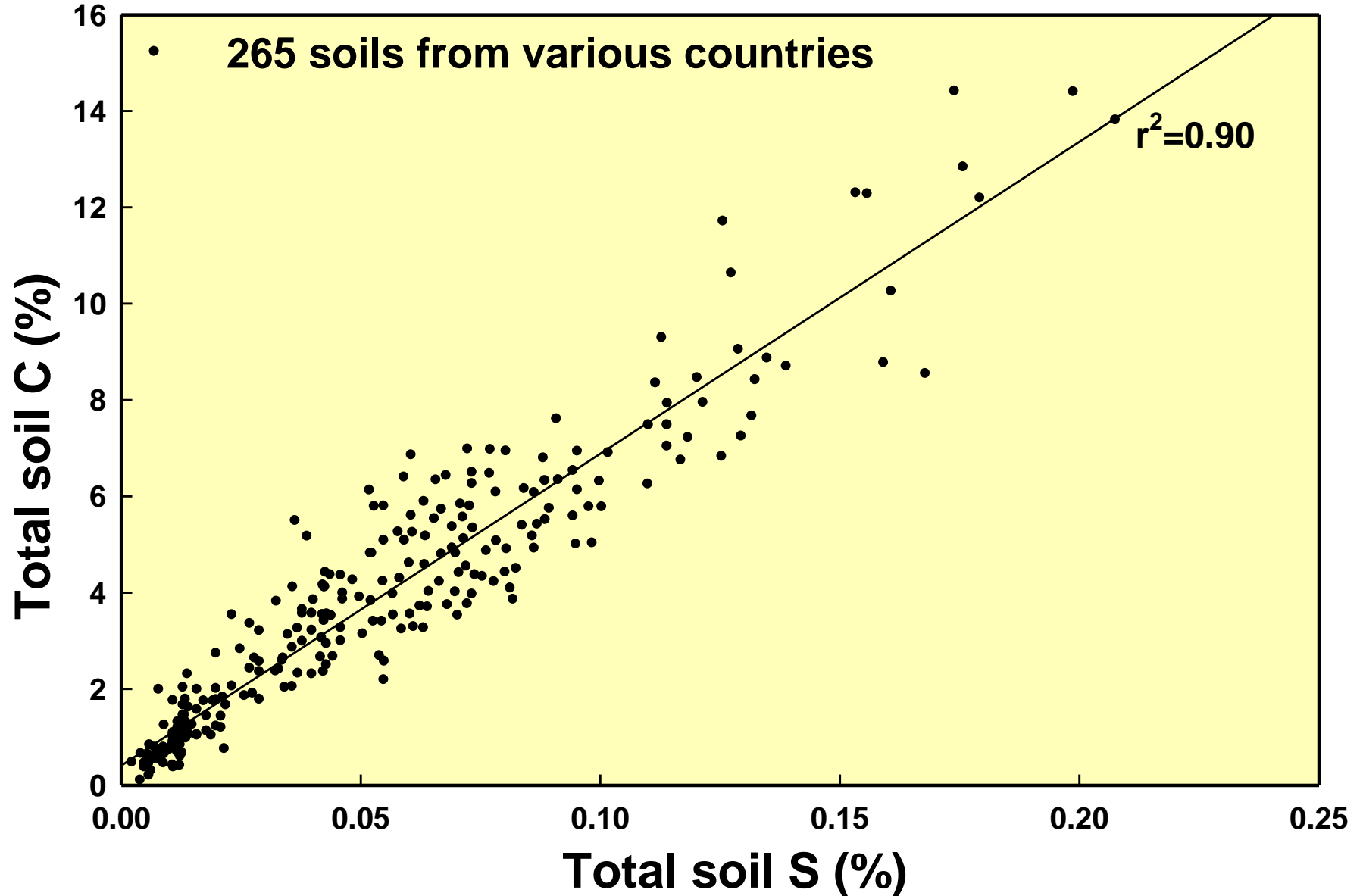
Total soil C:N



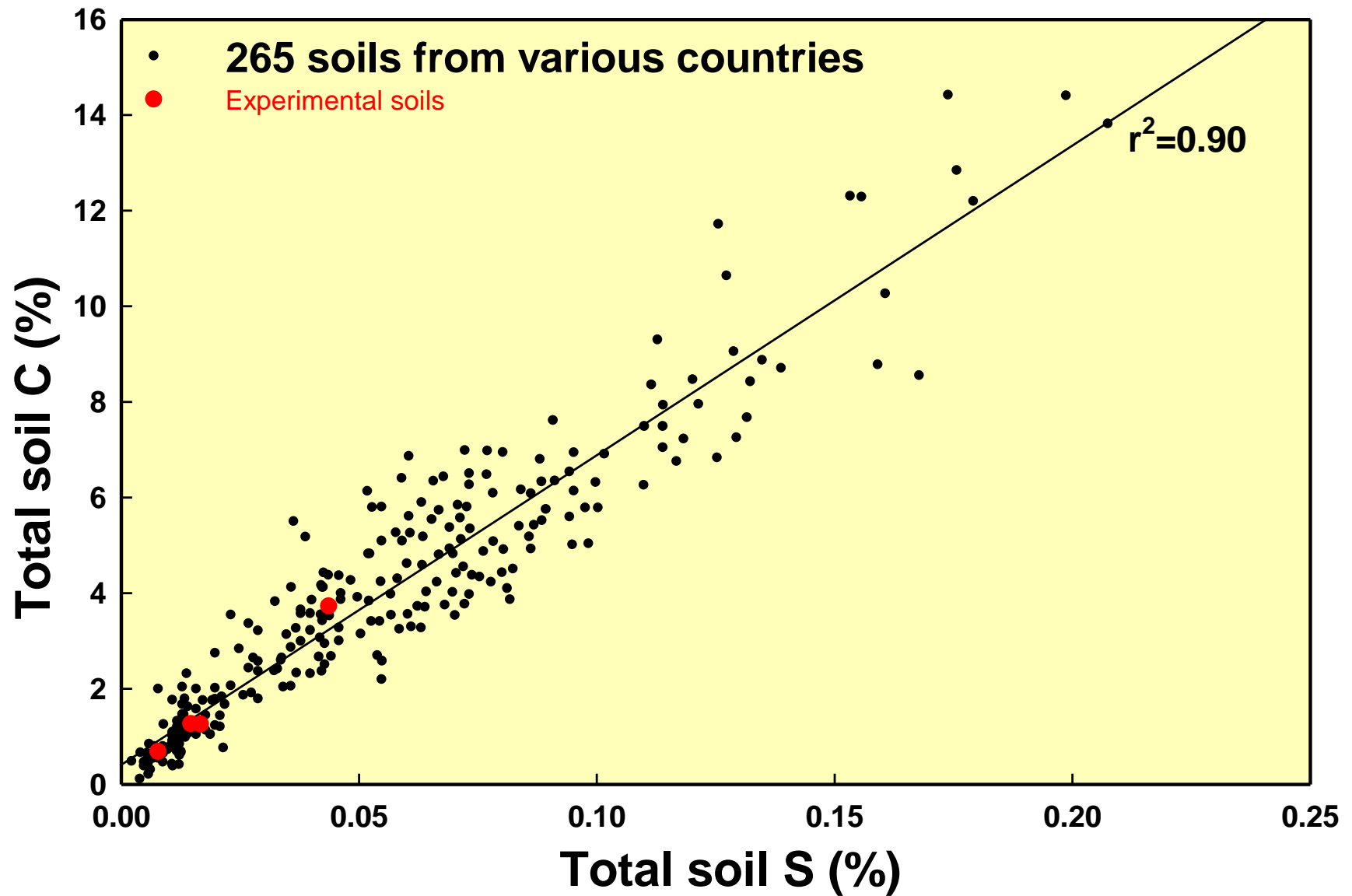
Total soil C:N



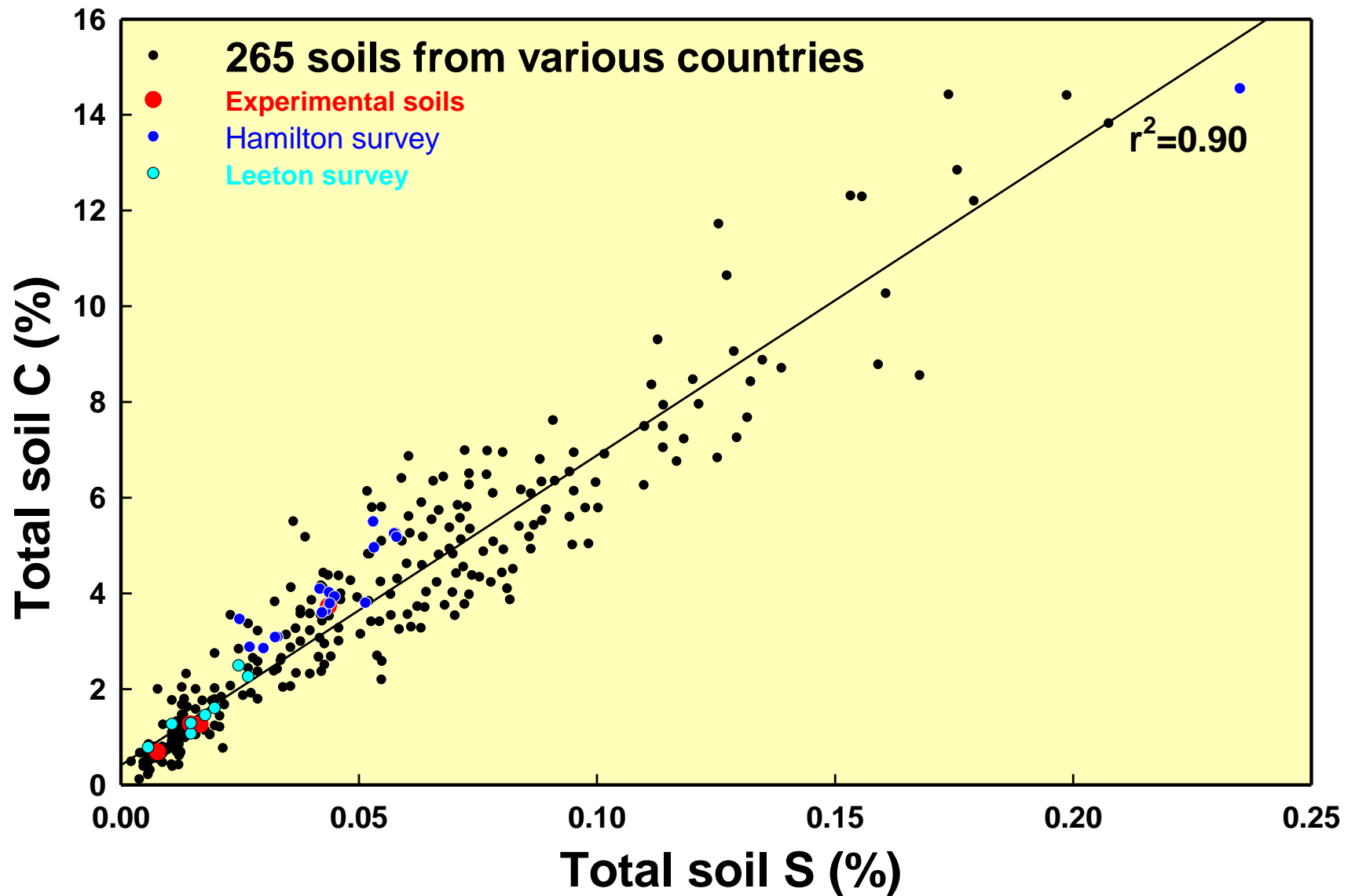
Total soil C:S



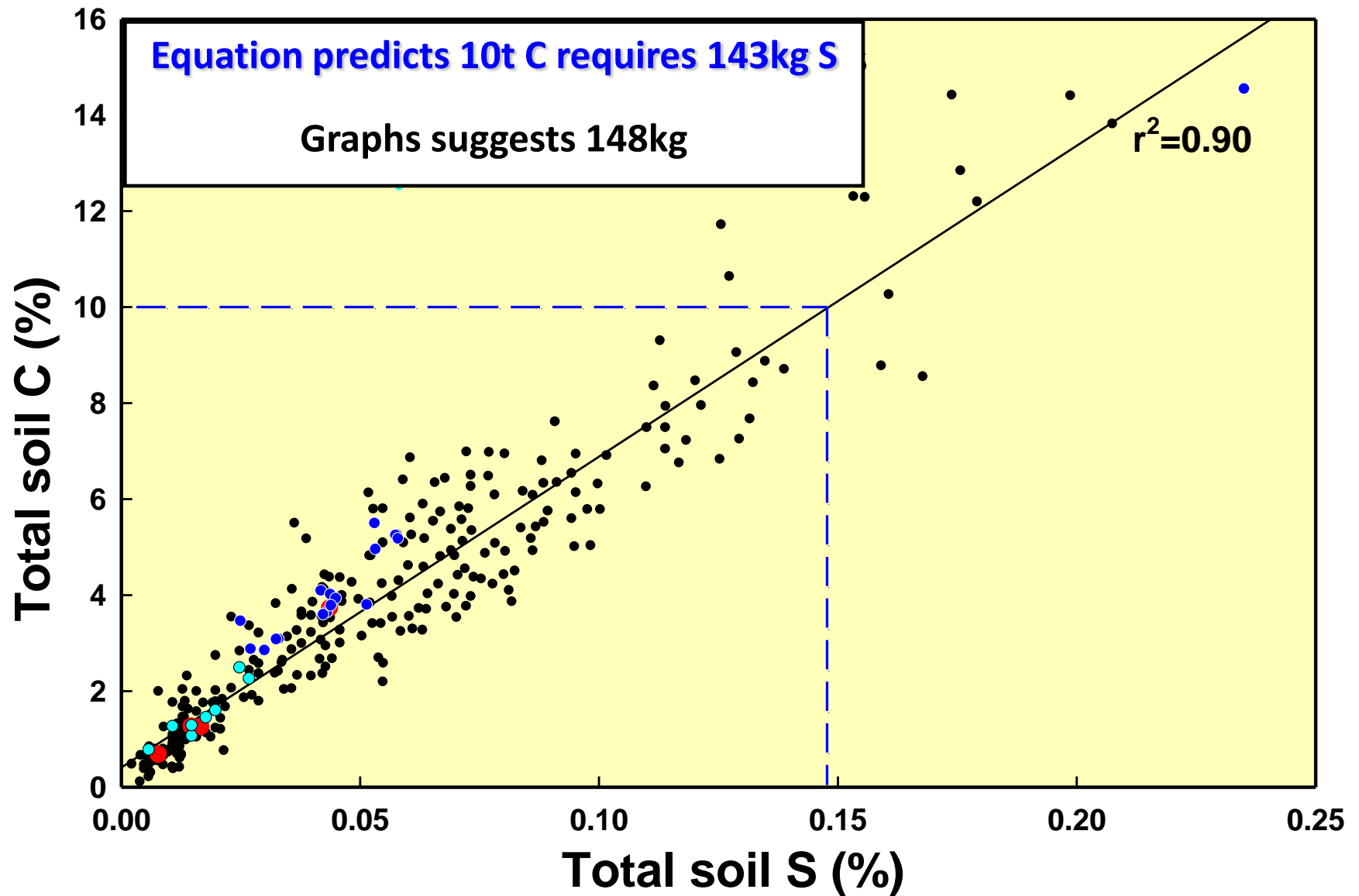
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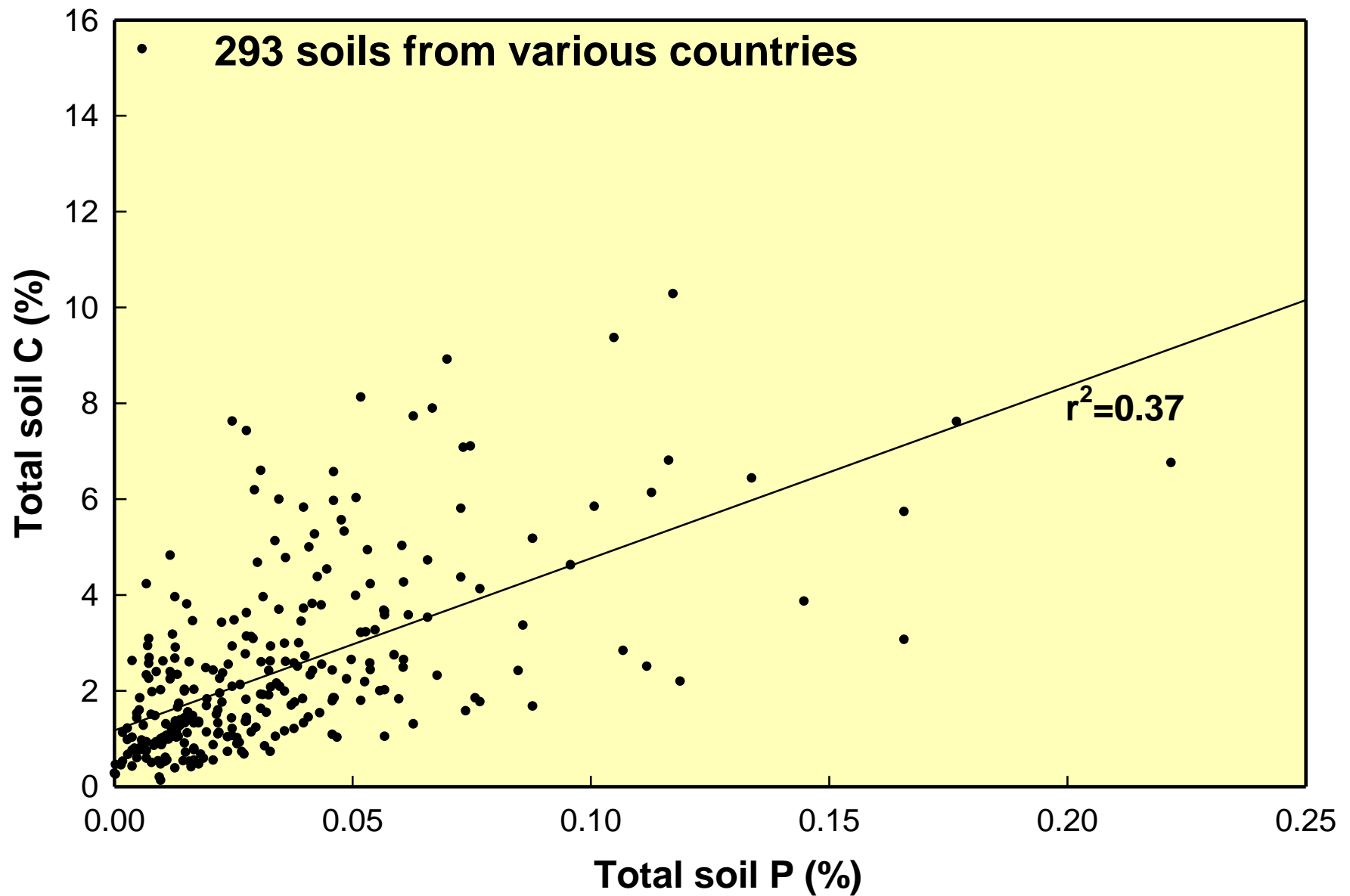
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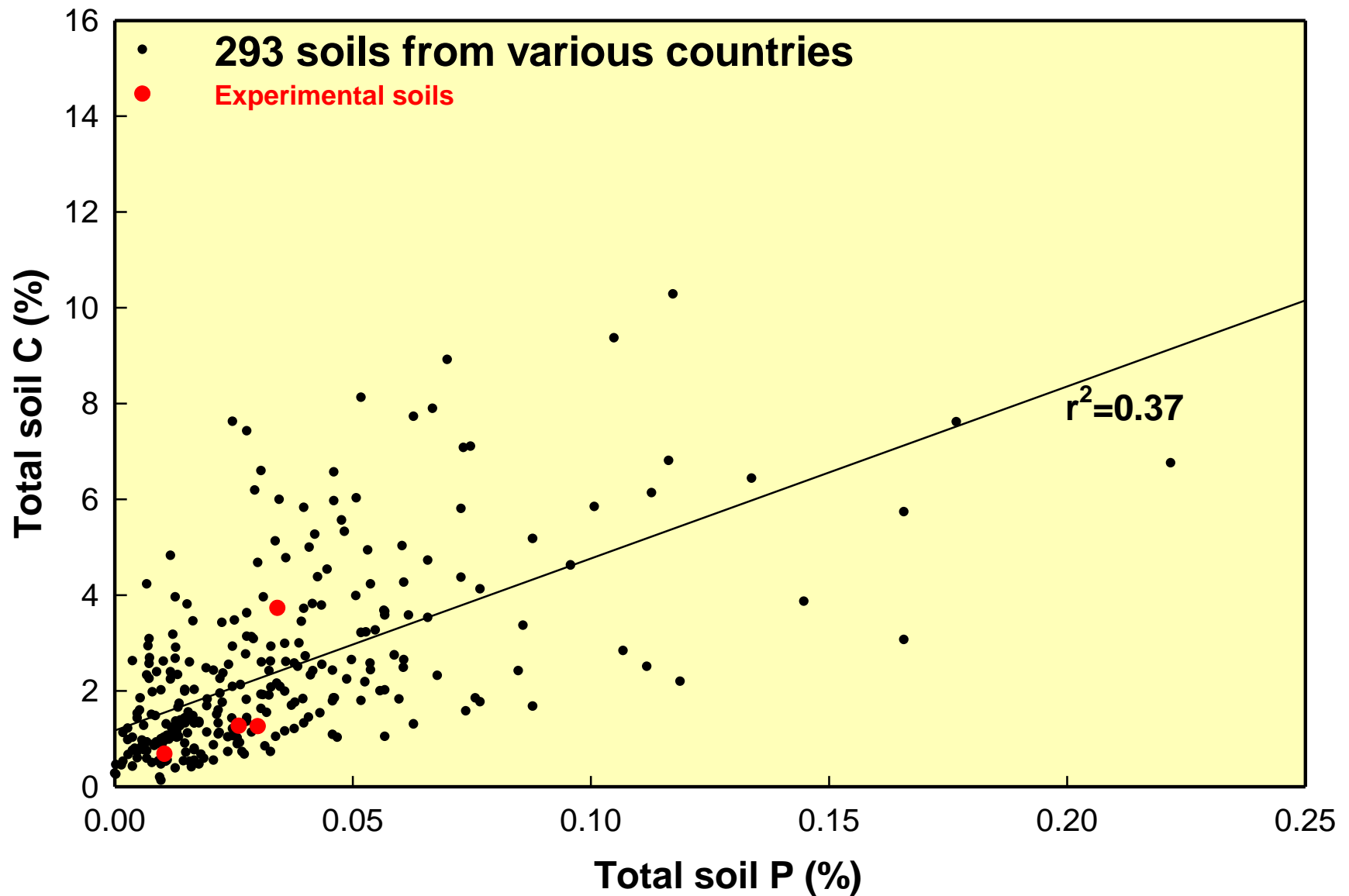
Total soil C:S



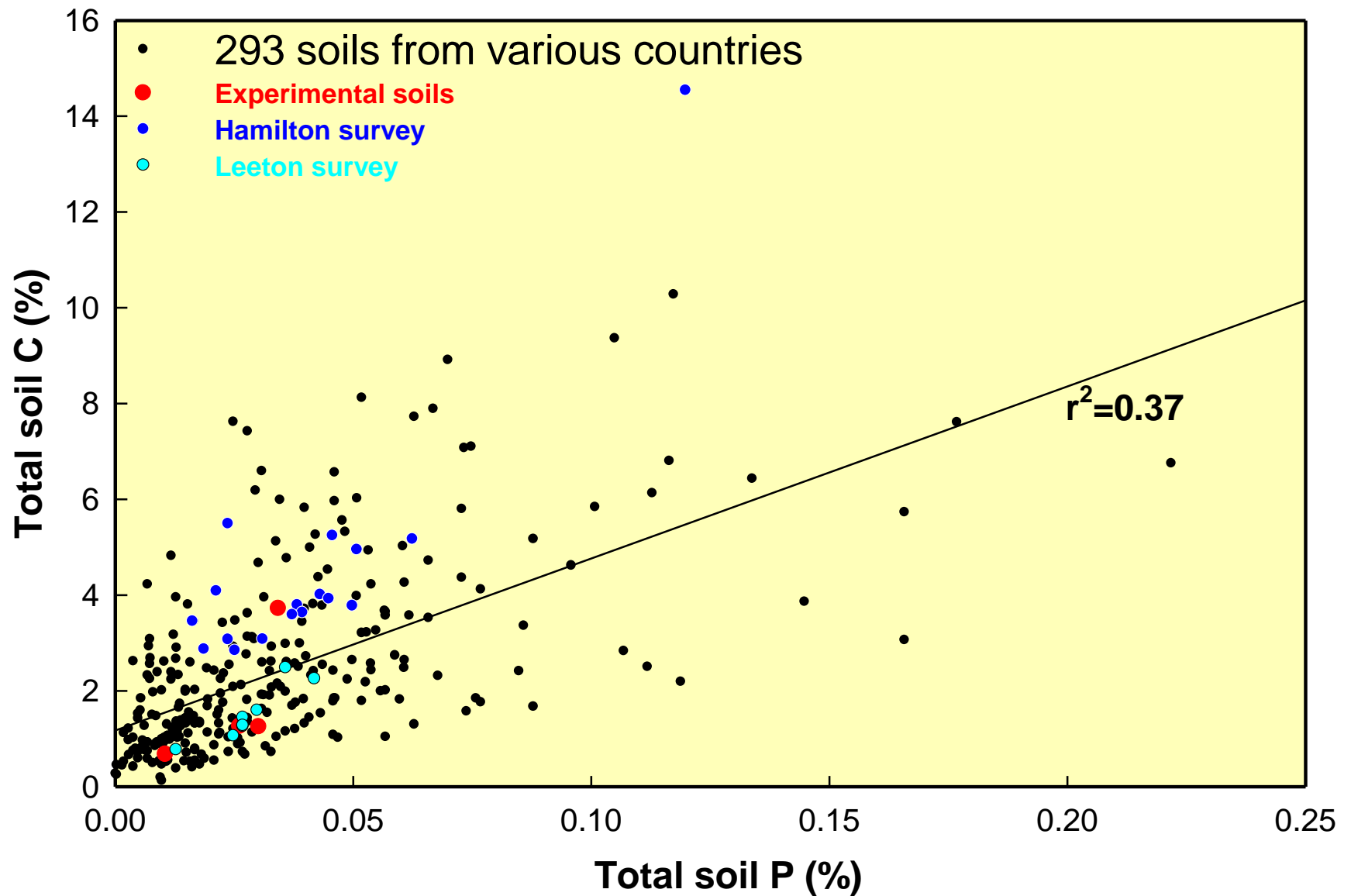
Total C:P



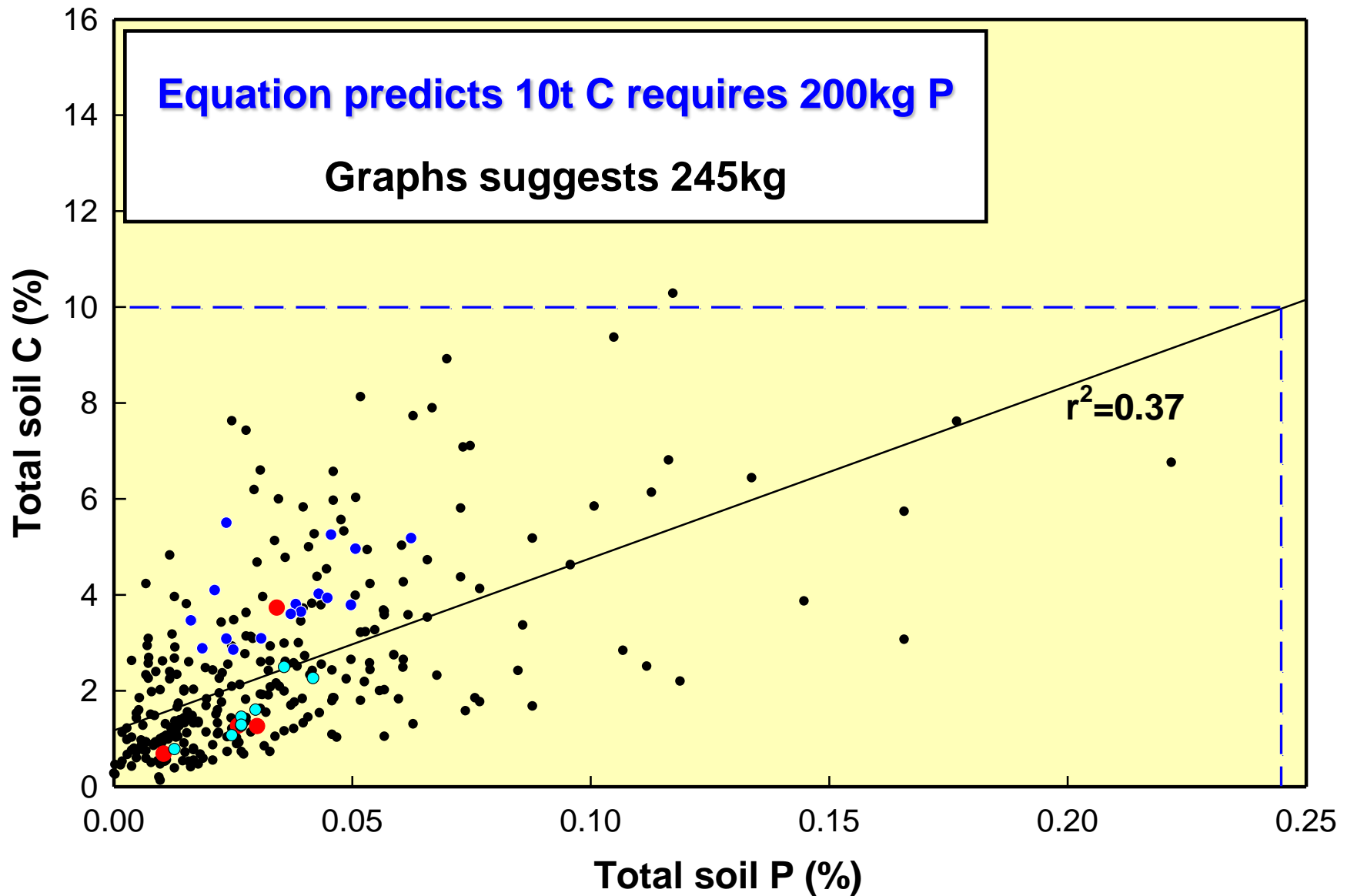
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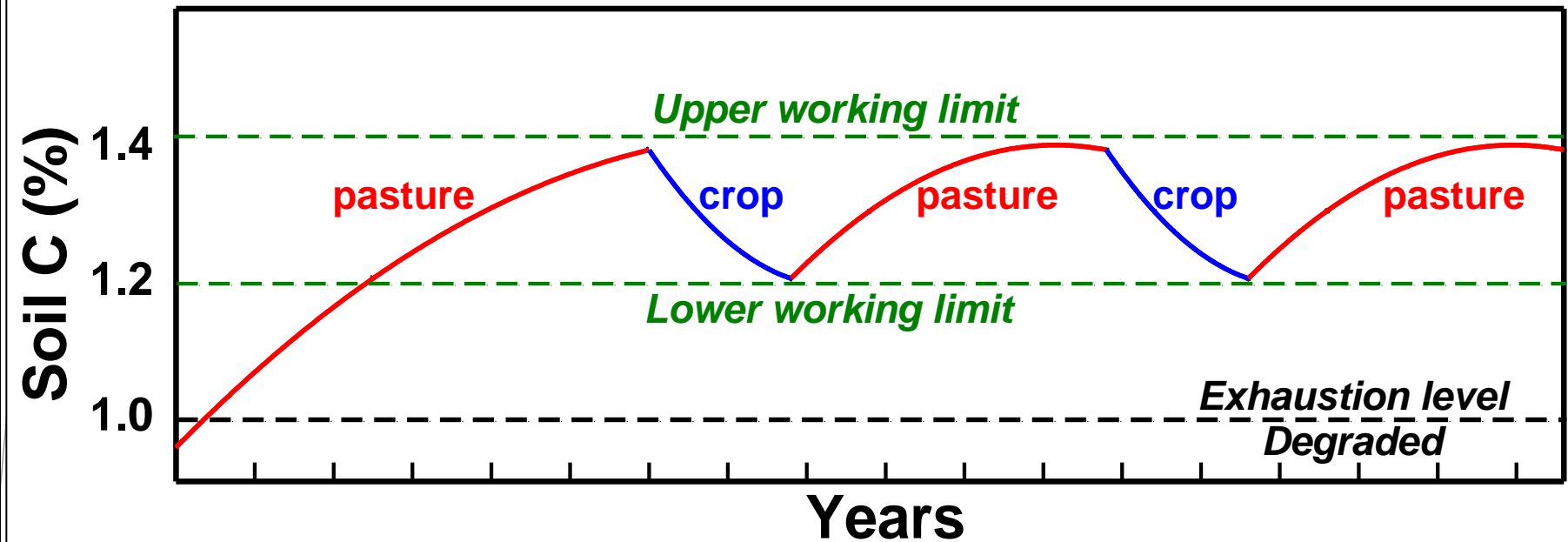
Total C:P



Active, Passive & Pastures

Wheat / pasture - C levels

(Connor 2004)



C:N ratio under pasture or continuous crop

Pasture	Cropping
13.3	11.1

%C %N C:N ratio

For virgin, pasture or continuous crop
("dirty" sample)

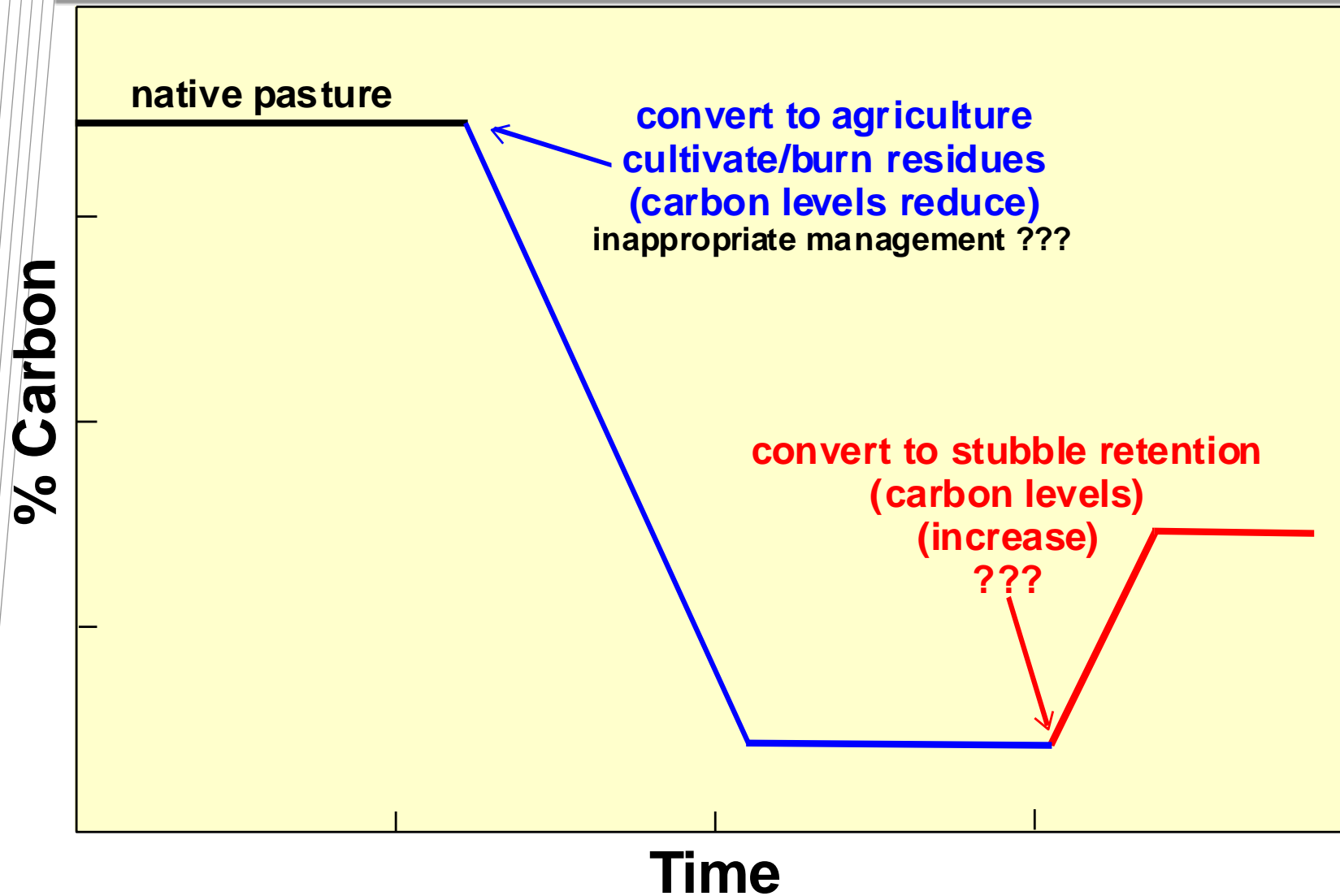
	C	N	C:N
Virgin	3.6	0.24	15.0
Pasture	4.2	0.32	13.0
Cropping	2.1	0.18	12.0

%C %N C:N ratio

For virgin, pasture or continuous crop
("cleaned" sample)

	C	N	C:N
Virgin	2.0	0.17	12.5
Pasture	2.8	0.26	10.8
Cropping	2.0	0.17	11.7

One Story of C Dynamics



**In some systems: C levels don't increase
(or increase very little)
despite many years of residue retention**

- Rumpel (2008) compared residue retention & burning over 31 yrs in France – found no difference in soil C levels
 - Chan & Heenan (2005) found no difference in soil C when comparing retention & burning over 5 yrs at Temora
- Hamilton et al (1996) had a 7 yr trial in W.A. – found no difference between burning or retaining residues

Crop vs Adjacent Virgin soil

