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Storing C in agricultural soils
Does it have a role in C-trading?

Mark Peoples

CSIRO Plant Industry

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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

Courtesy of Fran Hoyle DAWA

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?

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Options for increasing soil C reserves

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

- *CO_2 capture by photosynthesis*
- *Net inputs of C to soil*

Greater than current levels

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- ***CO_2 capture by photosynthesis***
- ***Net inputs of C to soil***

Greater than current levels

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*

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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

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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 CO_2 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

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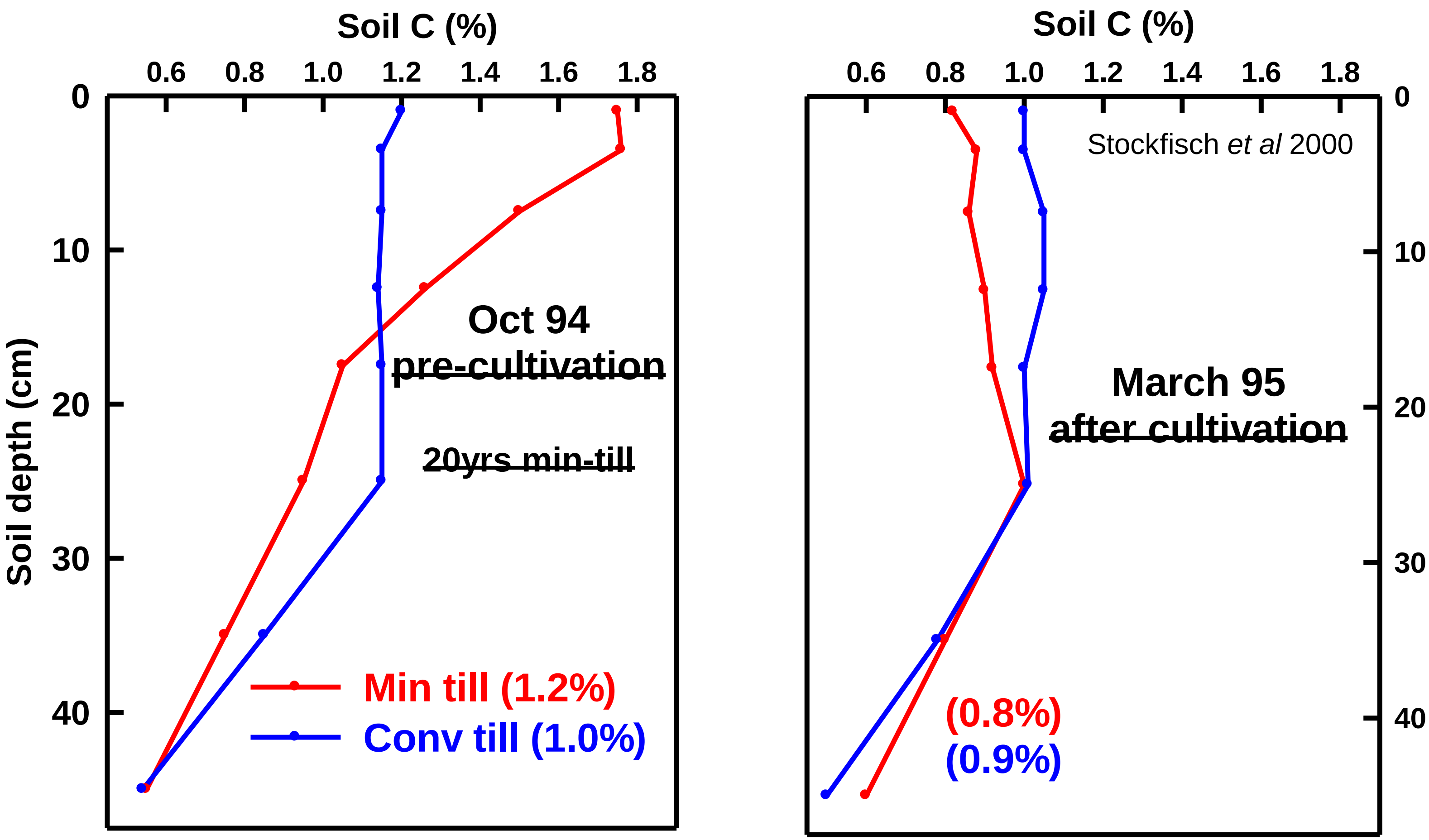
Large losses of soil C in response to changed management



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

Humus 40-60% C pool

Slow SOM

20-40 y

Protected humus, charcoal

Charcoal 0-50% C pool

Stable SOM

Up to 1000 y

Courtesy of Fran Hoyle DAWA

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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

Source: Jeff Baldock CSIRO Land & Water

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**
C:N ratio	*75:1*	*47:1*	*20:1*
Phosphorus (P)	**1.6**	**3.6**	**7.1**
C:P ratio	*625:1*	*278:1*	*141:1*
Sulphur (S)	**1.7**	**3.8**	**2.9**
C:S ratio	*625:1*	*263.1*	*345:1*

Source: Clive Kirkby, CSIRO PI

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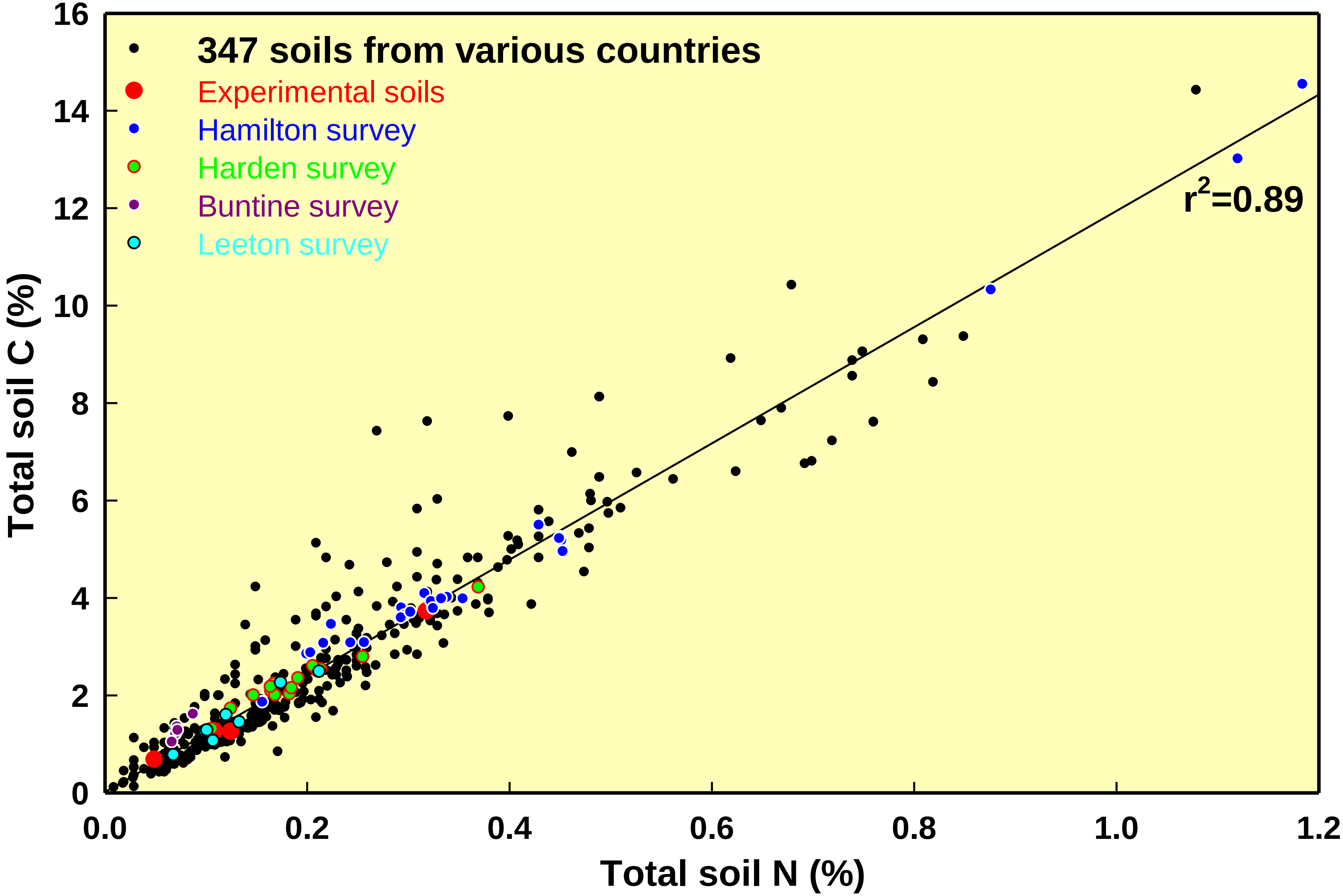
The amounts (kg) of N, P & S per tonne (1,000kg) of C in crop residues, humus, soil fungi or bacteria

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
C:N ratio	*75:1*	*47:1*	*20:1*	***12:1***	*9:1*	*4:1*
Phosphorus (P)	1.6	3.6	7.1	**20 kg**	10.9	52
C:P ratio	*625:1*	*278:1*	*141:1*	***50:1***	*92:1*	*19:1*
Sulphur (S)	1.7	3.8	2.9	**14.3 kg**	3.6	10
C:S ratio	*625:1*	*263.1*	*345:1*	***70:1***	*278.1*	*100:1*

Source: Clive Kirkby, CSIRO PI

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

Source: Clive Kirkby & Jeff Baldock CSIRO

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

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

Source: Clive Kirkby & Jeff Baldock CSIRO

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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 CO_2 equivalent

The value of CO_2 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 CO_2, then 1 tonne soil C
(= 3.7 tonne CO_2) would be worth approx $150

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

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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 CO_2 within 1-2 yrs

Basic Assumptions:

1. It will be relatively easy for farmers to increase the amo… 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-…ts in a C-trading scheme

   (b) Farm… prese…

• 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

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

Basic Assum

1. It will be rela C stored in agr op stubbles cor

• 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

2. Increases in soil 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

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

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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

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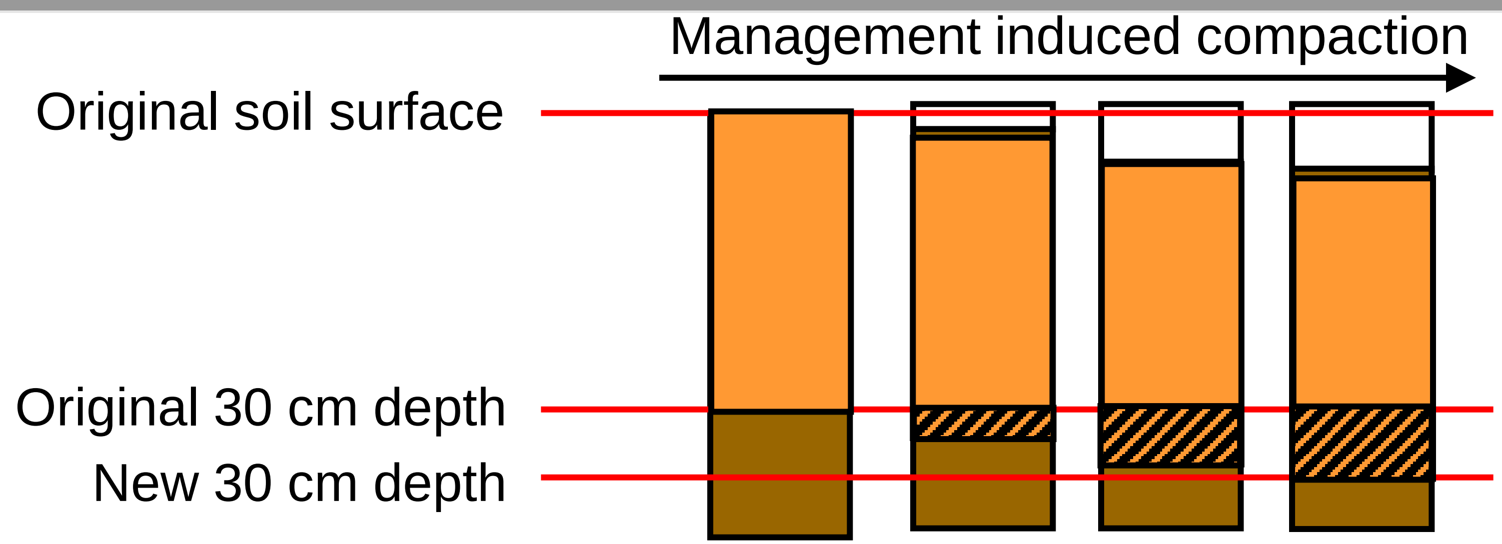
Correcting soil carbon for management induced changes in bulk density



Soil bulk density (Mg/m^3)	1.1	1.2	1.3	1.4
Mass Soil 0-30 cm (Mg/ha)	3300	3600	3900	4200
Depth for equivalent mass (cm)	30.0	27.5	25.4	23.6
Organic C loading (Mg/ha)				
1% OC, no BD correction	33	36	39	42
1% OC, with BD correction	33	33	33	33

Source: Jeff Baldock CSIRO Land and Water

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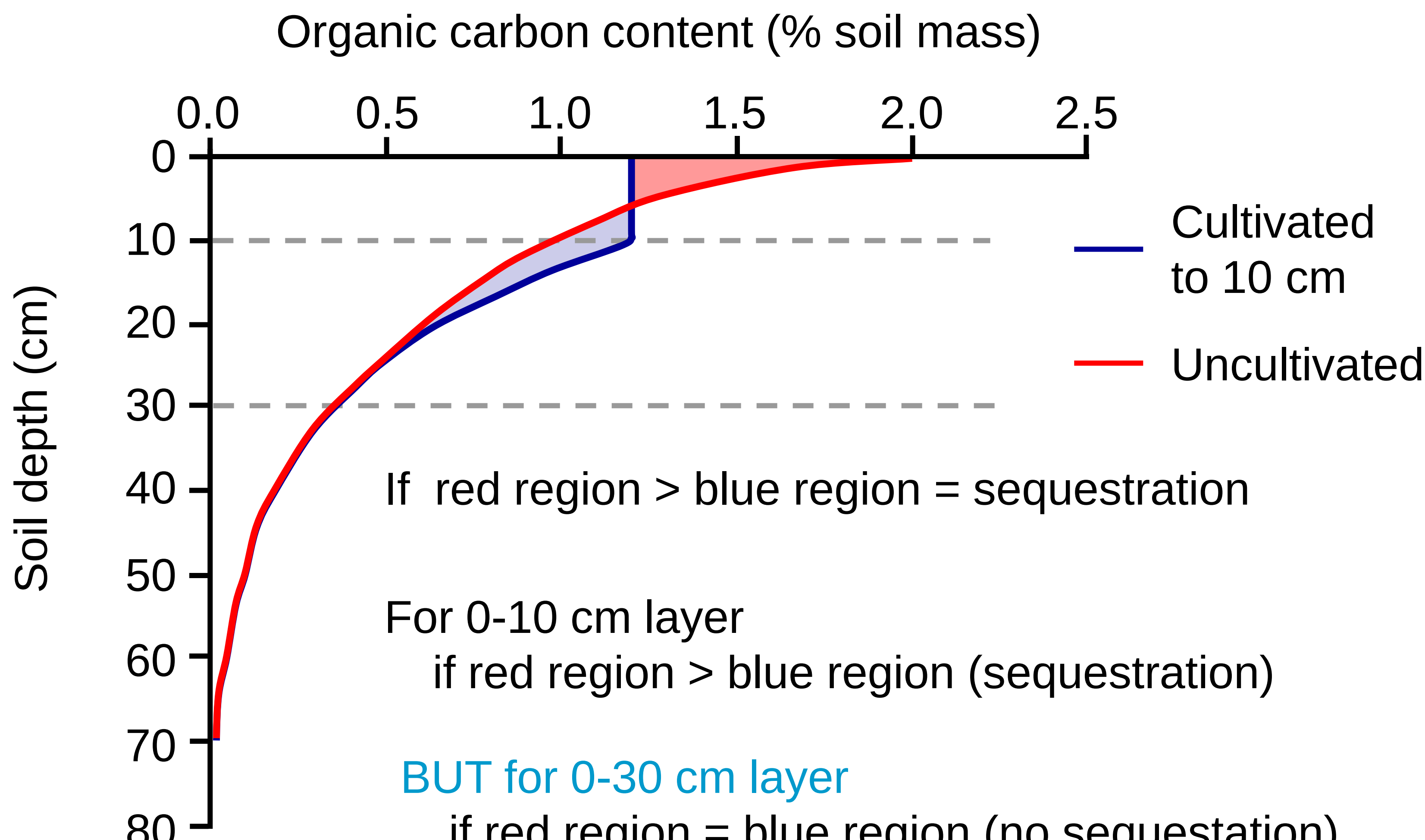
Influence of tillage on changes in soil carbon with depth



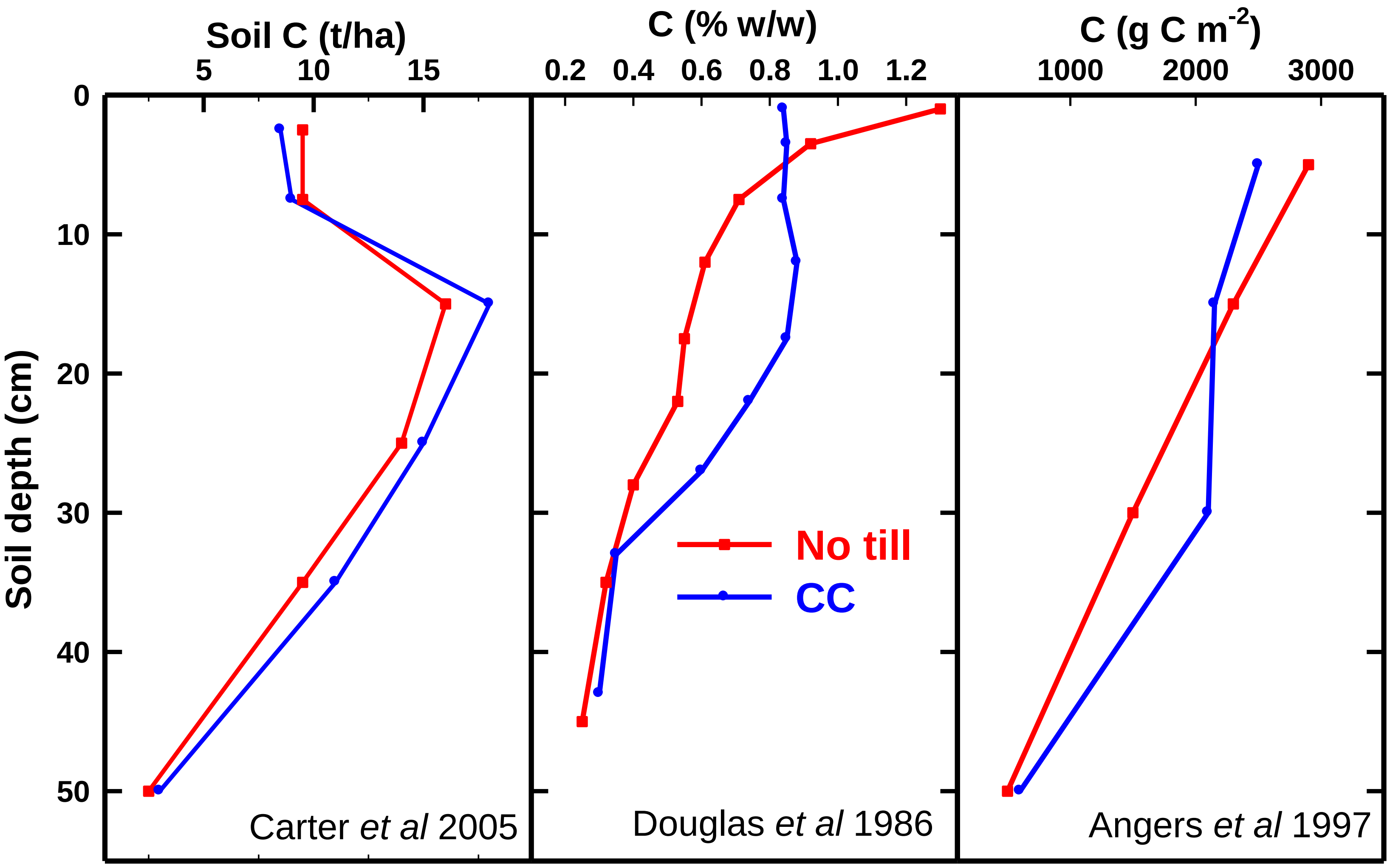
If red region > blue region = sequestration

For 0-10 cm layer
if red region > blue region (sequestration)

BUT for 0-30 cm layer
if red region = blue region (no sequestation)

Source: Jeff Baldock CSIRO Land & Water

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

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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
bacteria	*10,000*	*2,400*	*520*	*100*
fungi	*10,000*	*1,091*	*109*	*36*
humus	10,000	833	200	143

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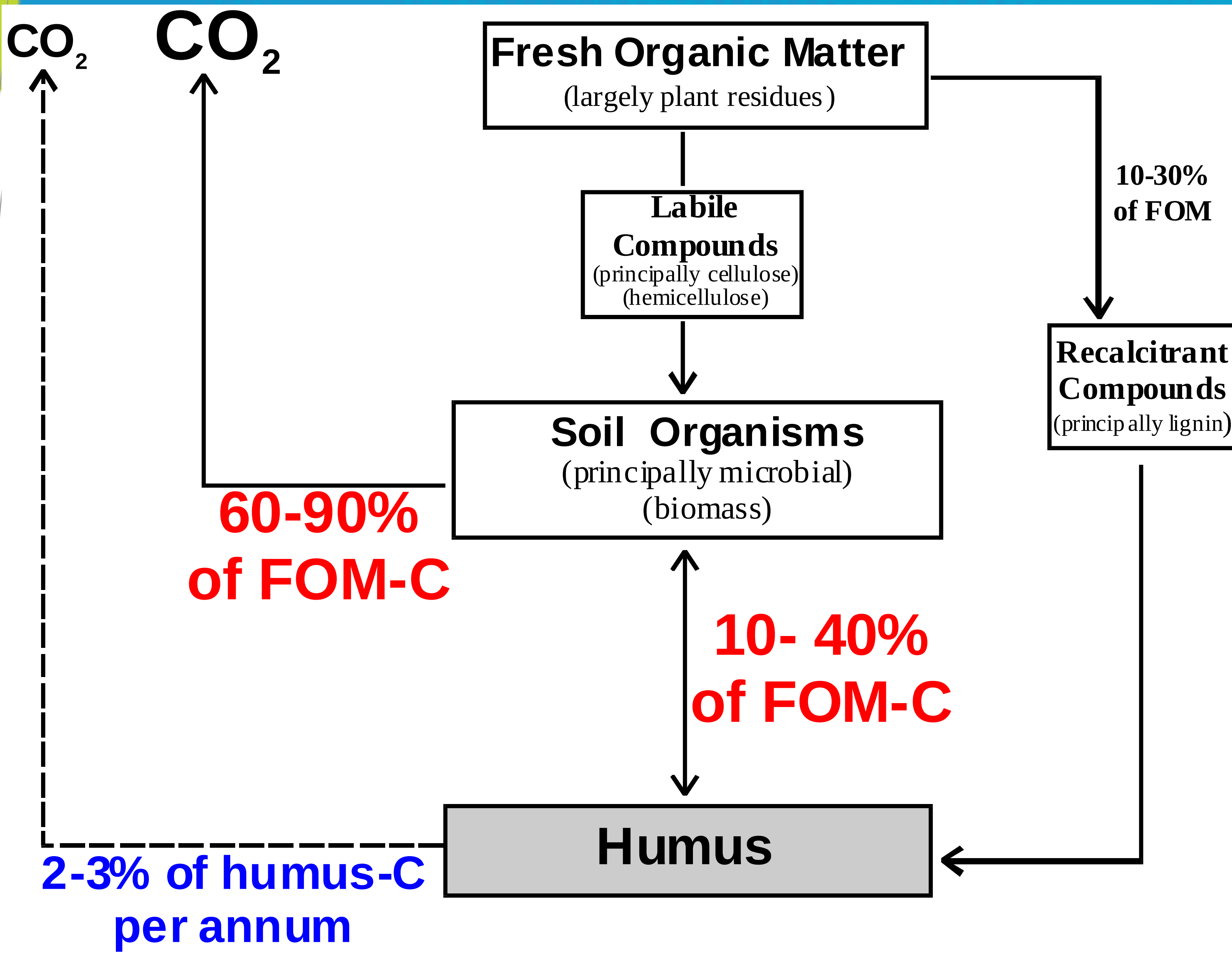
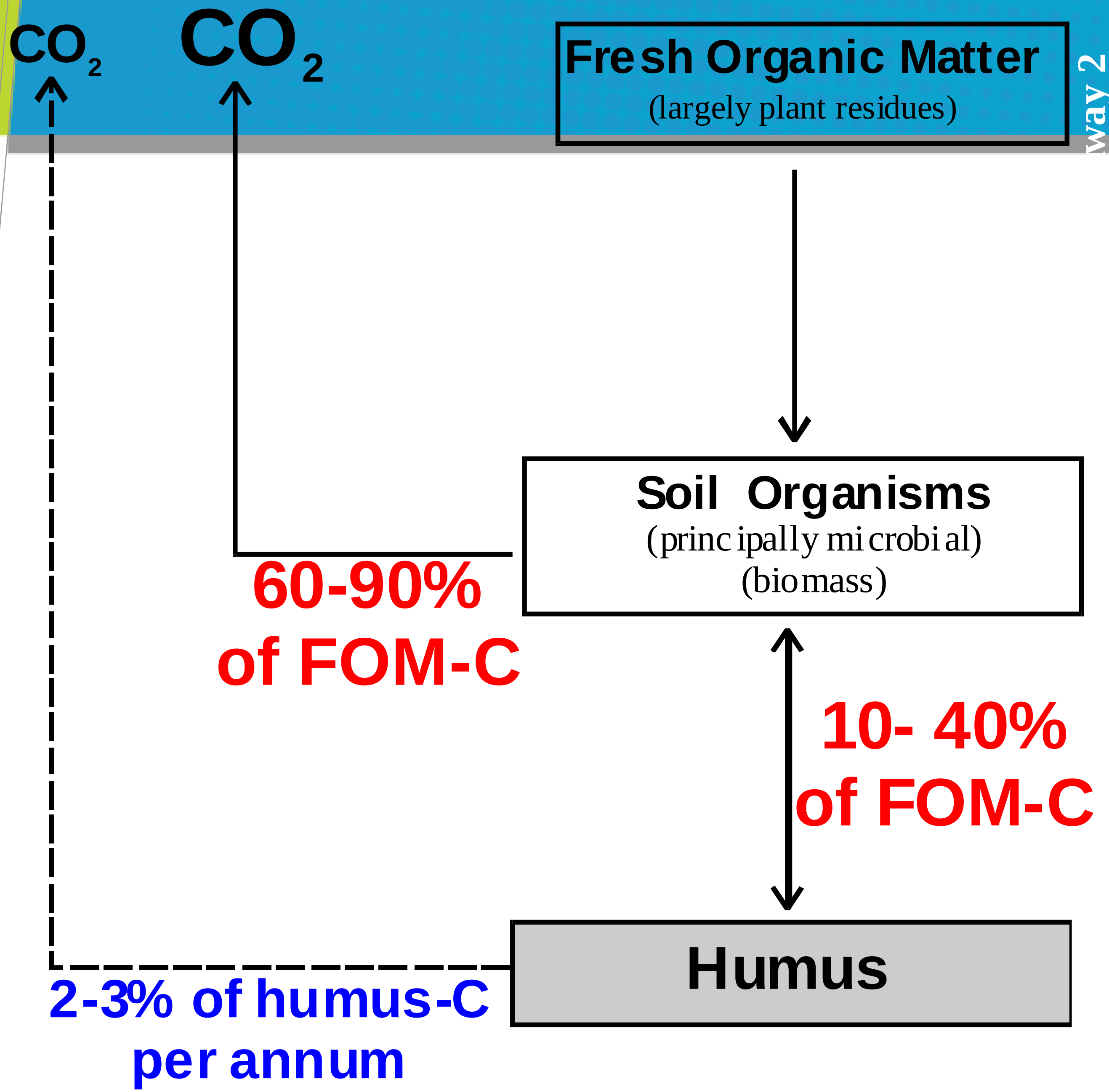
To sequest 10 tonnes of C as humus one must also sequest

833 kg N, 200 kg P and 143 kg S

(one cannot sequest C in isolation)



CO_2
CO_2
Fresh Organic Matter
(largely plant residues)
Labile Compounds
(principally cellulose)
(hemicellulose)
10-30% of FOM
Recalcitrant Compounds
(principally lignin)
Soil Organisms
(principally microbial)
(biomass)
60-90% of FOM-C
10- 40% of FOM-C
Humus
2-3% of humus-C per annum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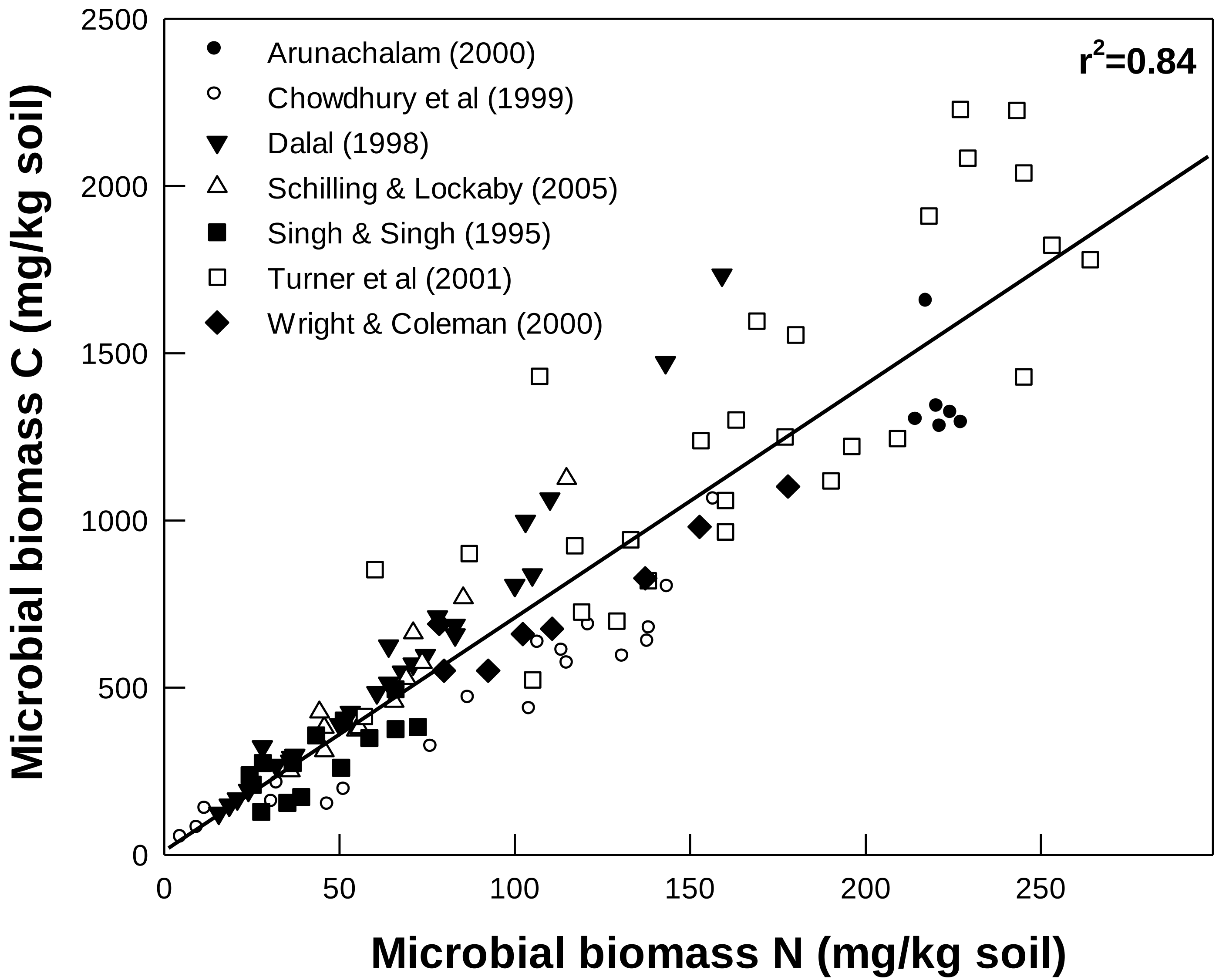
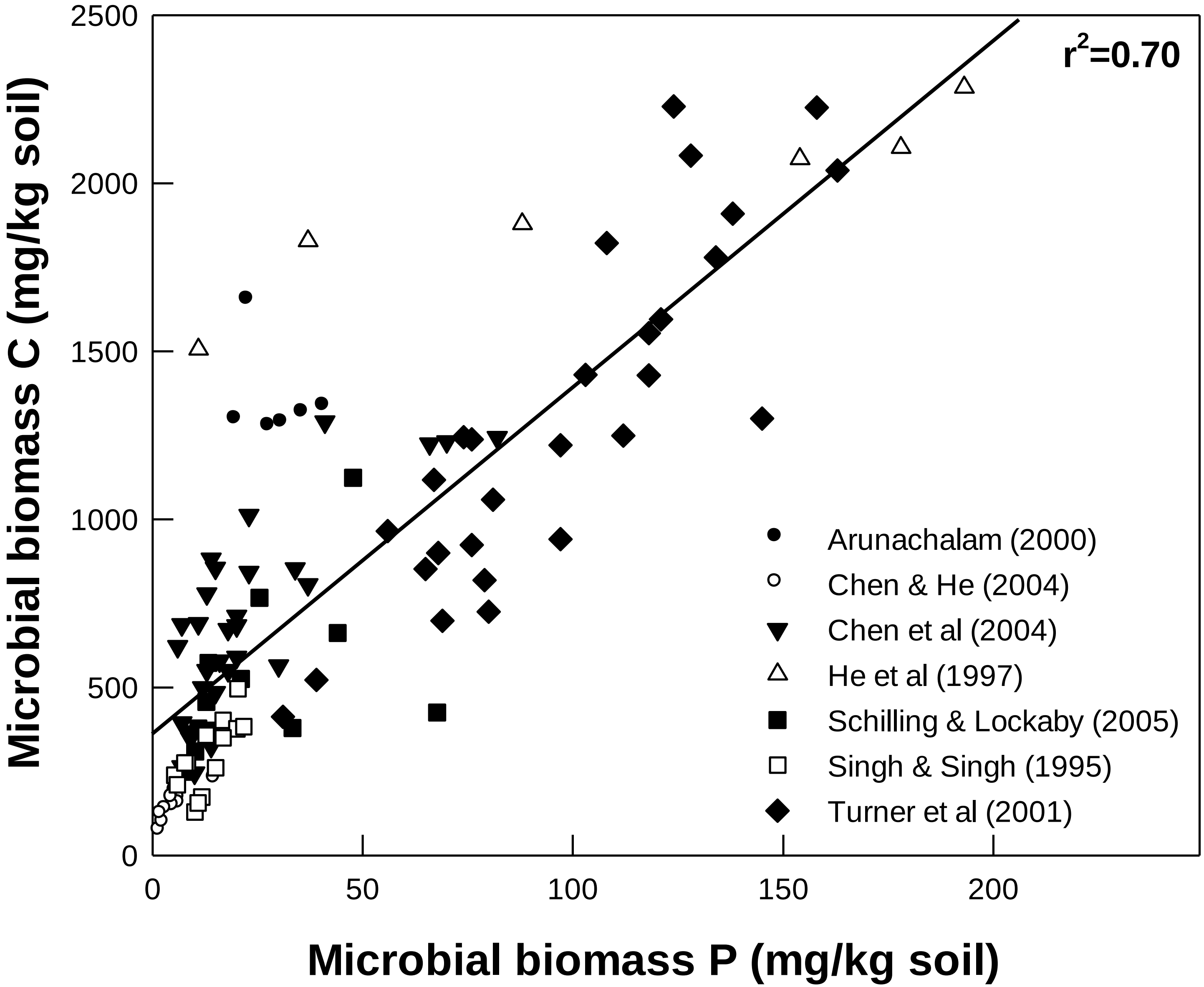
Humus
2-3% of humus-C
per annum

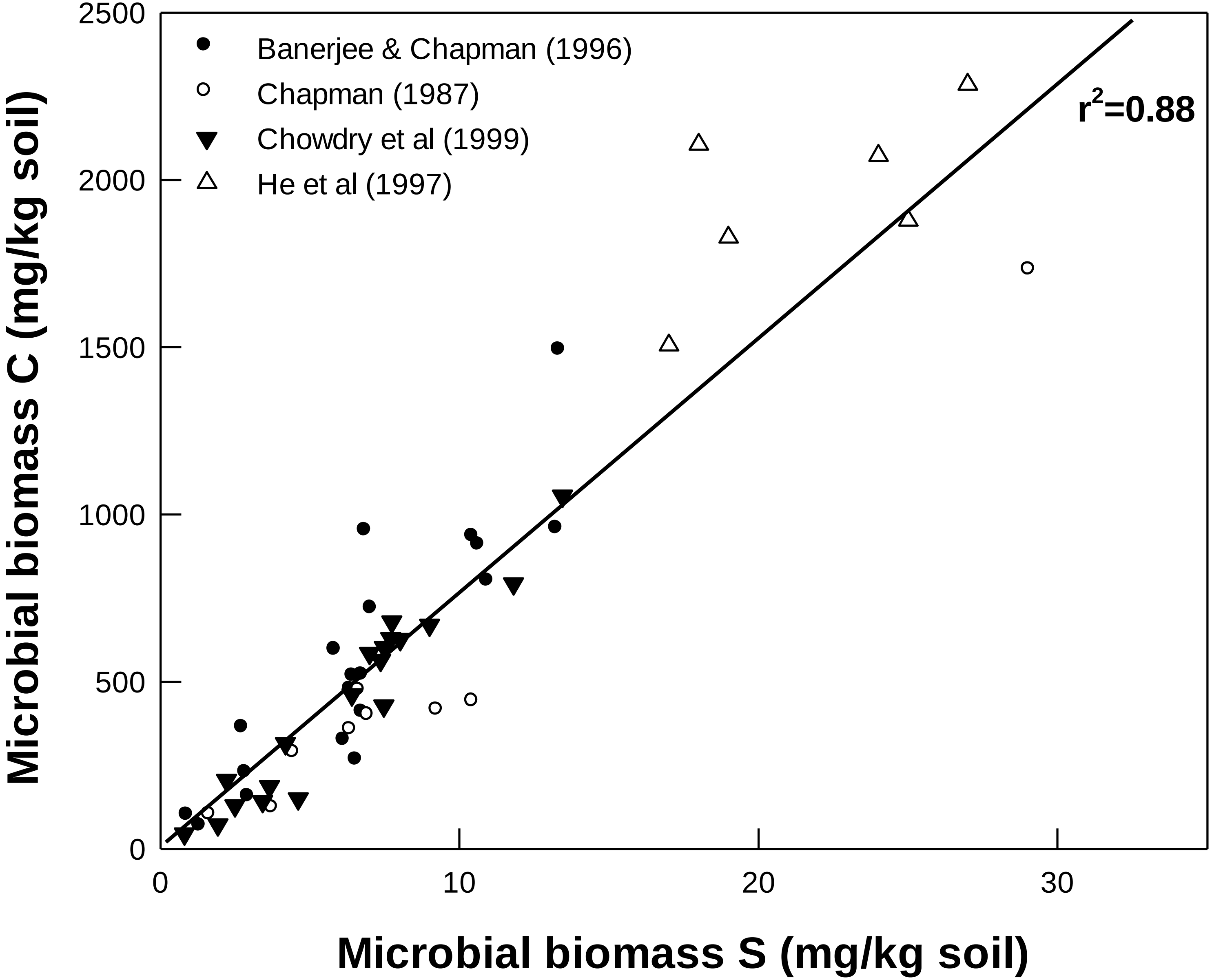
Microbial C:N



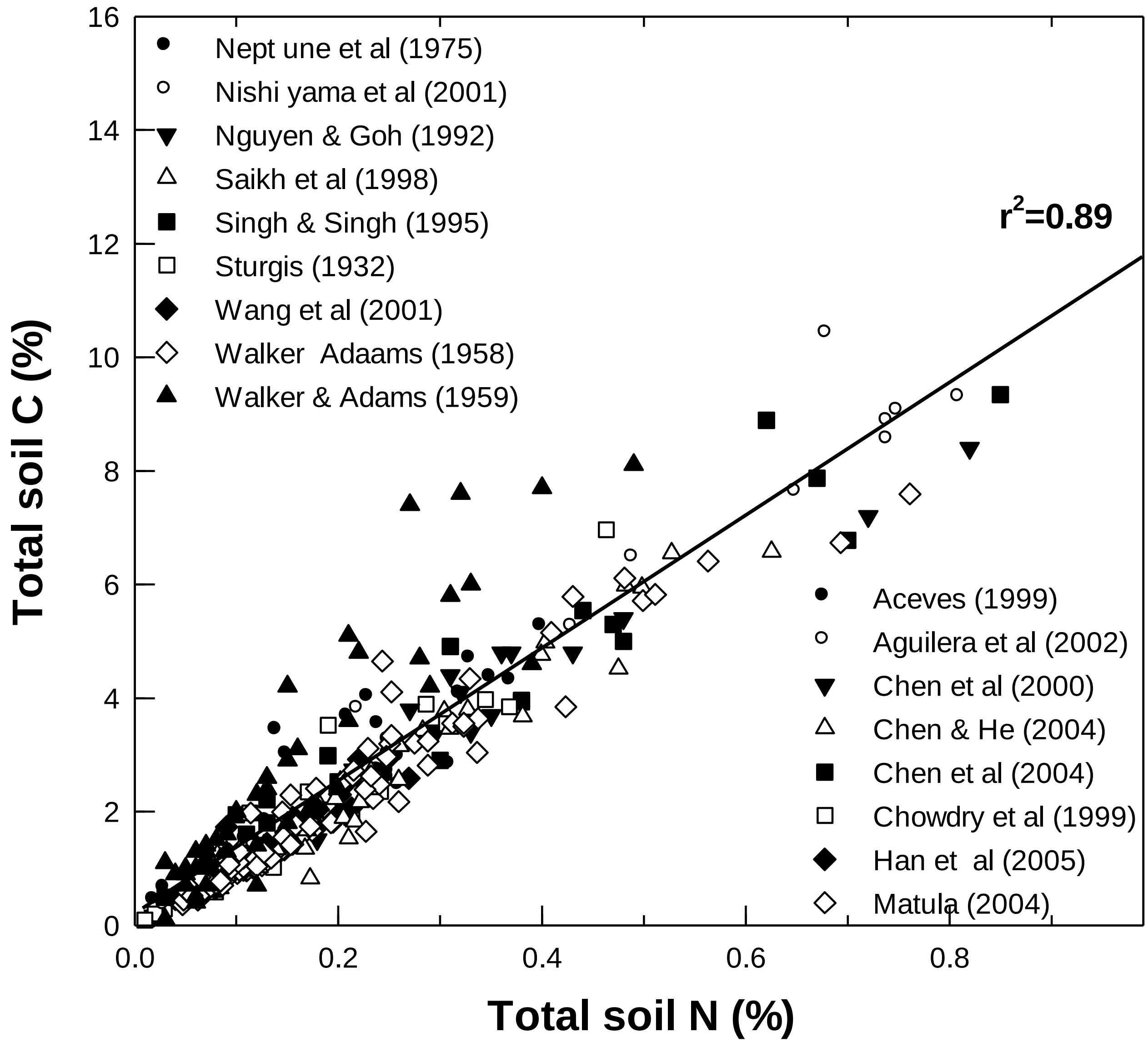
Microbial C:P



Microbial C:S

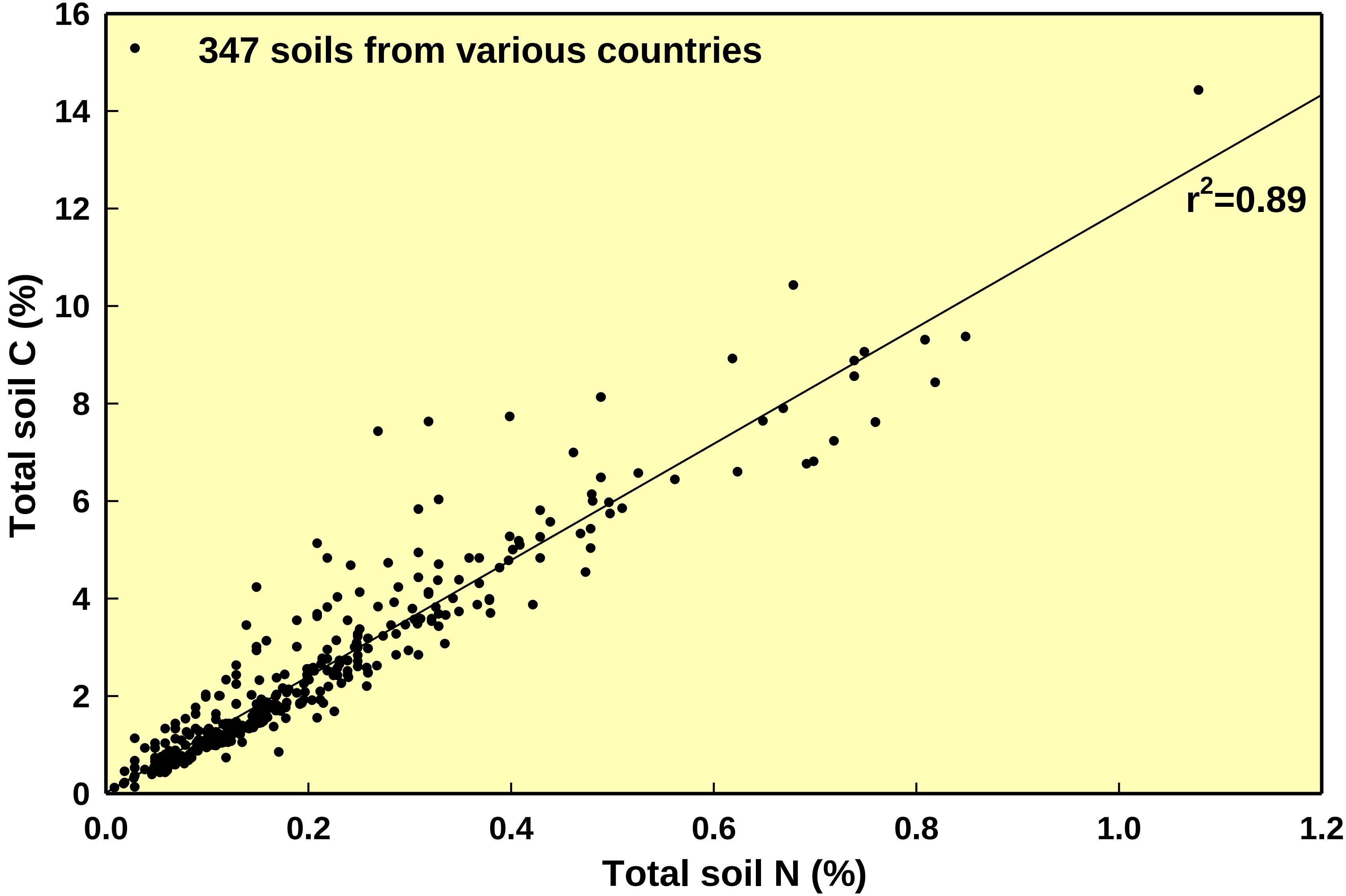


Soil C:N

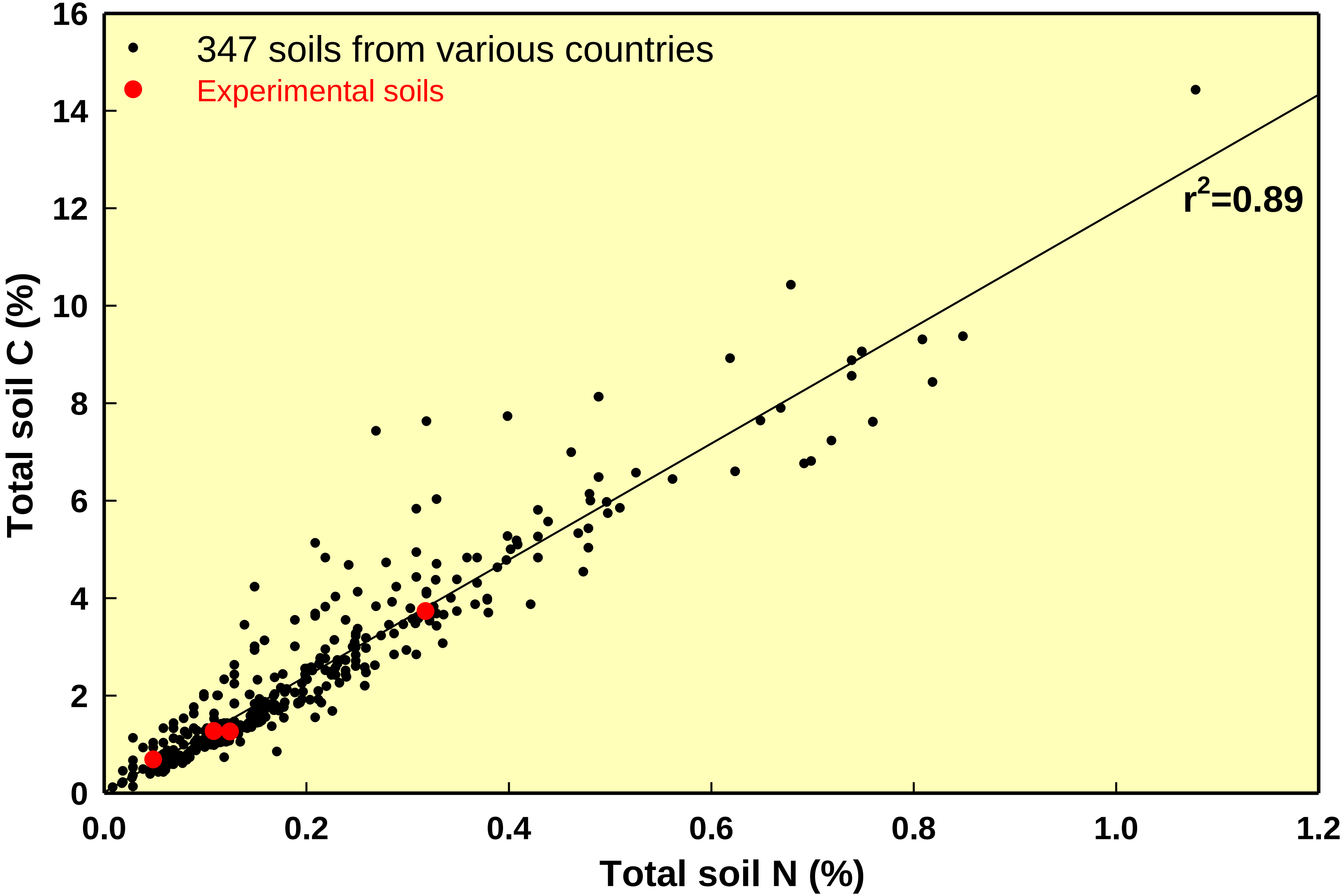


Nept une et al (1975)
Nishi yama et al (2001)
Nguyen & Goh (1992)
Saikh et al (1998)
Singh & Singh (1995)
Sturgis (1932)
Wang et al (2001)
Walker Adaams (1958)
Walker & Adams (1959)
r^2=0.89
Aceves (1999)
Aguilera et al (2002)
Chen et al (2000)
Chen & He (2004)
Chen et al (2004)
Chowdry et al (1999)
Han et al (2005)
Matula (2004)
Total soil C (%)
Total soil N (%)
0
2
4
6
8
10
12
14
16
0.0
0.2
0.4
0.6
0.8

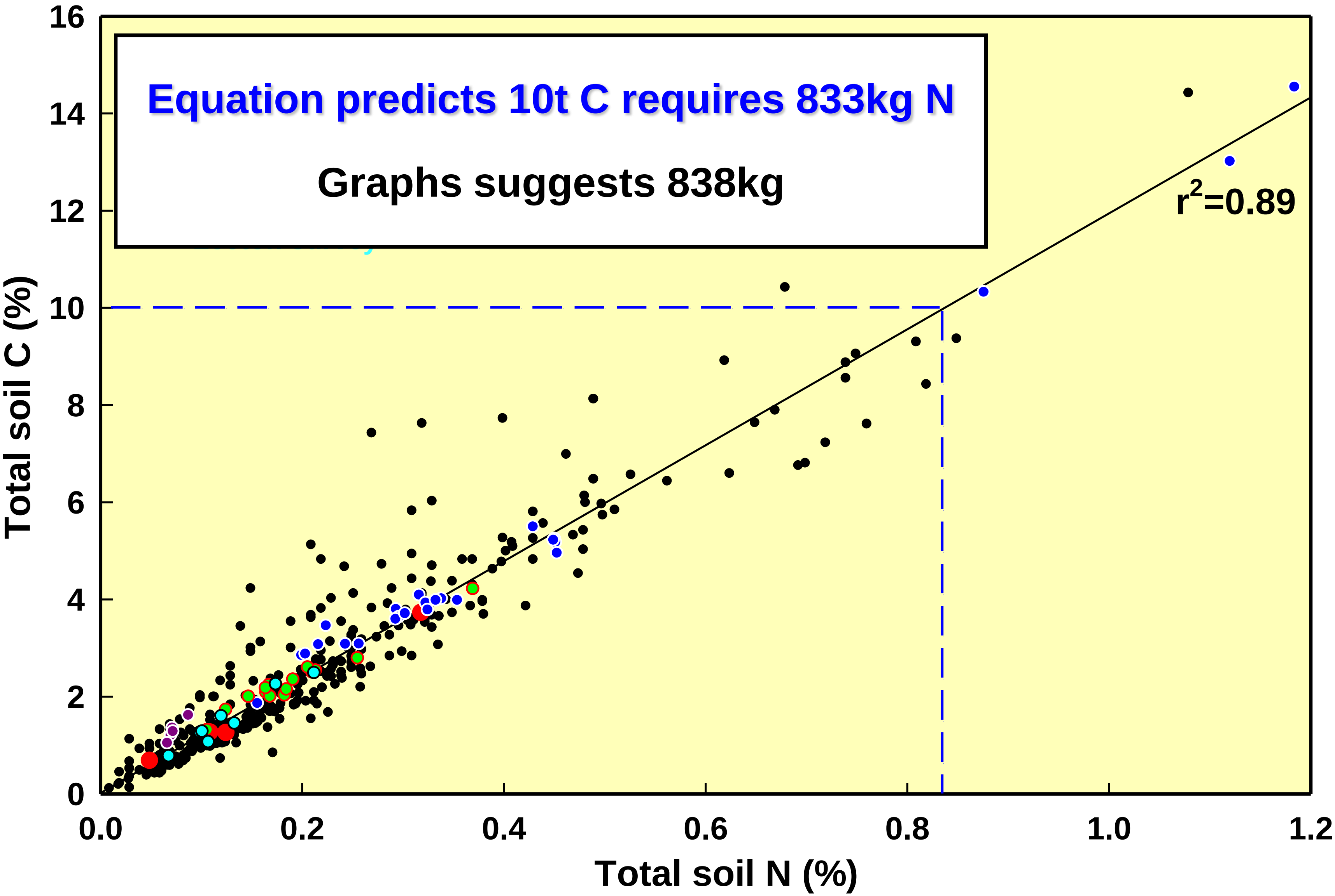
Total soil C:N



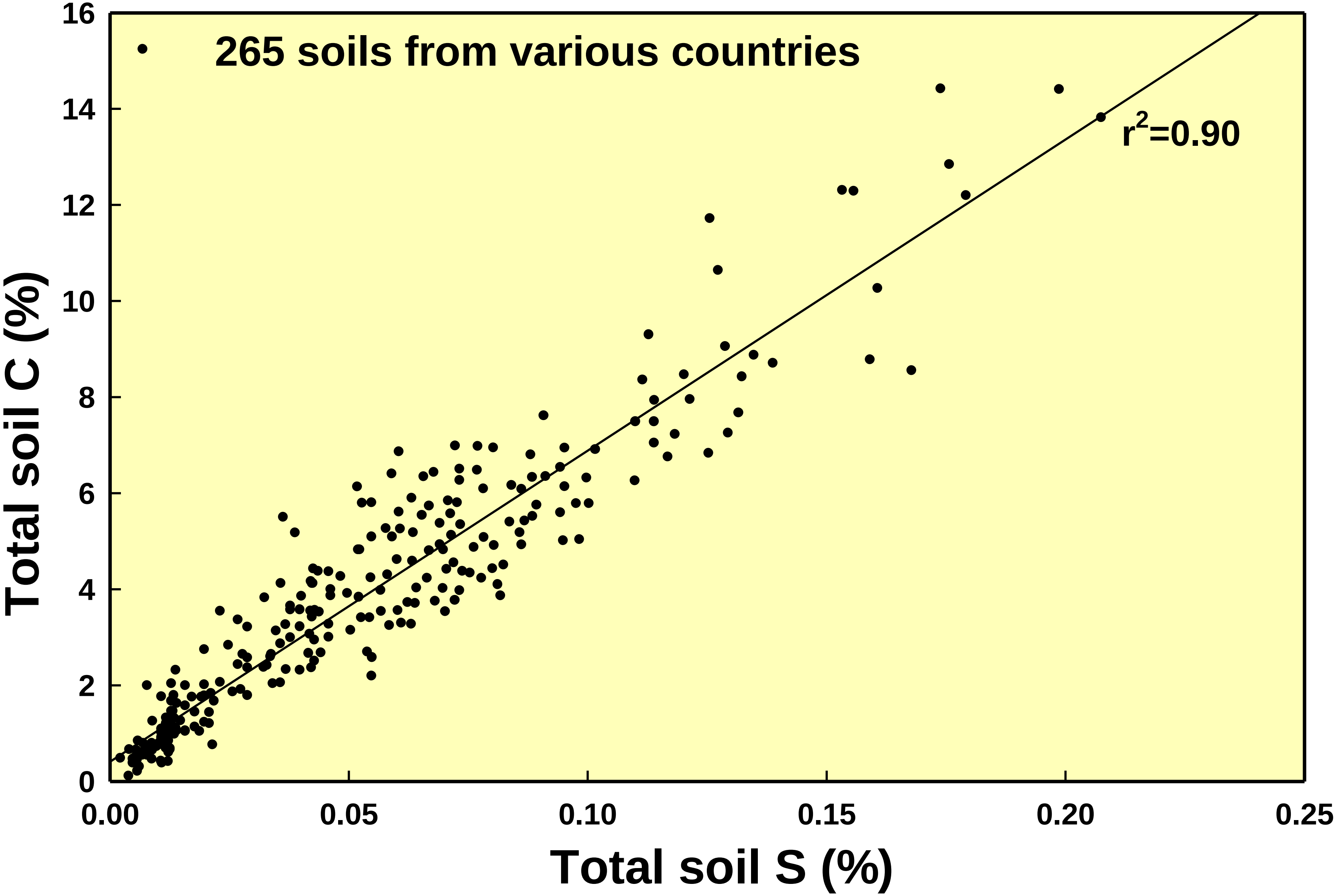
Total soil C:N



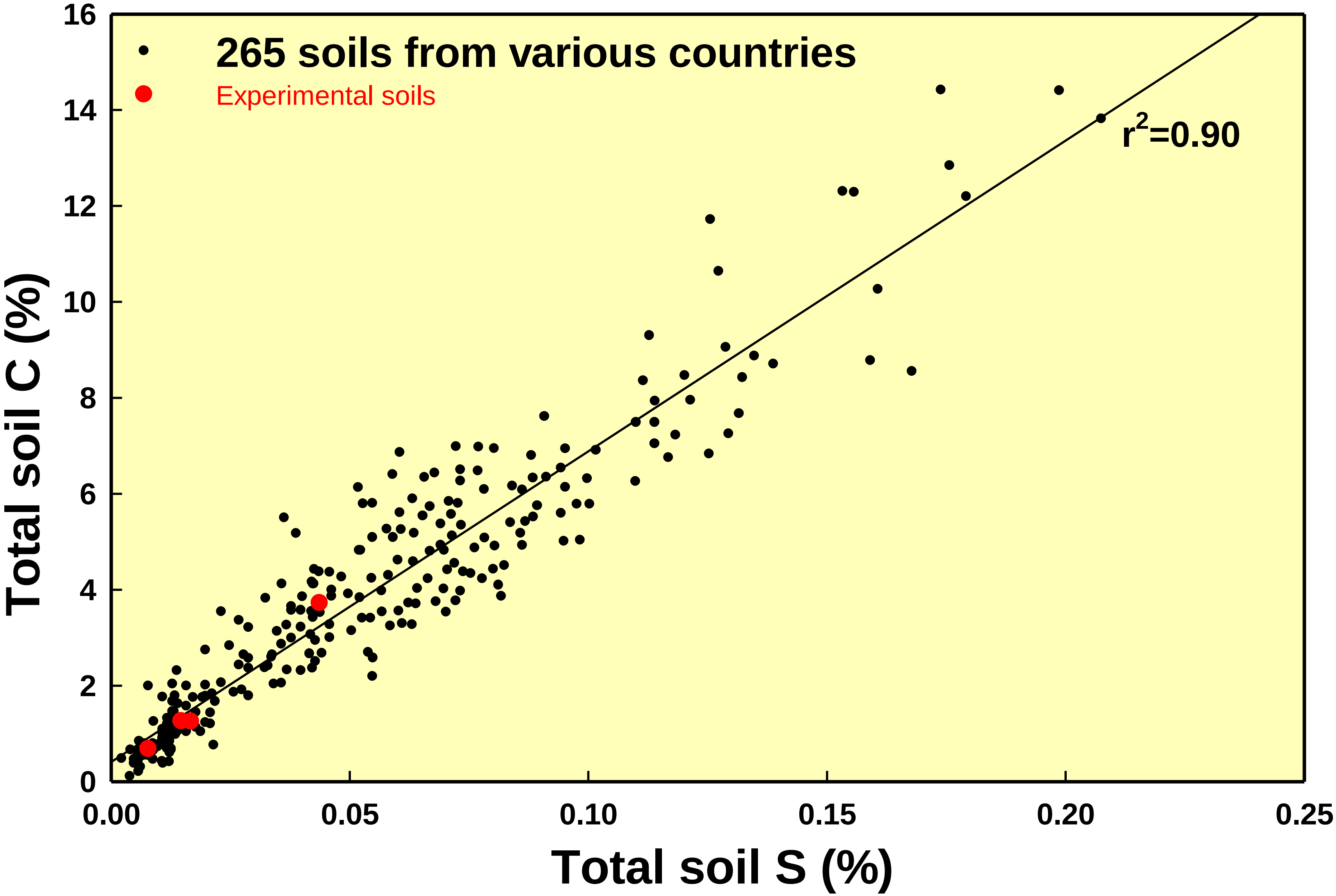
Total soil C:N



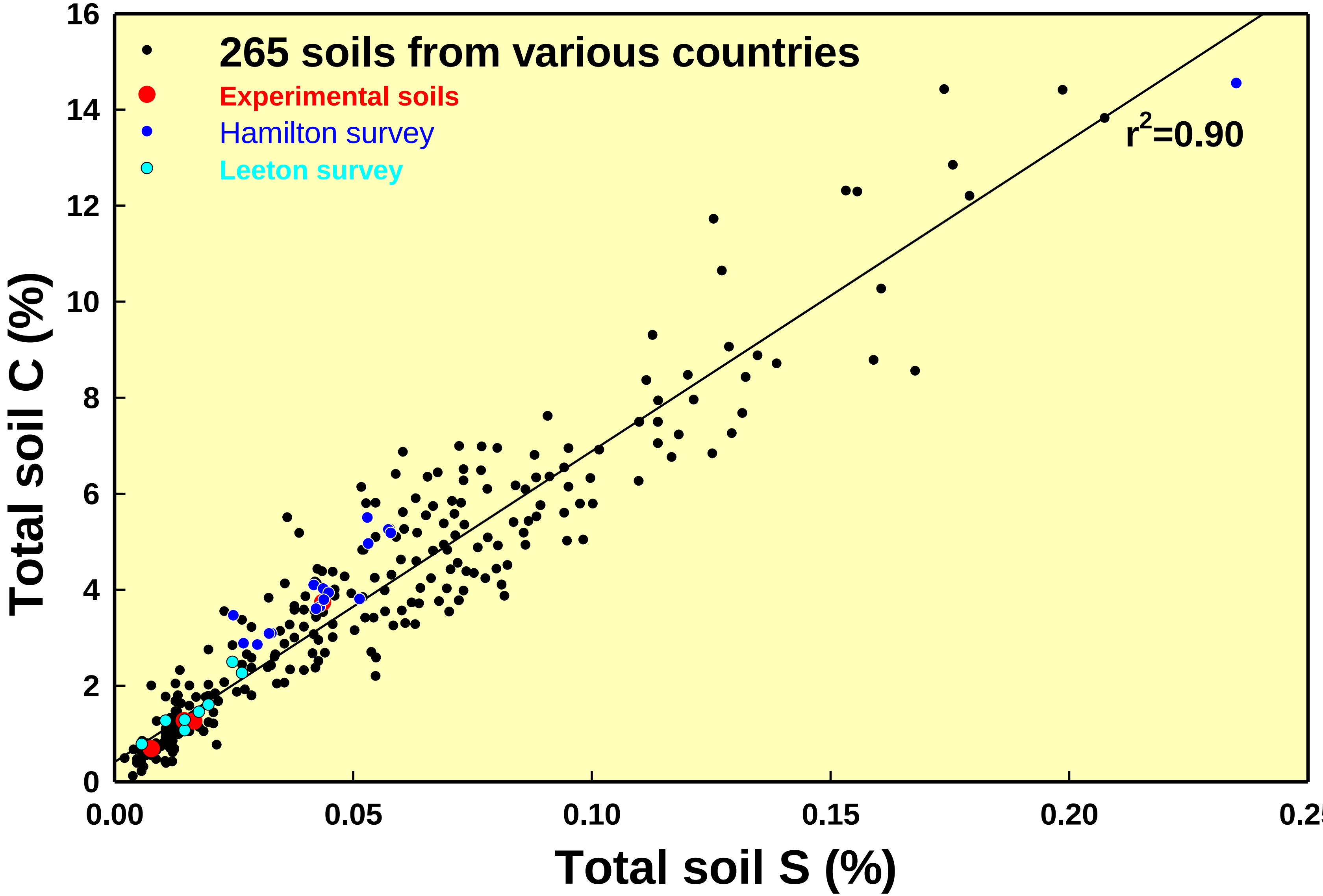
Total soil C:S



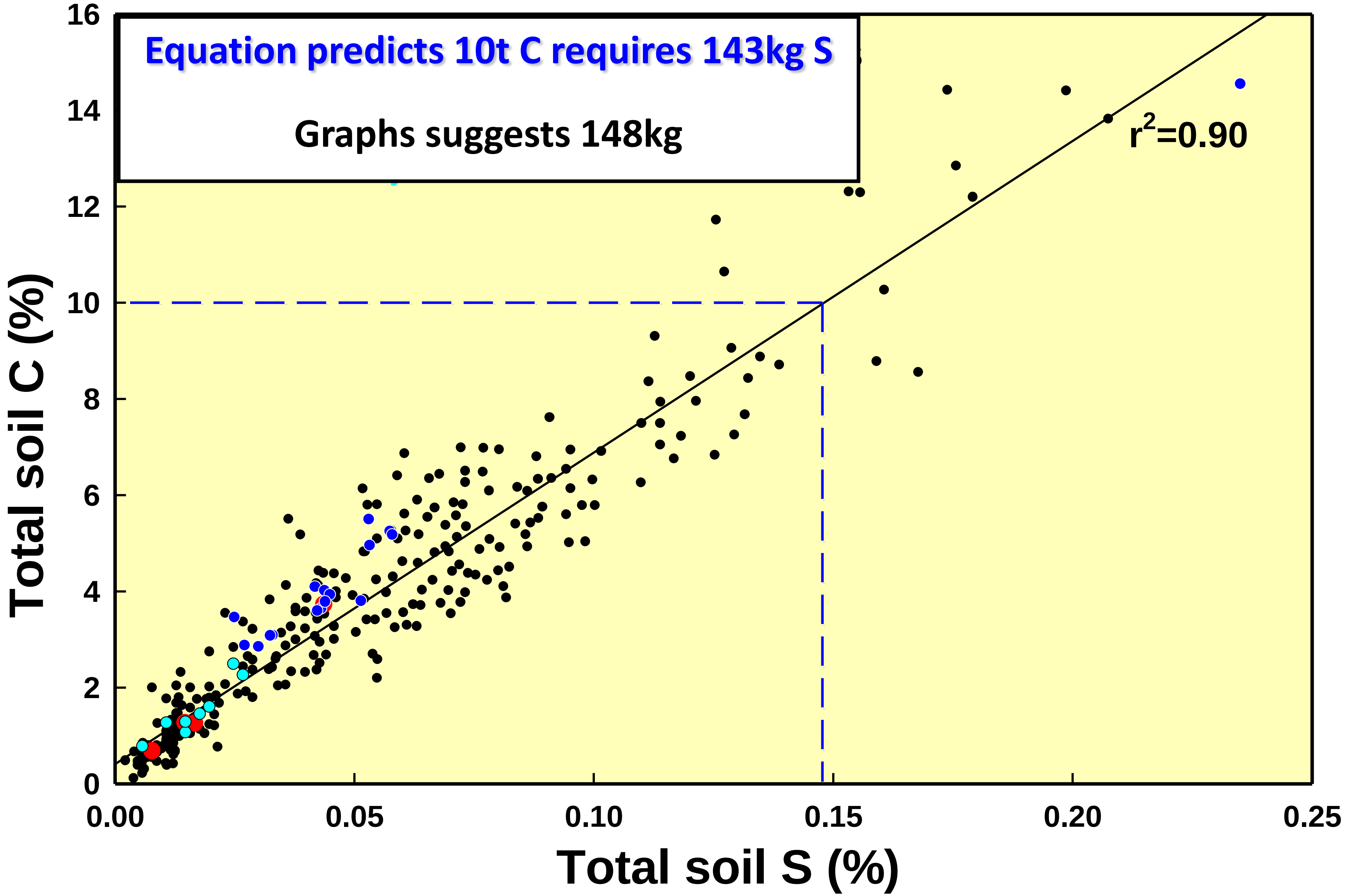
Total soil C:S



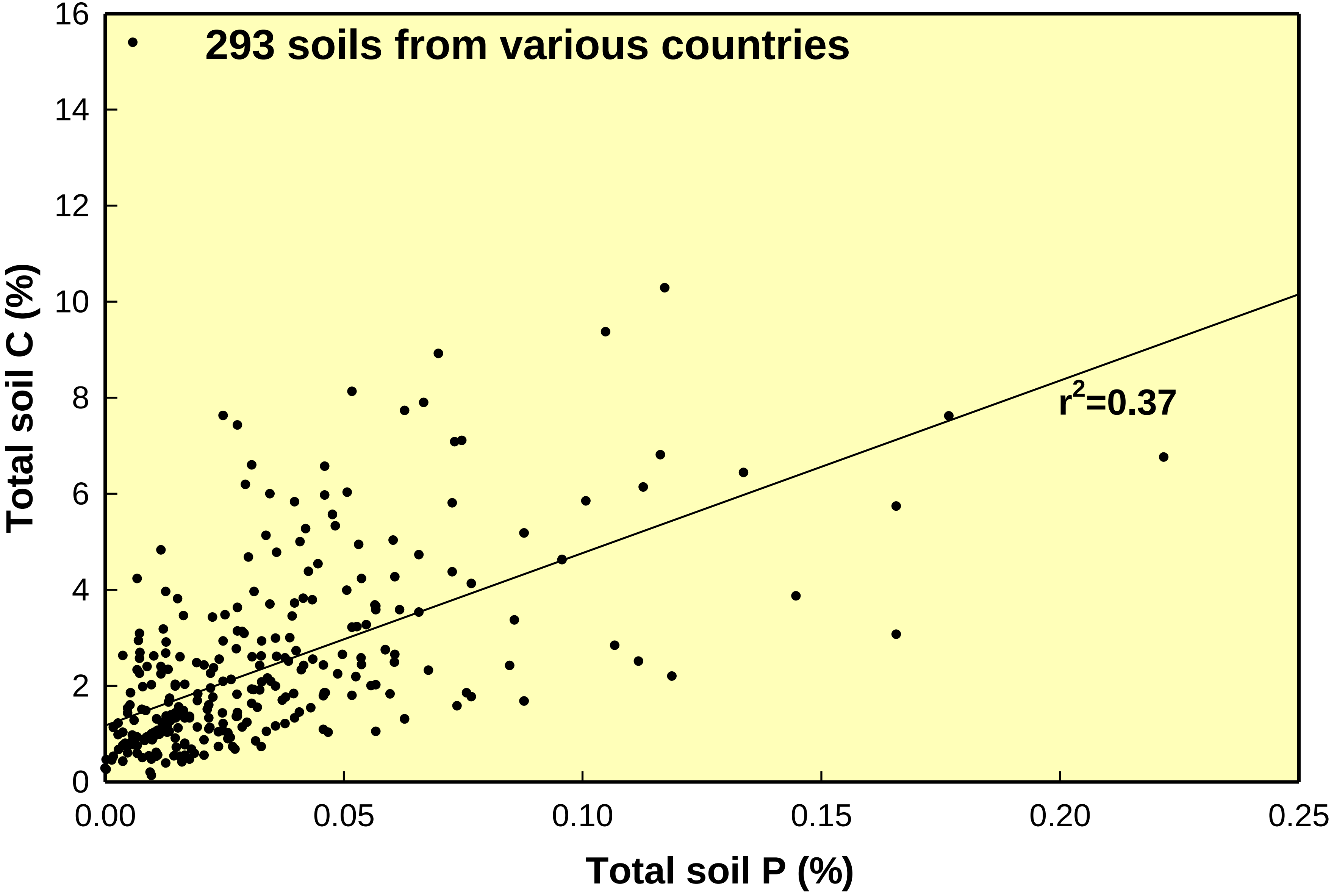
Total soil C:S



Total soil C:S

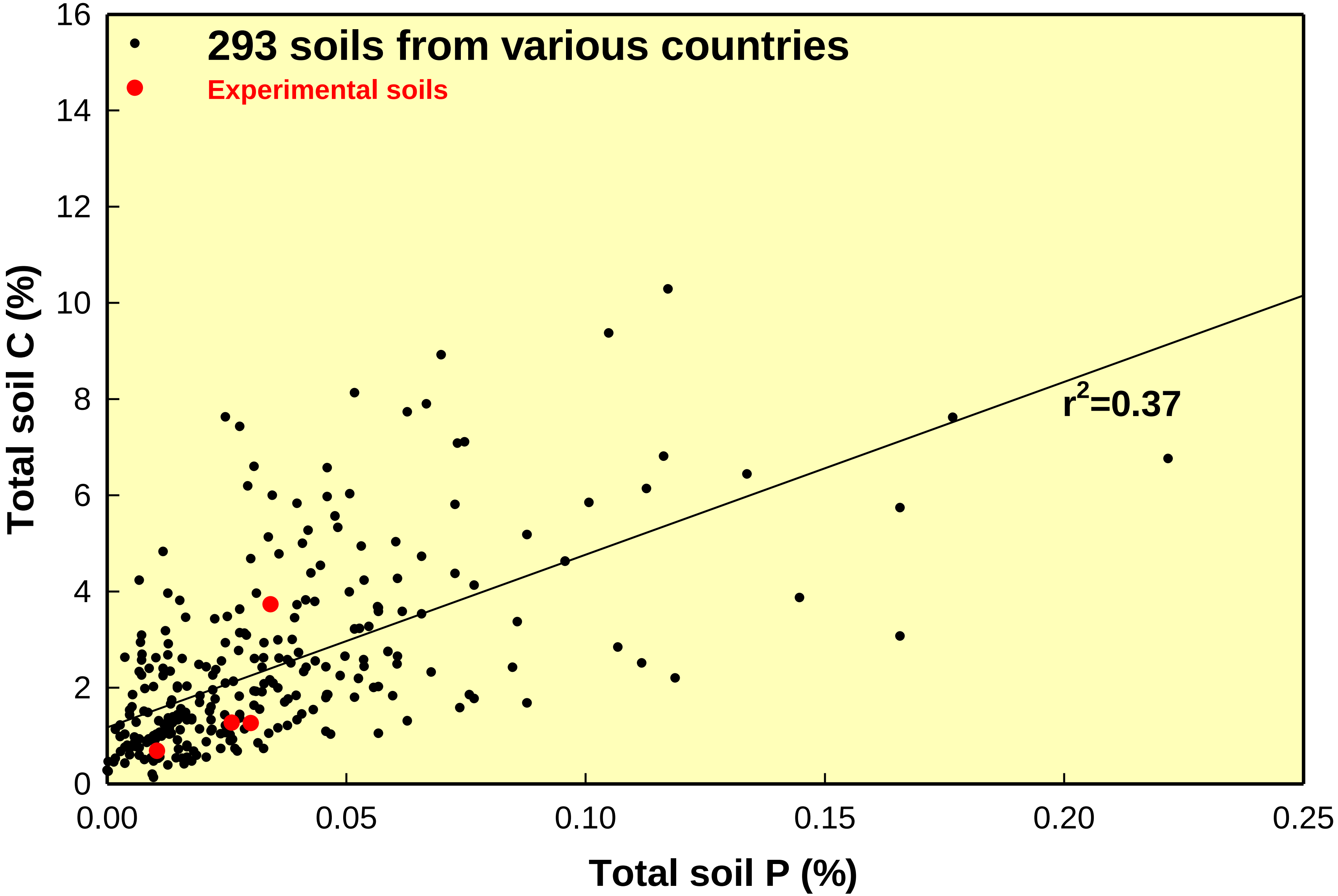


Total C:P



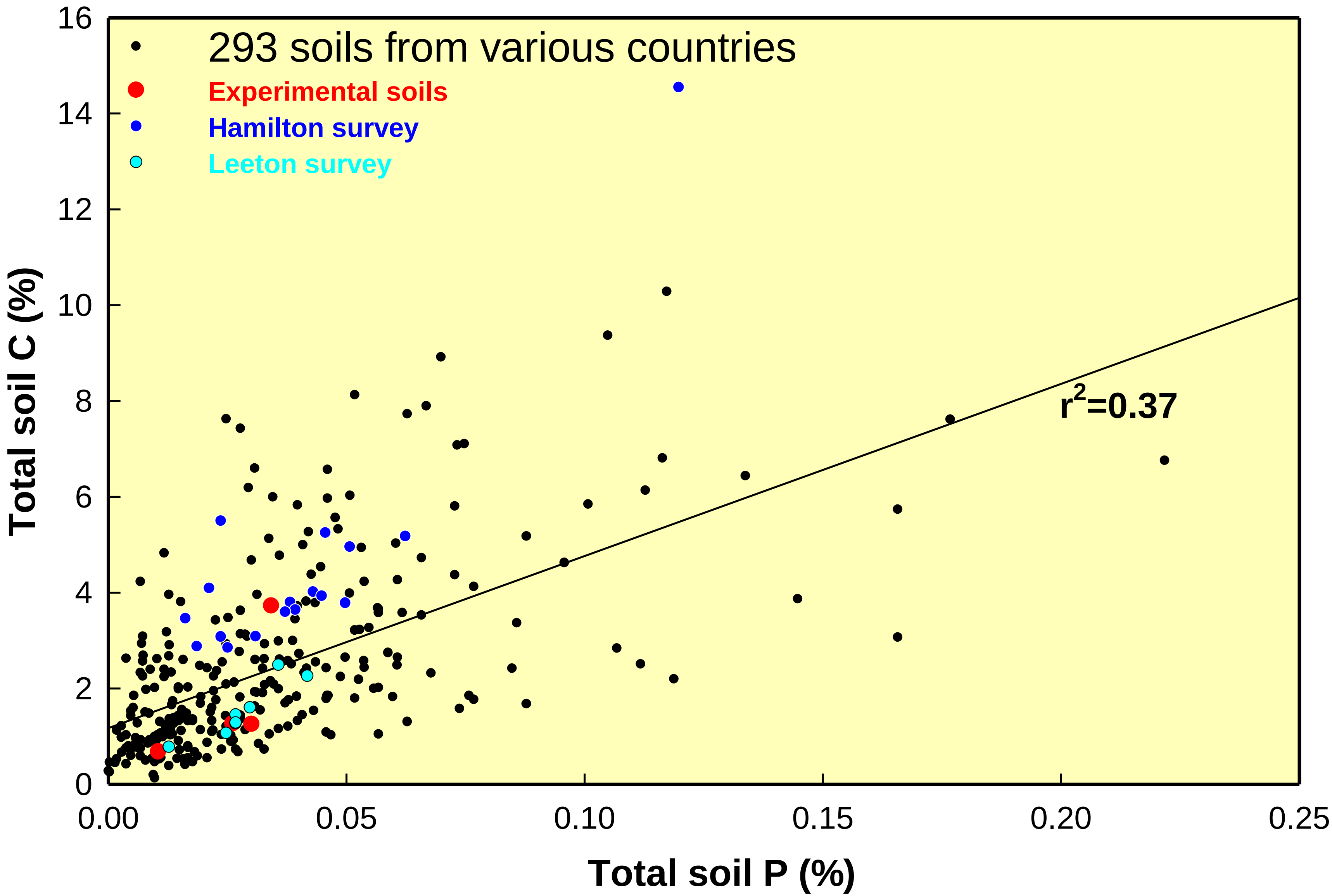
293 soils from various countries
r²=0.37
Total soil C (%)
Total soil P (%)
0
2
4
6
8
10
12
14
16
0.00
0.05
0.10
0.15
0.20
0.25

Total C:P

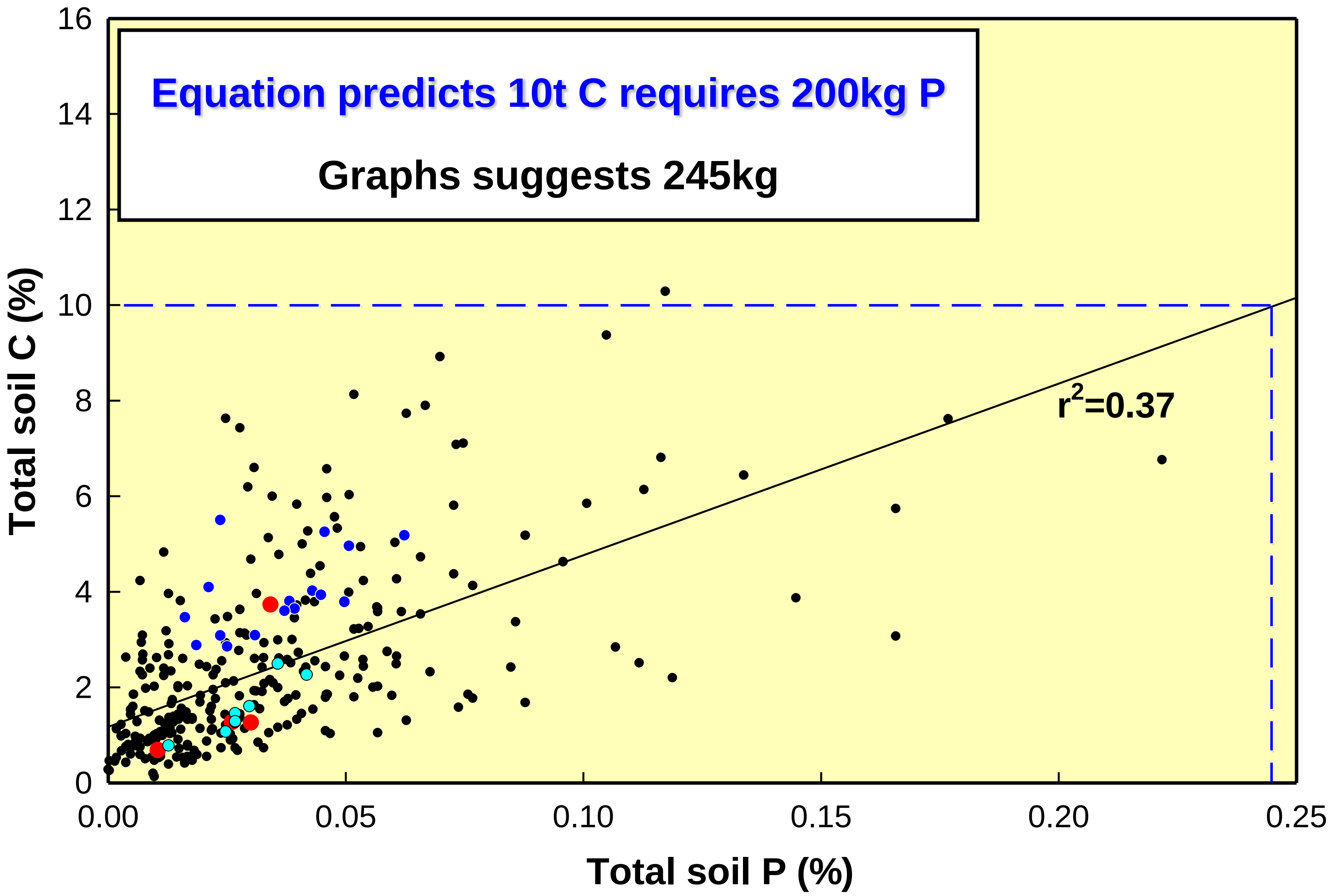


293 soils from various countries
Experimental soils
r2=0.37
Total soil C (%)
Total soil P (%)
16
14
12
10
8
6
4
2
0
0.00
0.05
0.10
0.15
0.20
0.25

Total C:P

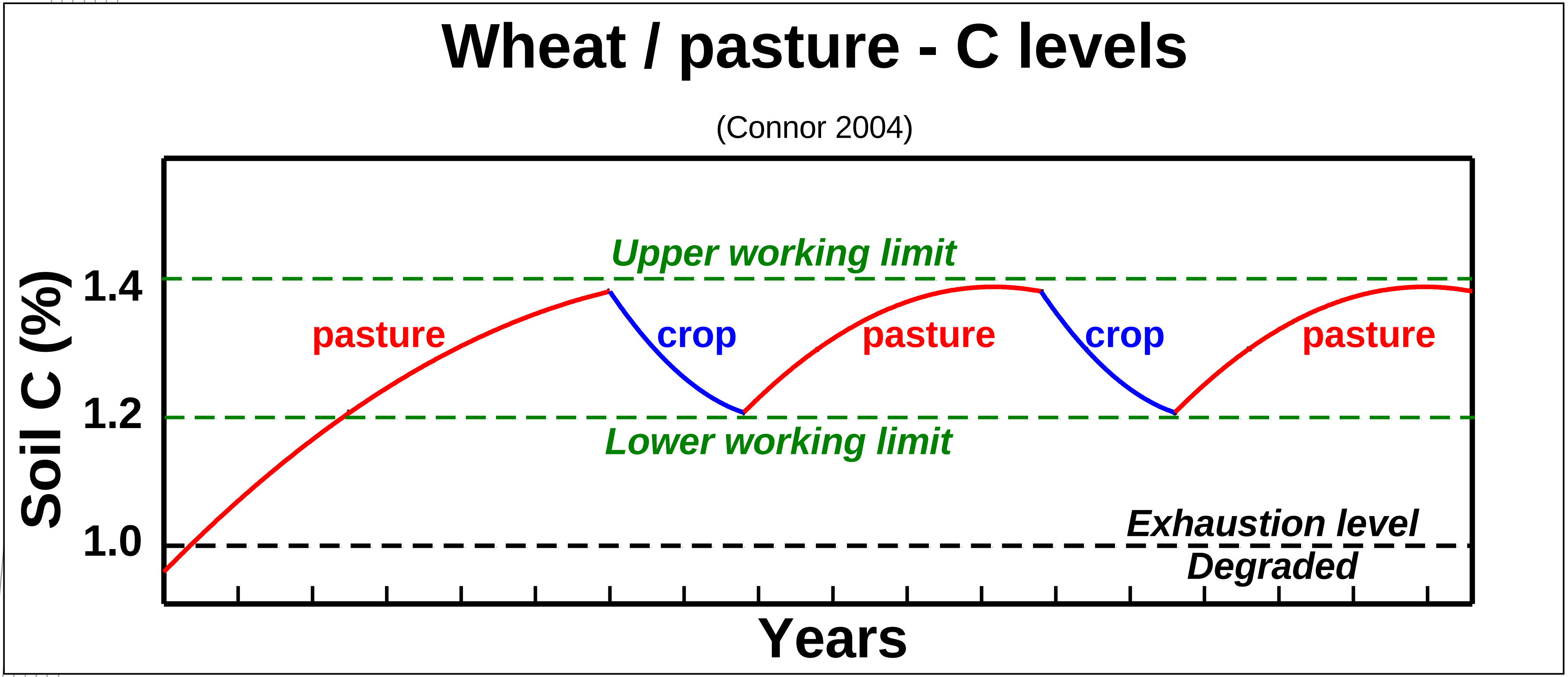

293 soils from various countries
Experimental soils
Hamilton survey
Leeton survey
r2=0.37
Total soil C (%)
Total soil P (%)
0
2
4
6
8
10
12
14
16
0.00
0.05
0.10
0.15
0.20
0.25

Total C:P



Equation predicts 10t C requires 200kg P
Graphs suggests 245kg
r²=0.37
Total soil C (%)
Total soil P (%)
0
2
4
6
8
10
12
14
16
0.00
0.05
0.10
0.15
0.20
0.25

Active, Passive & Pastures



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

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%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

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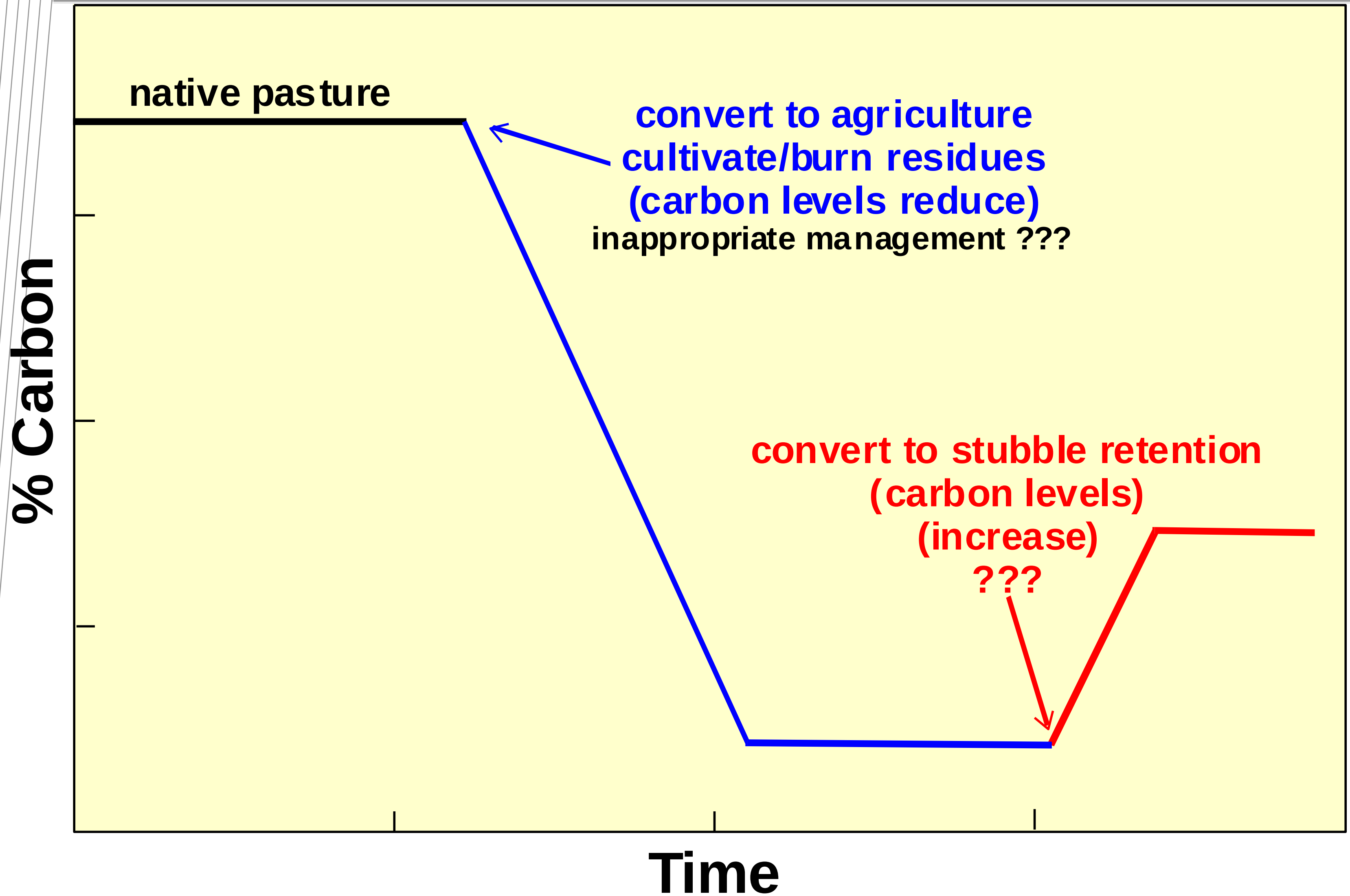
One Story of C Dynamics



A Conundrum

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

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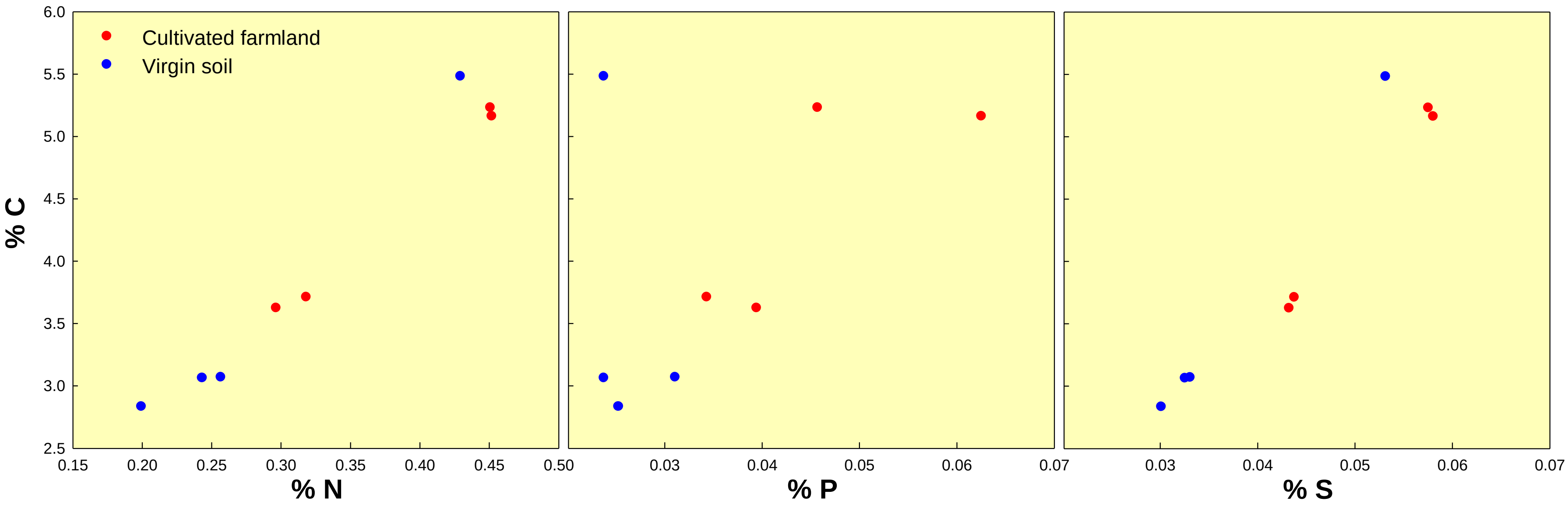
Crop vs Adjacent Virgin soil



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