Storing C in agricultural soils

Does it have a role in C-trading?

www.csiro.au

Mark Peoples

CSIRO Plant Industry

CSIRO

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%

Fauna:
- Break up organic matter
- Soil turnover
- Biopore formation

Microorganisms:
- Degrade chemicals
- Nutrient Cycling
- Aggregate stabilisation

Courtesy of Fran Hoyle DAWA

CSIRO

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?

CSIRO

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

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

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*

CSIRO

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*

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*

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)

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*

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)

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

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

High inherent spatial variability

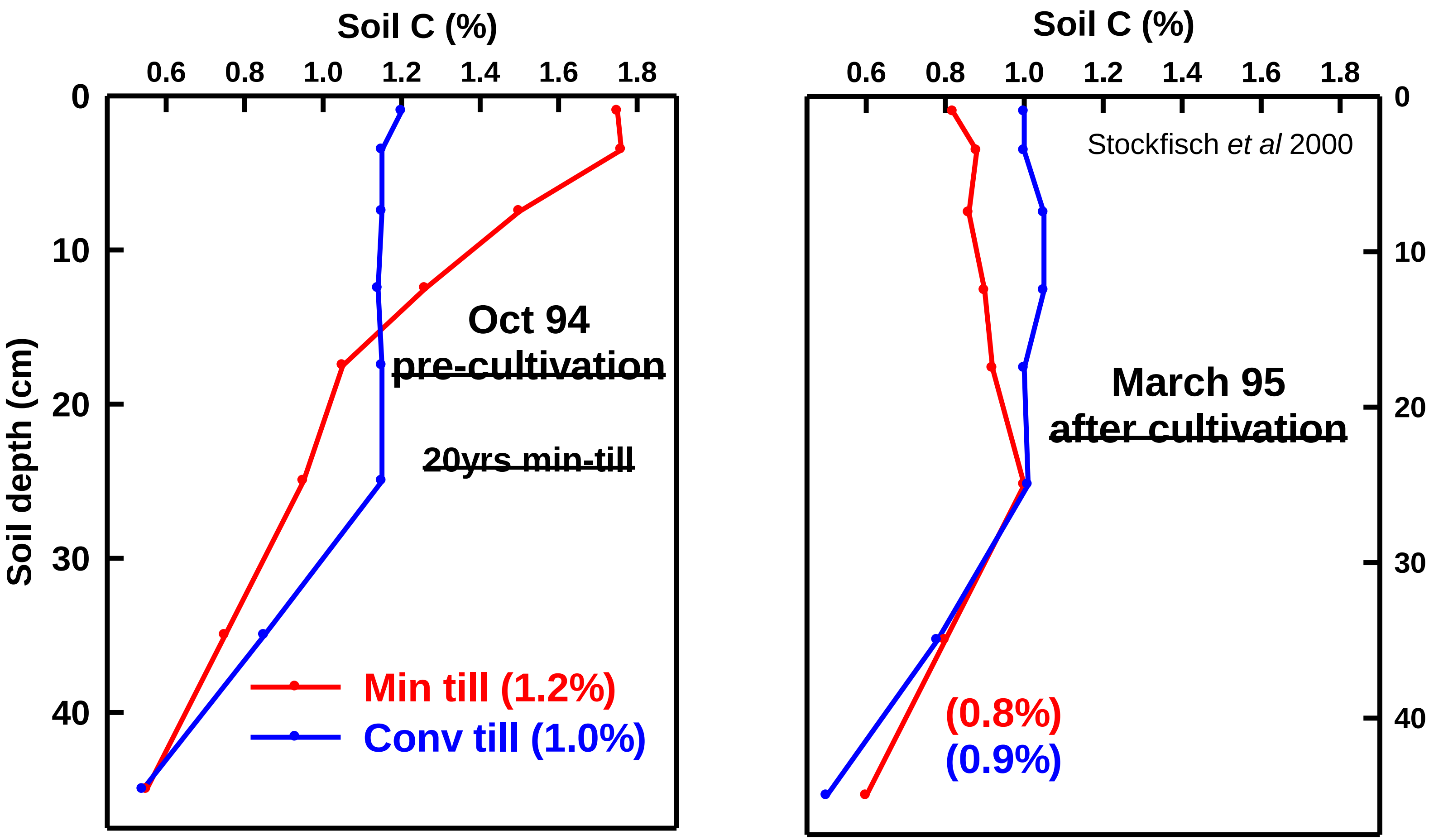
Variable across the landscape & down the soil profile

Can fluctuate widely from year to year

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

CSIRO

Large losses of soil C in response to changed management



Different pools of C in Soil Organic Matter (SOM)

Fresh residues, living organisms

'Resistant' residues, physically protected

Protected humus, charcoal

<1-10% C pool

POM 10-20% C pool

Humus 40-60% C pool

Charcoal 0-50% C pool

Active (labile) SOM	Slow SOM	Stable SOM
<1-3 y	20-40 y	Up to 1000 y

Courtesy of Fran Hoyle DAWA

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

CSIRO

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*

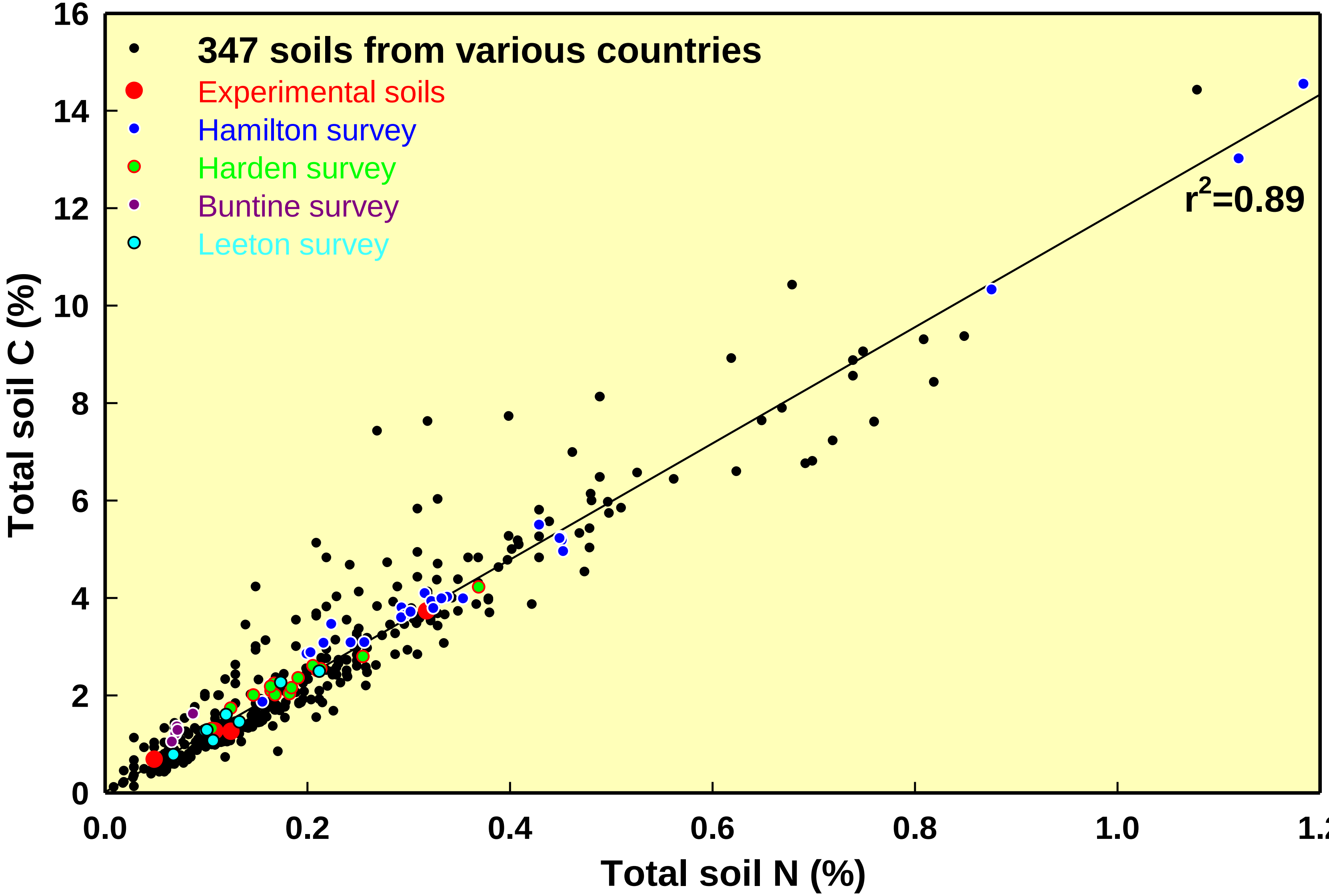
Source: Clive Kirkby, CSIRO PI

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

CSIRO

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

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

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

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

• 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

CSIRO

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

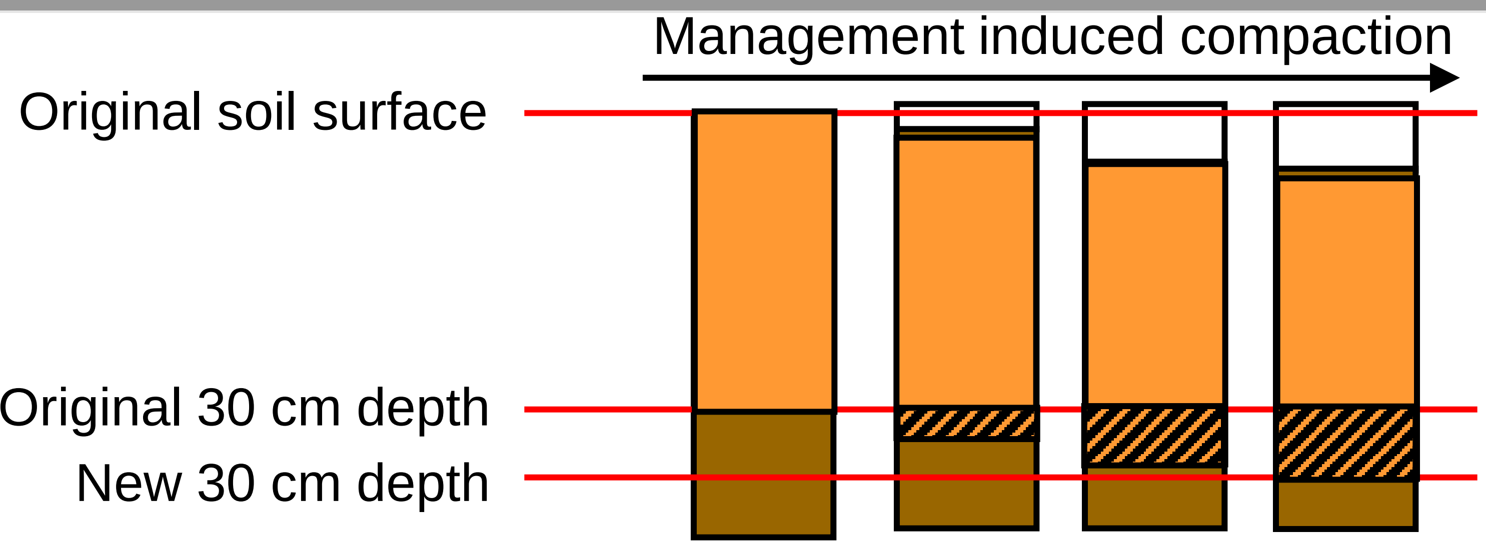
Take-Home Messages

- 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

CSIRO

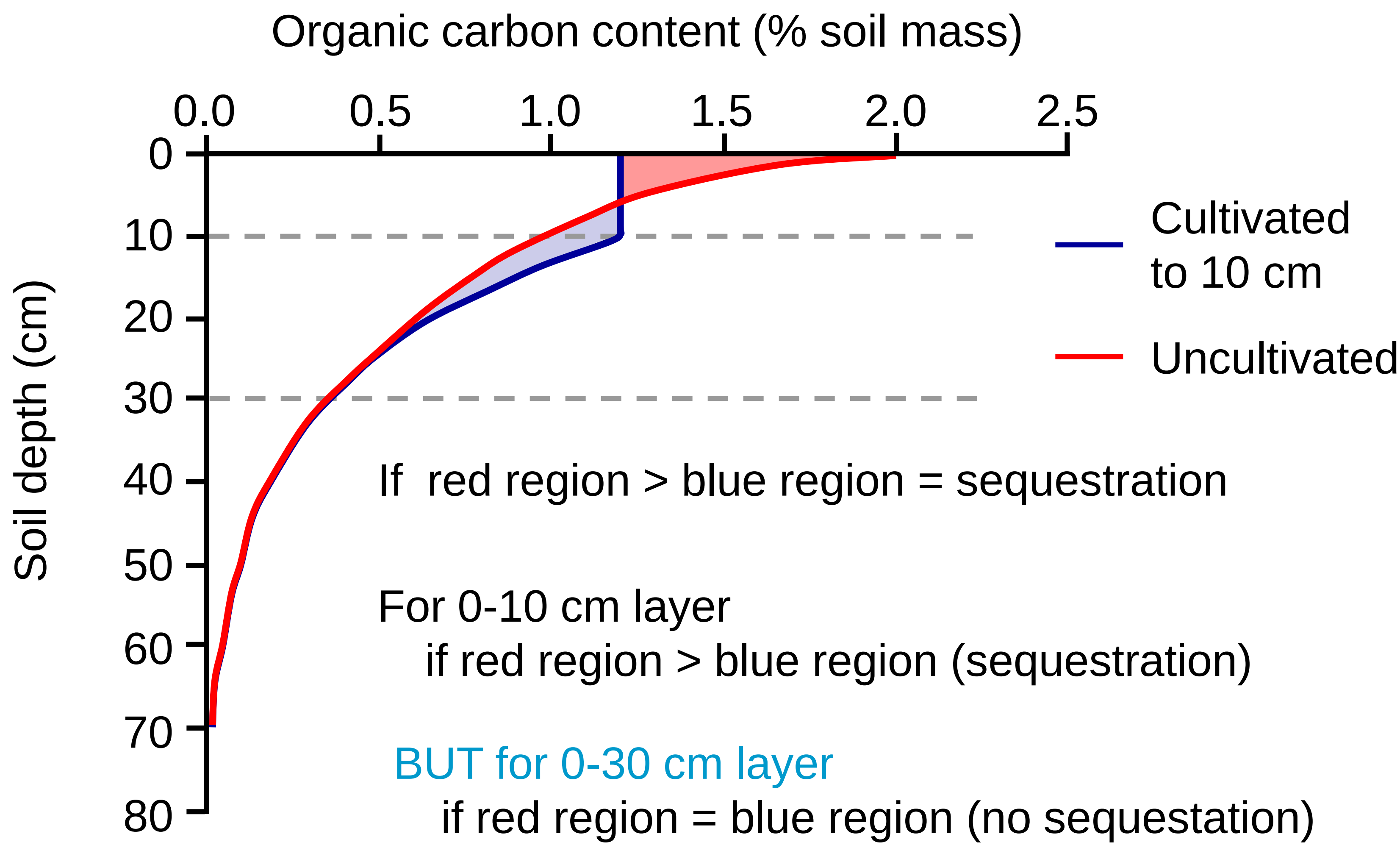
Correcting soil carbon for management induced changes in bulk density



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

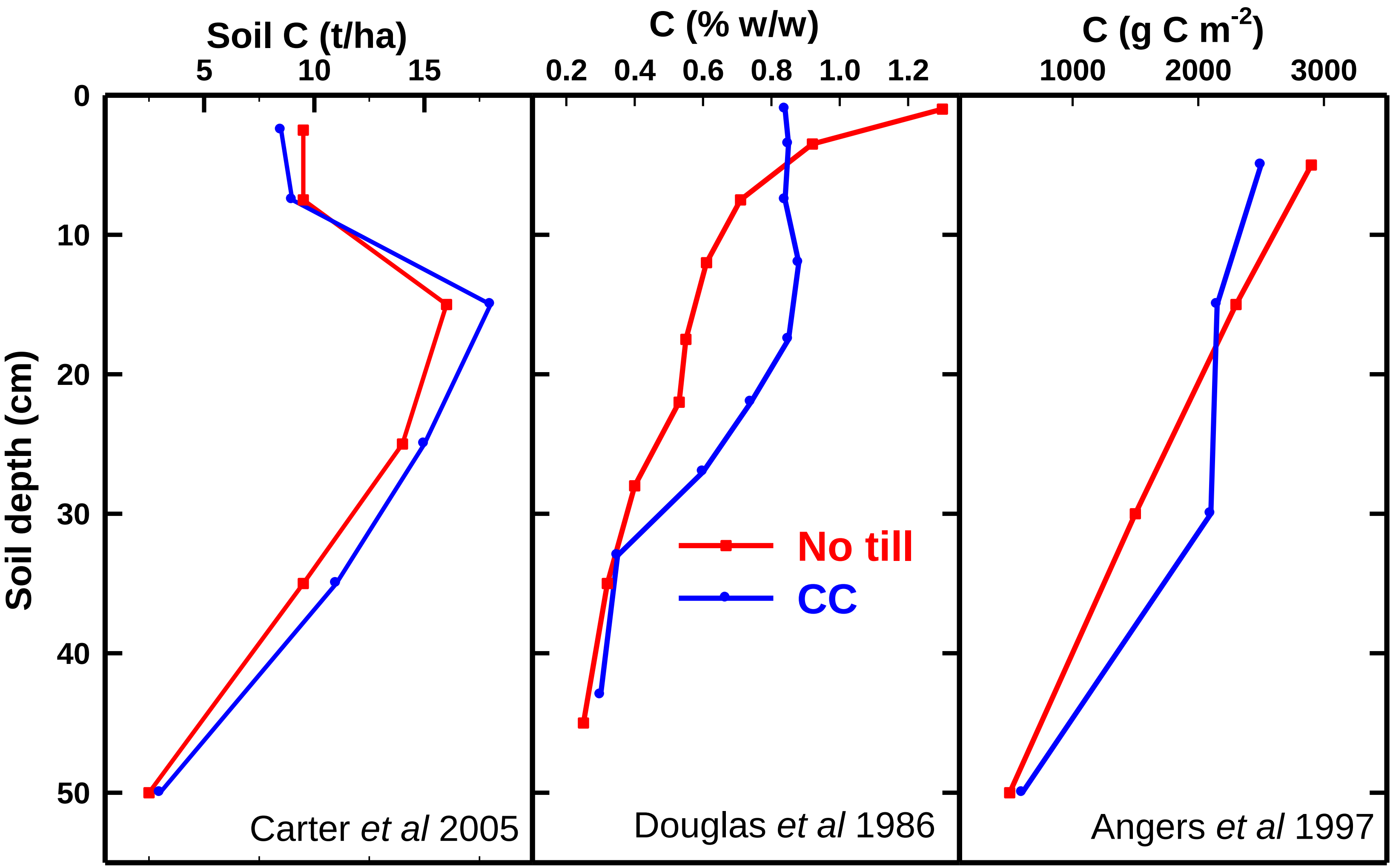
Influence of tillage on changes in soil carbon with depth



Source: Jeff Baldock CSIRO Land & Water

CSIRO

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

CSIRO

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

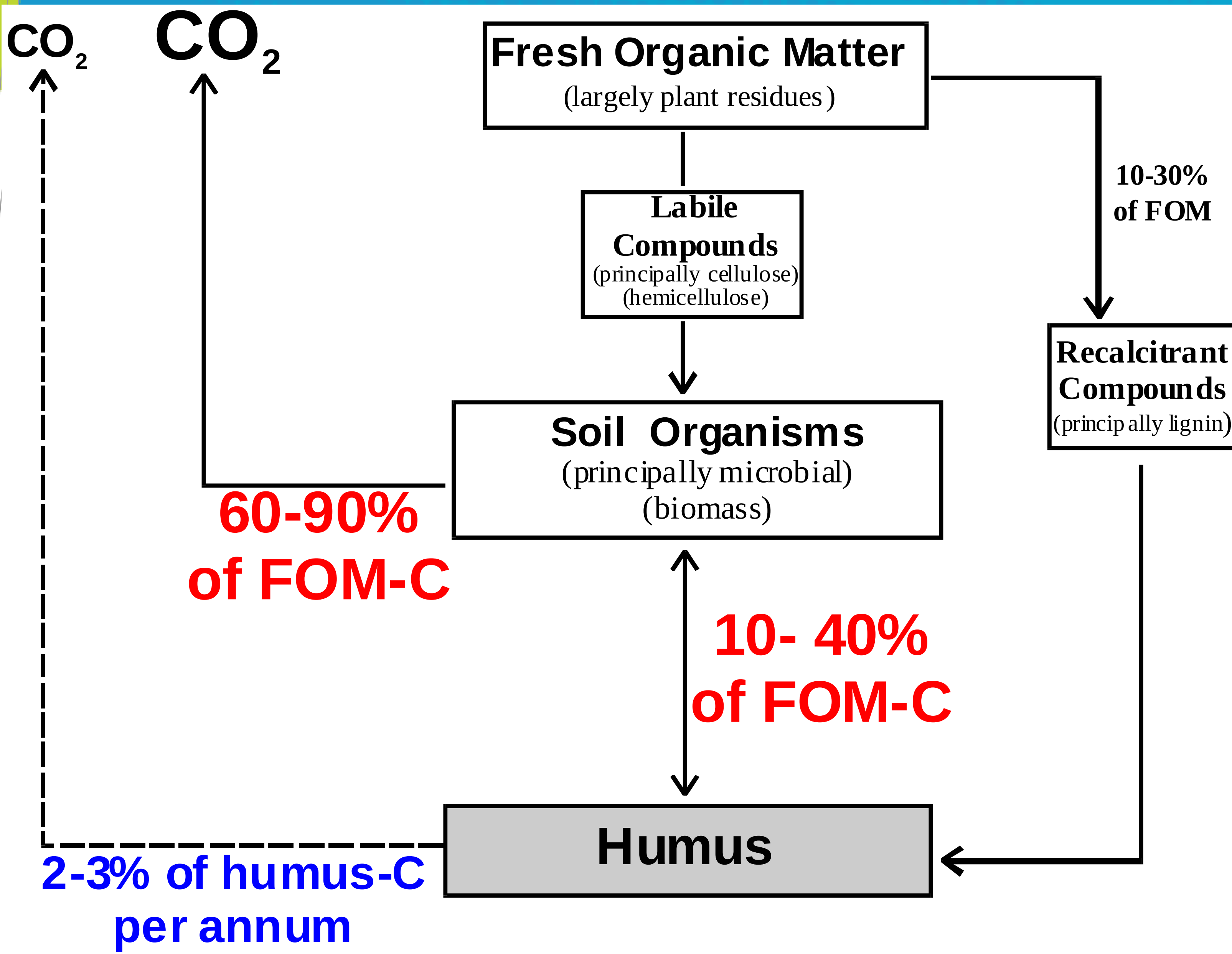
	C	N	P	S
wheat	10,000	134	16	36
maize	10,000	214	36	38
rice	10,000	95	12	14
bacteria	*10,000*	*2,400*	*520*	*100*
fungi	*10,000*	*1,091*	*109*	*36*
humus	10,000	833	200	143

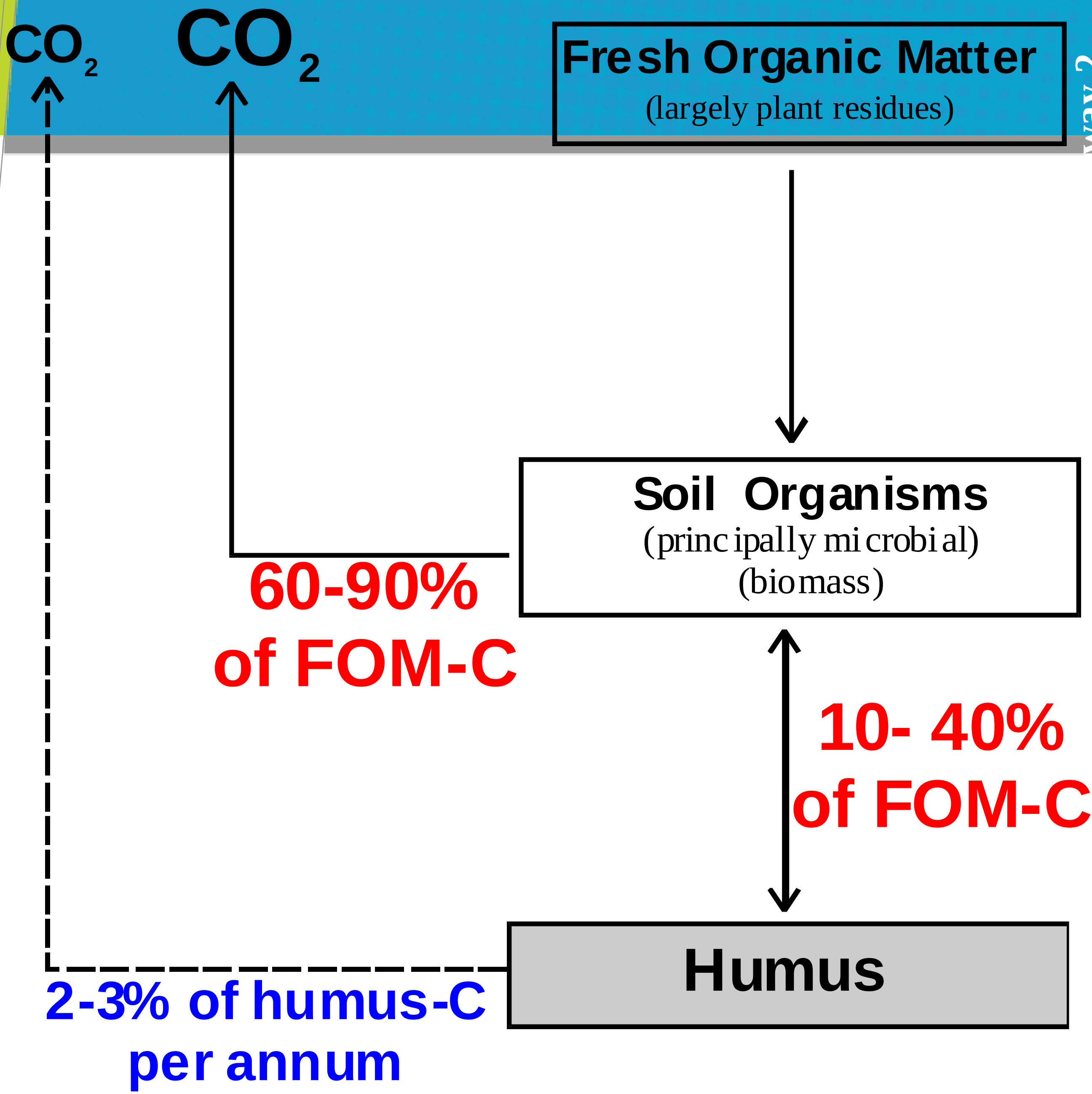
CSIRO

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

833 kg N, 200 kg P and 143 kg S

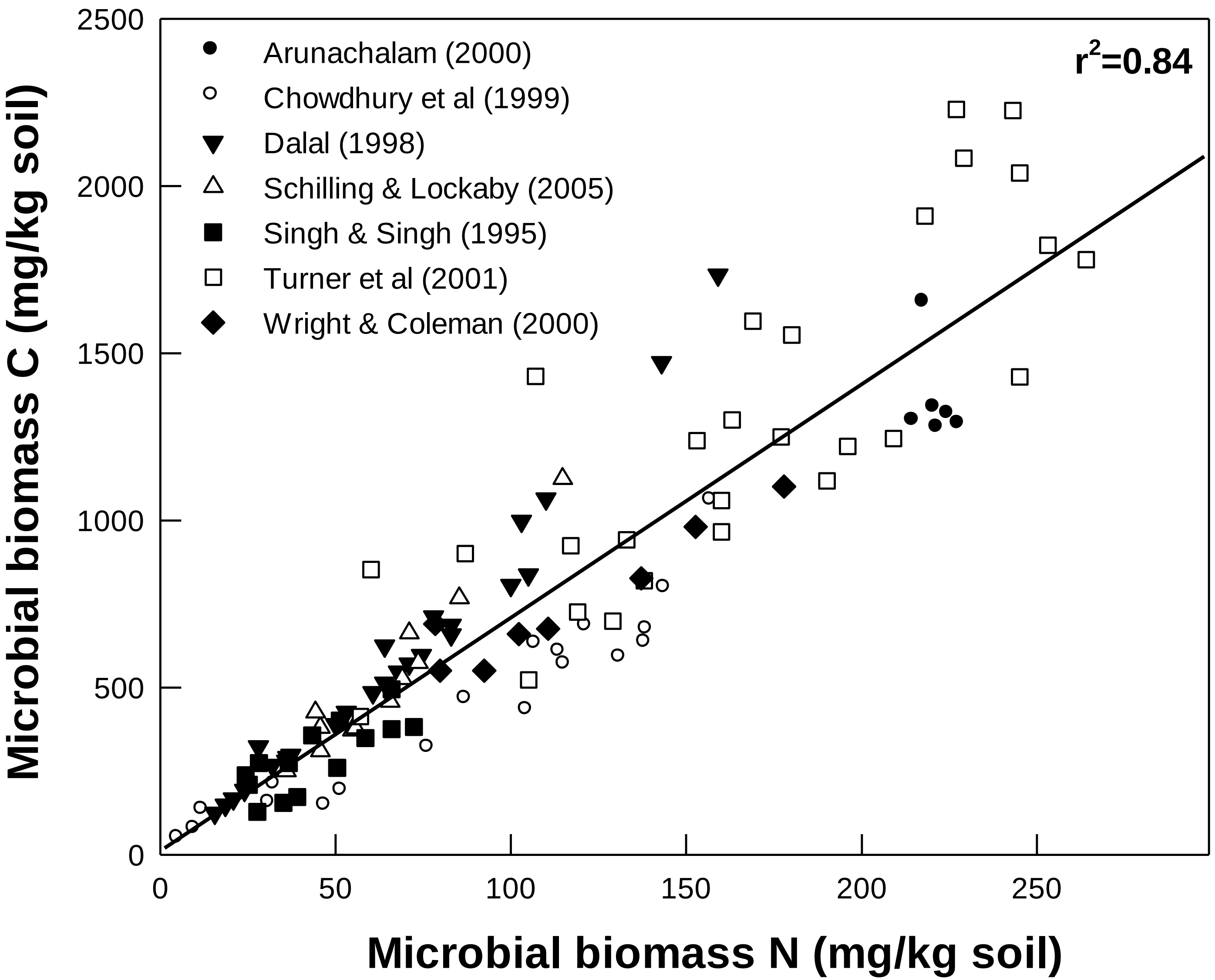
(one cannot sequest C in isolation)


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

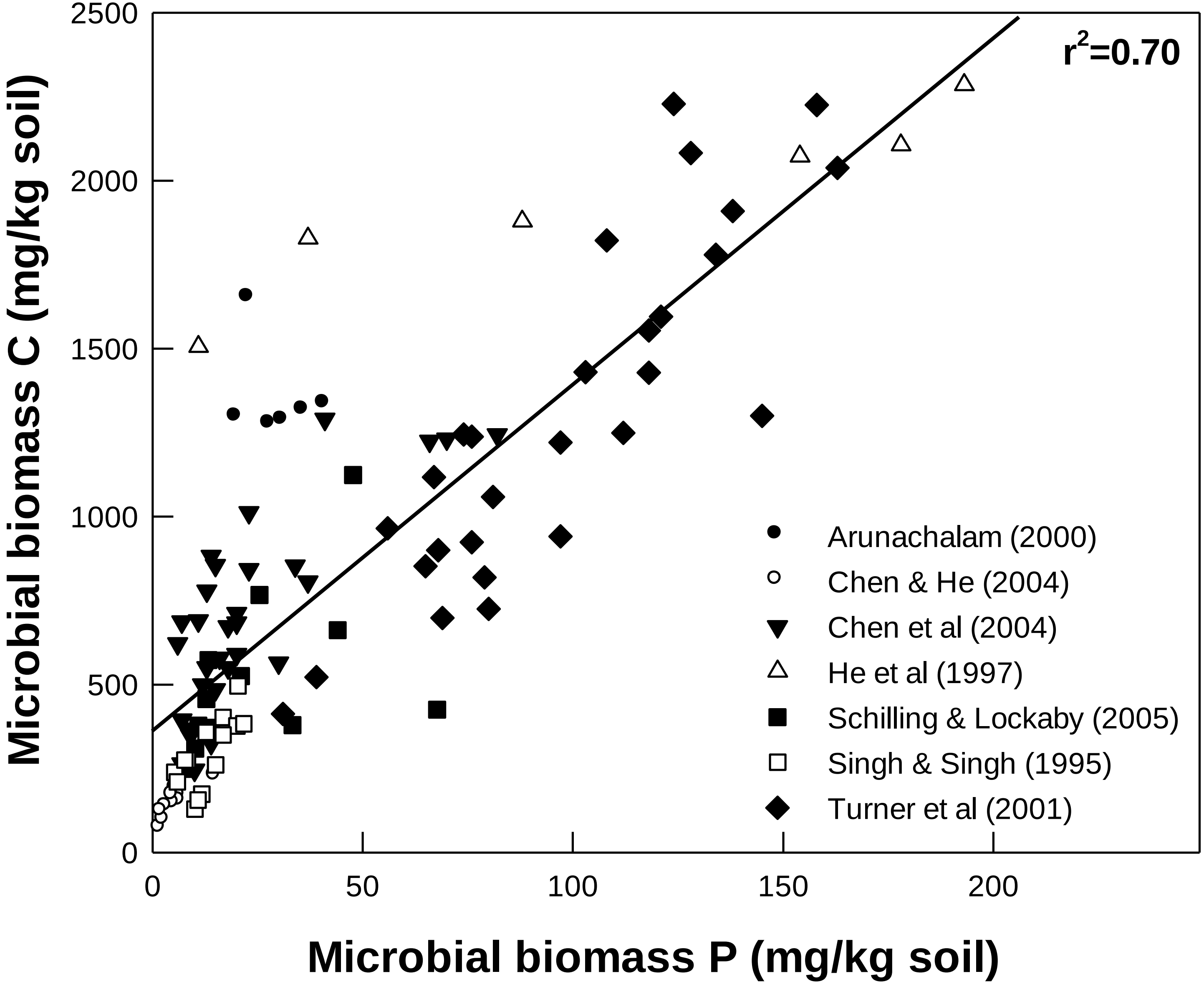


CO_2
CO_2
Fresh Organic Matter
(largely plant residues)
Soil Organisms
(principally microbial)
(biomass)
60-90%
of FOM-C
10- 40%
of FOM-C
Humus
2-3% of humus-C
per annum

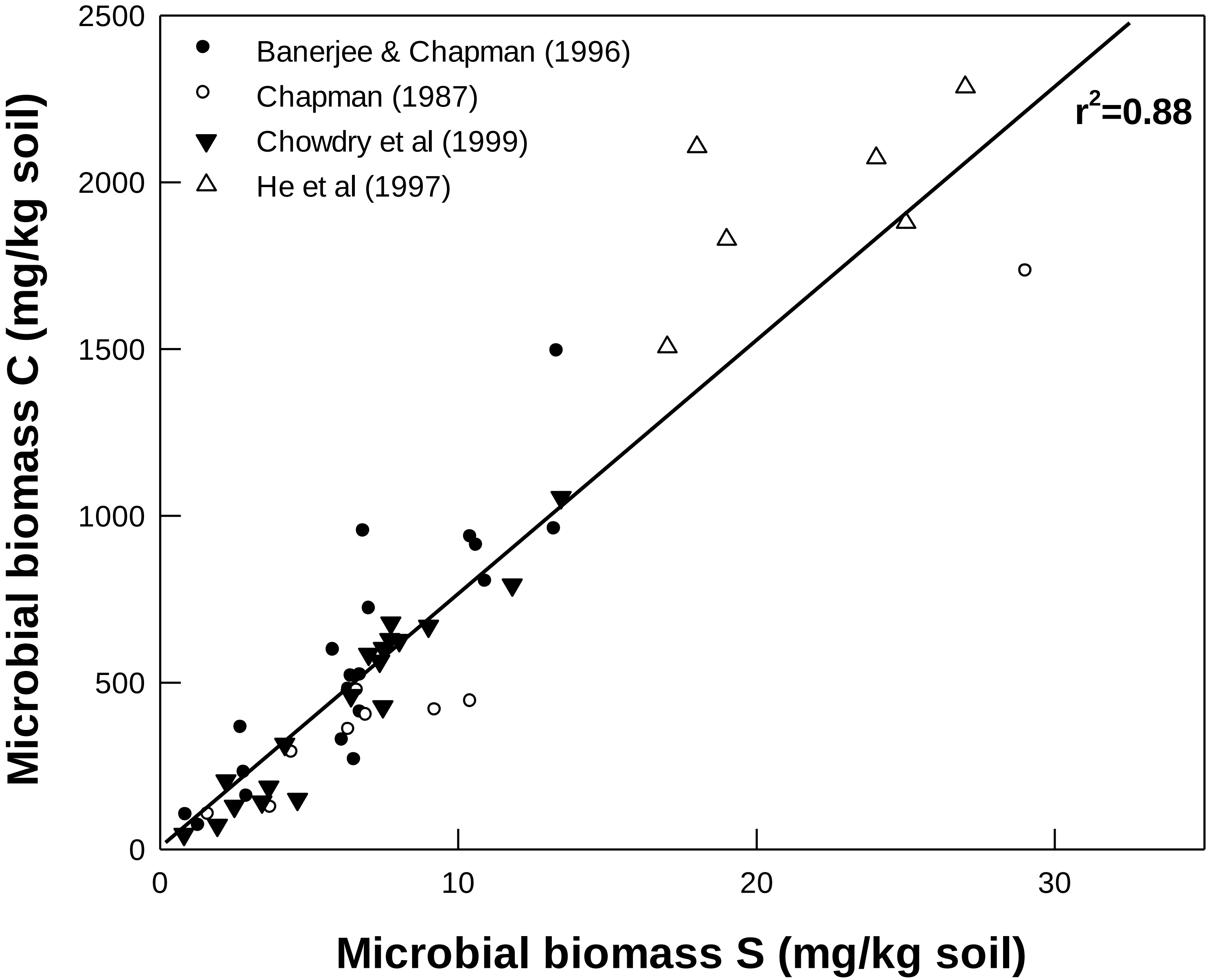
Microbial C:N



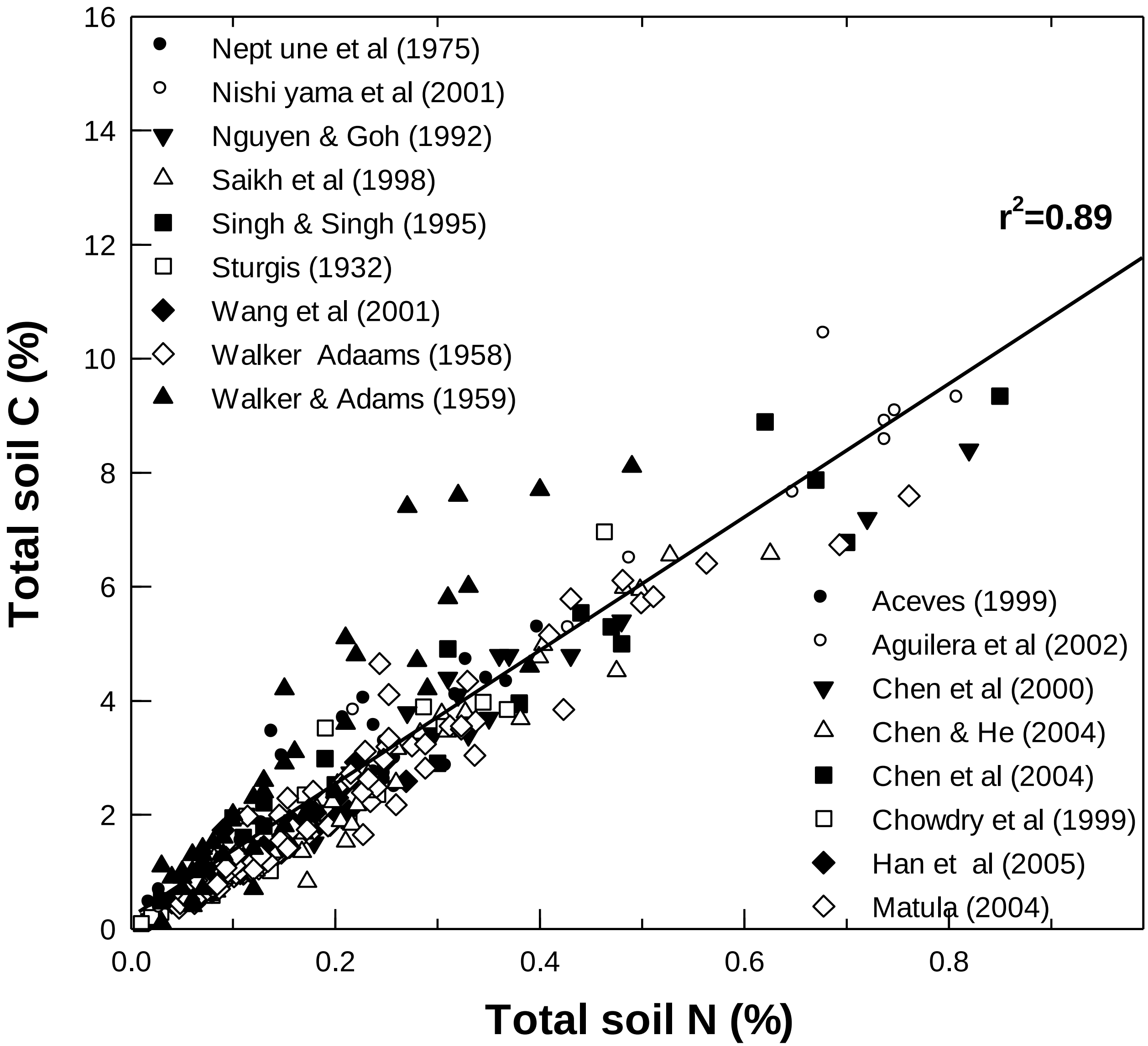
Microbial C:P



Microbial C:S

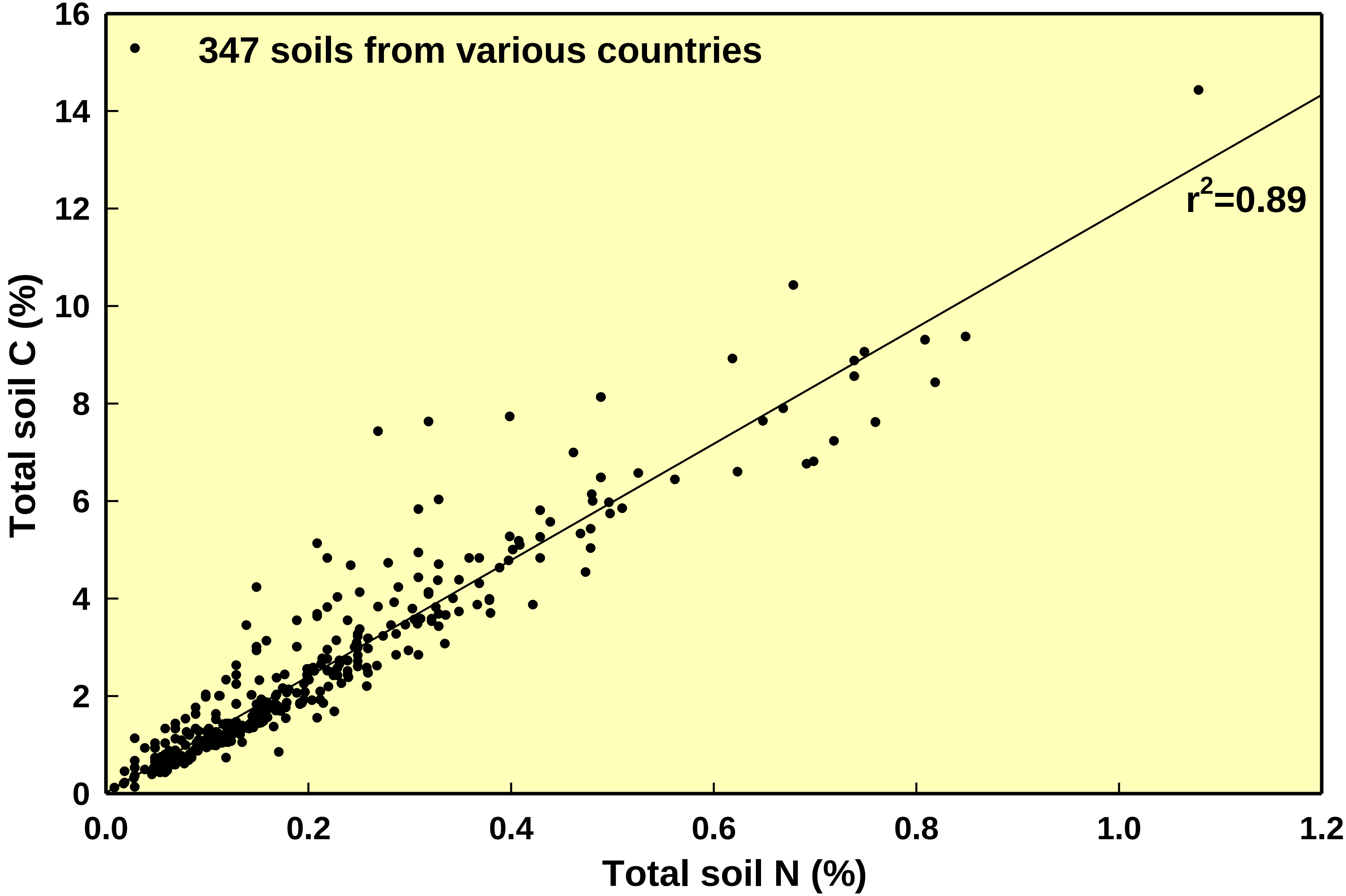


Soil C:N

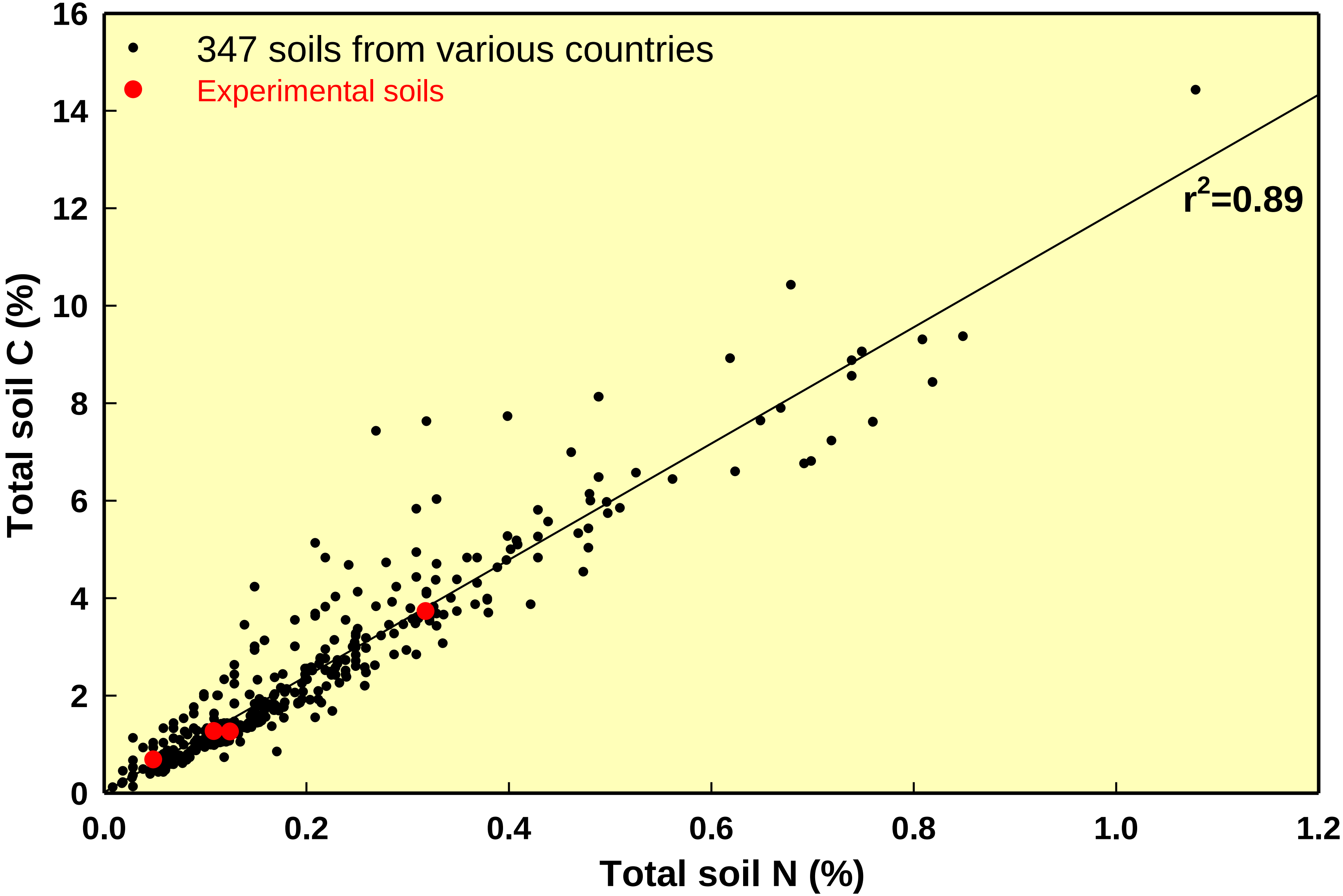


Total soil C (%)
Total soil N (%)
0
2
4
6
8
10
12
14
16
0.0
0.2
0.4
0.6
0.8
Nept une et al (1975)
Nishi yama et al (2001)
Nguyen & Goh (1992)
Saikh et al (1998)
Singh & Singh (1995)
Sturgis (1932)
Wang et al (2001)
Walker Adaams (1958)
Walker & Adams (1959)
r^2=0.89
Aceves (1999)
Aguilera et al (2002)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

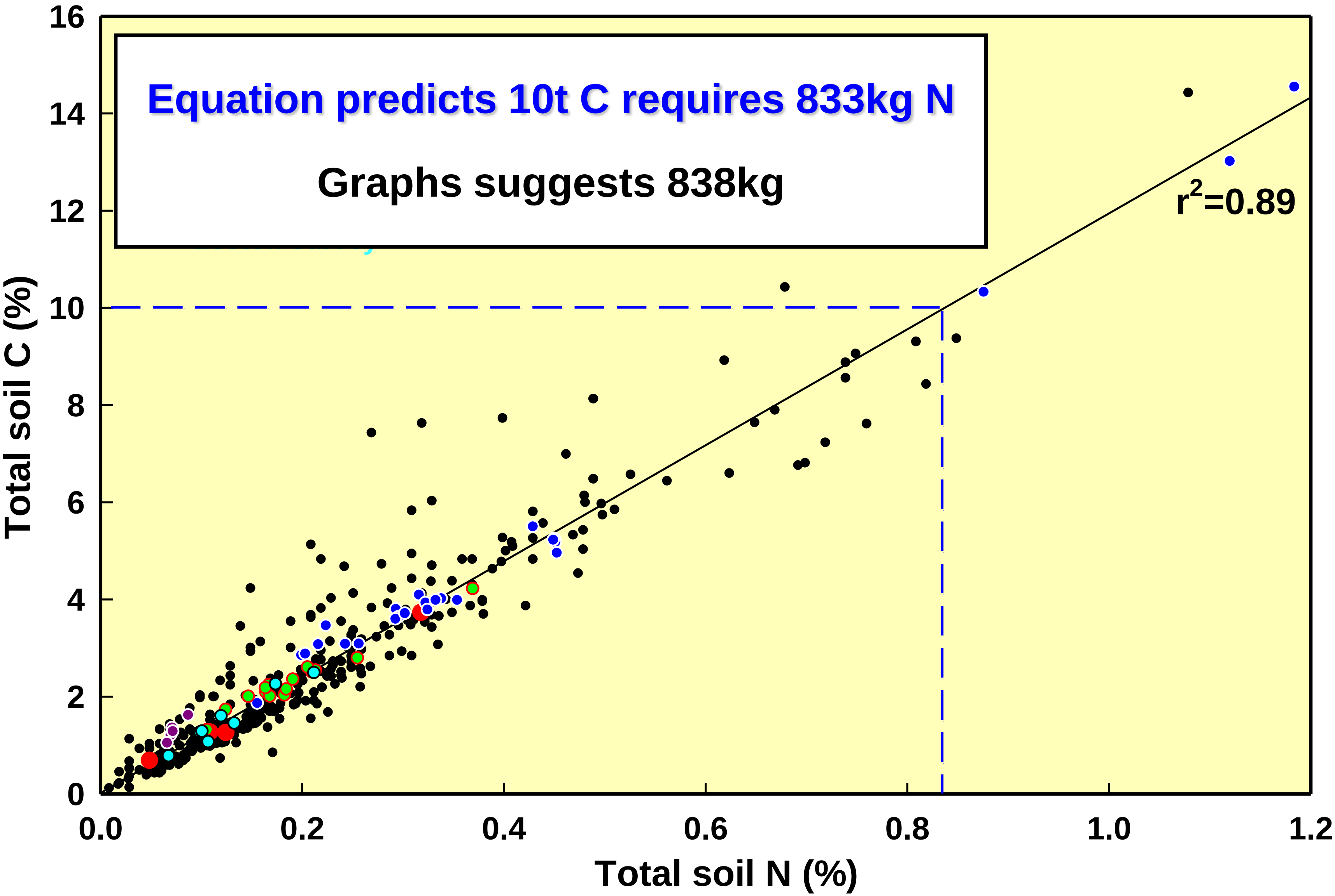
Total soil C:N



Total soil C:N

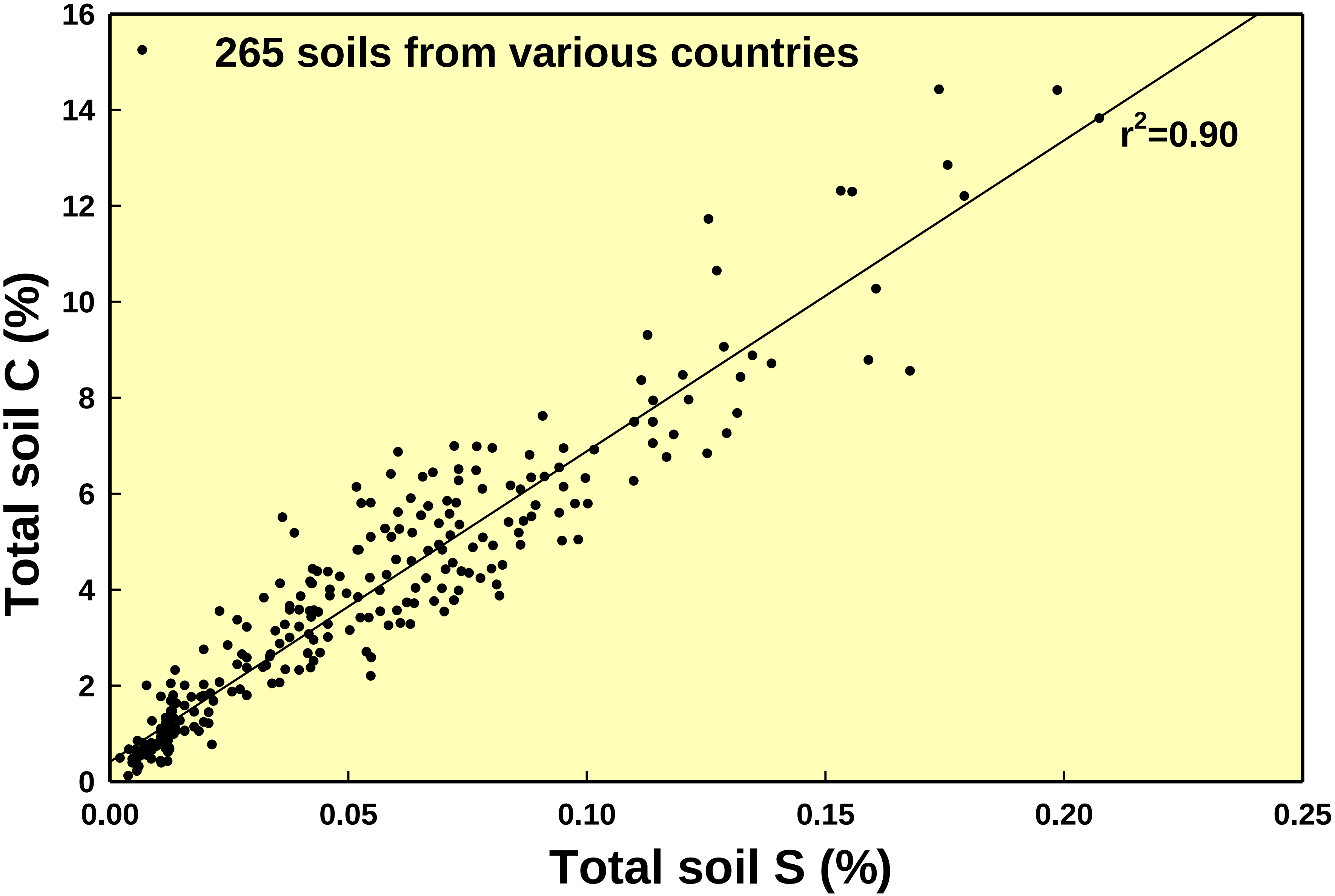


Total soil C:N

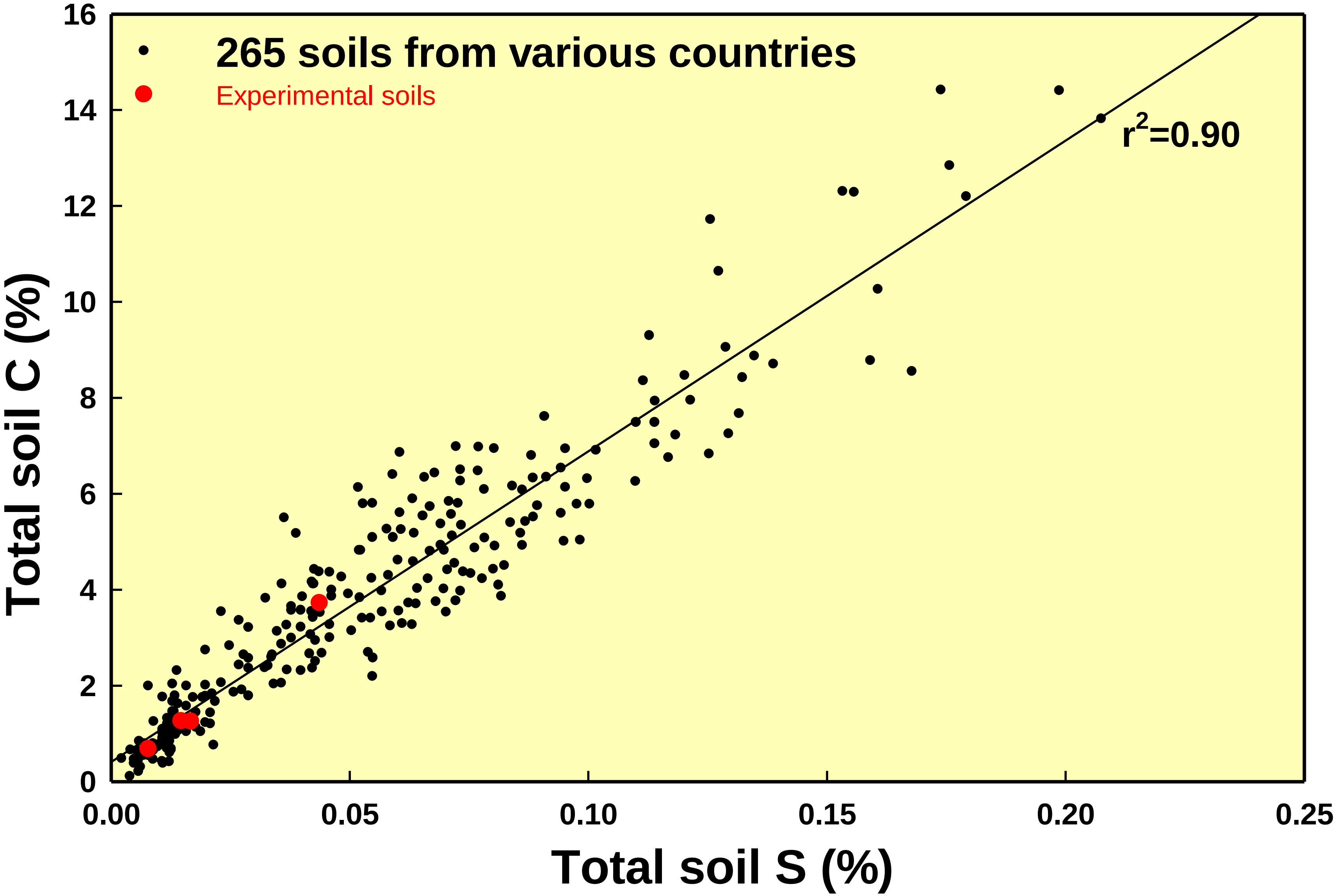


CSIRO

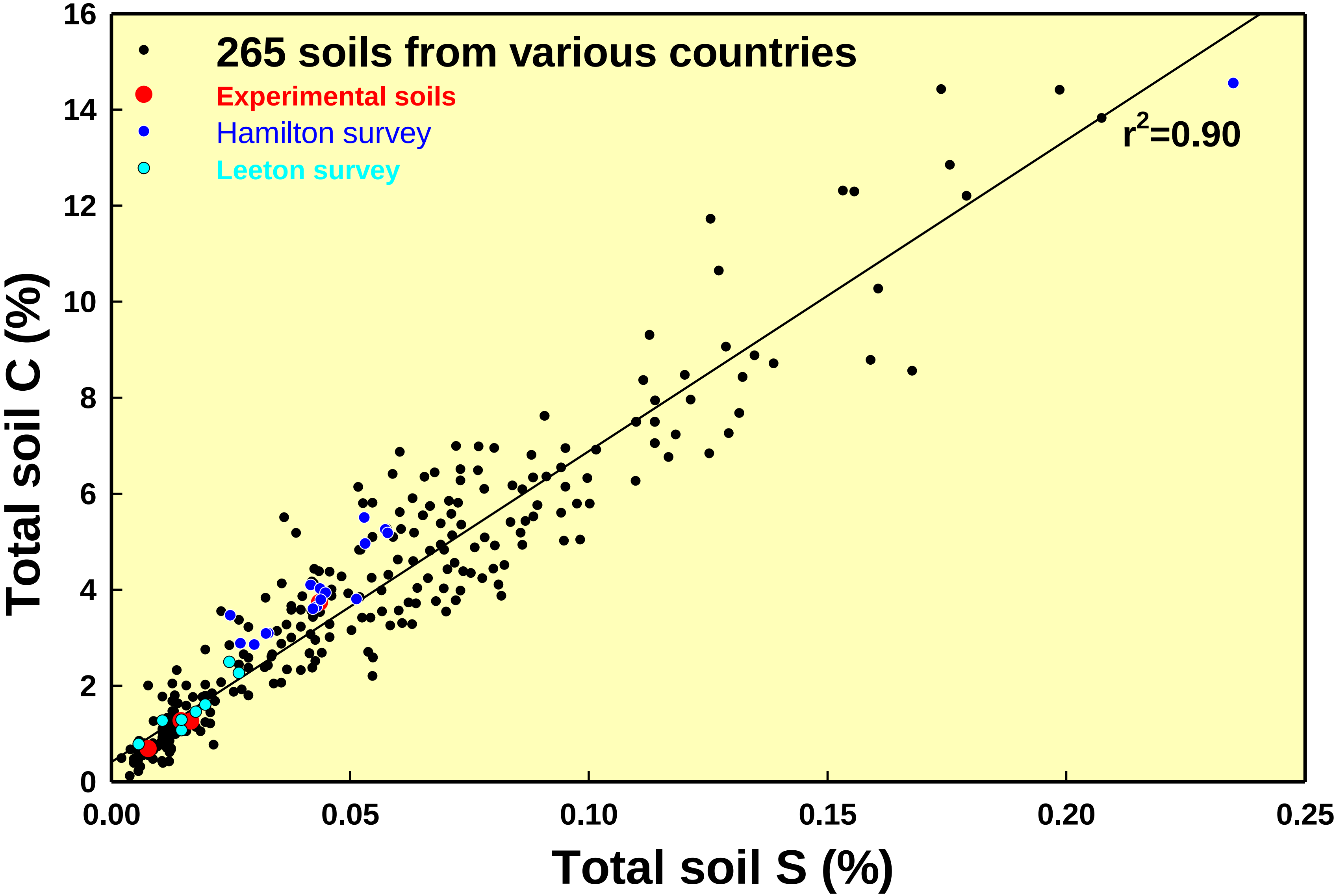
Total soil C:S



Total soil C:S

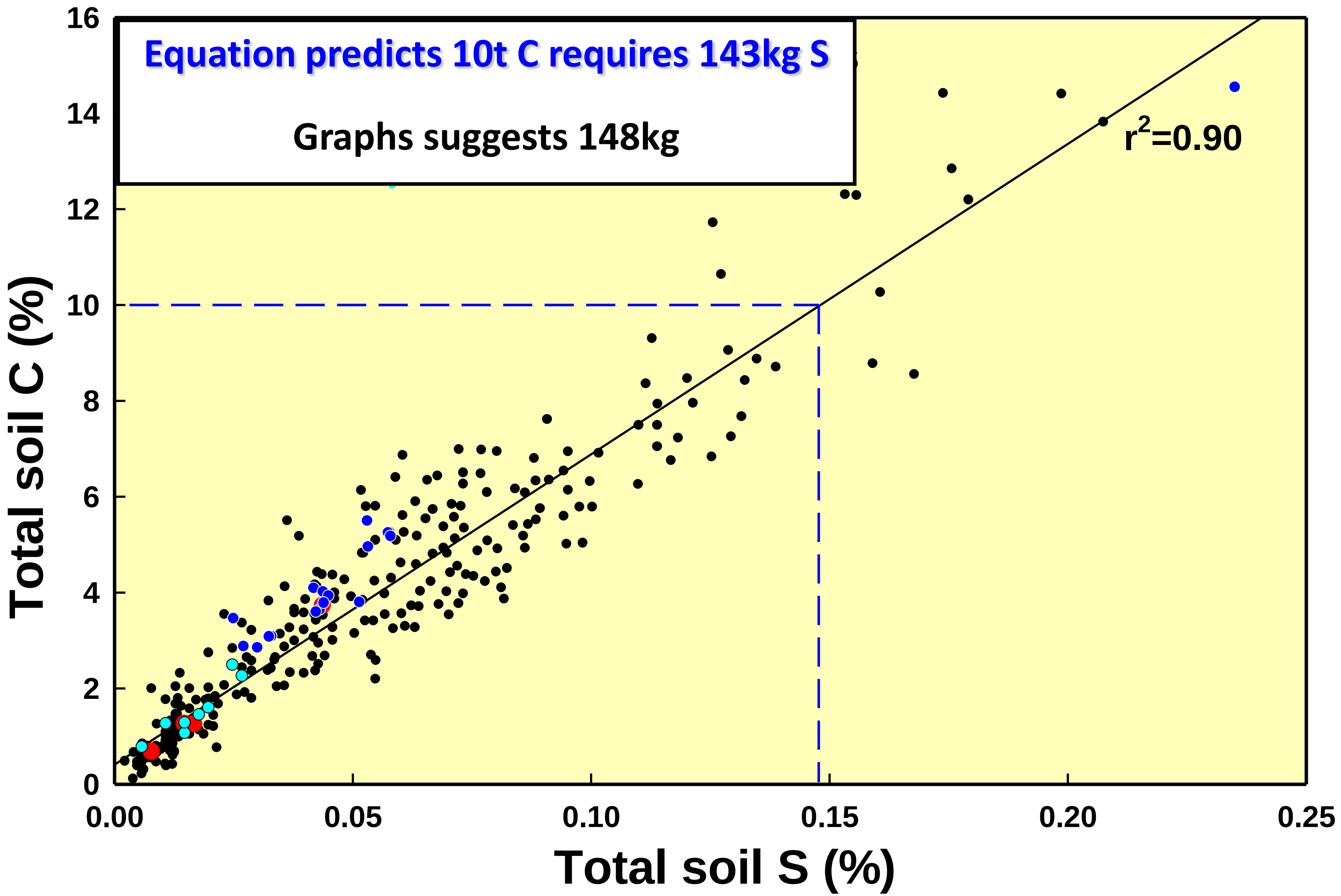


Total soil C:S

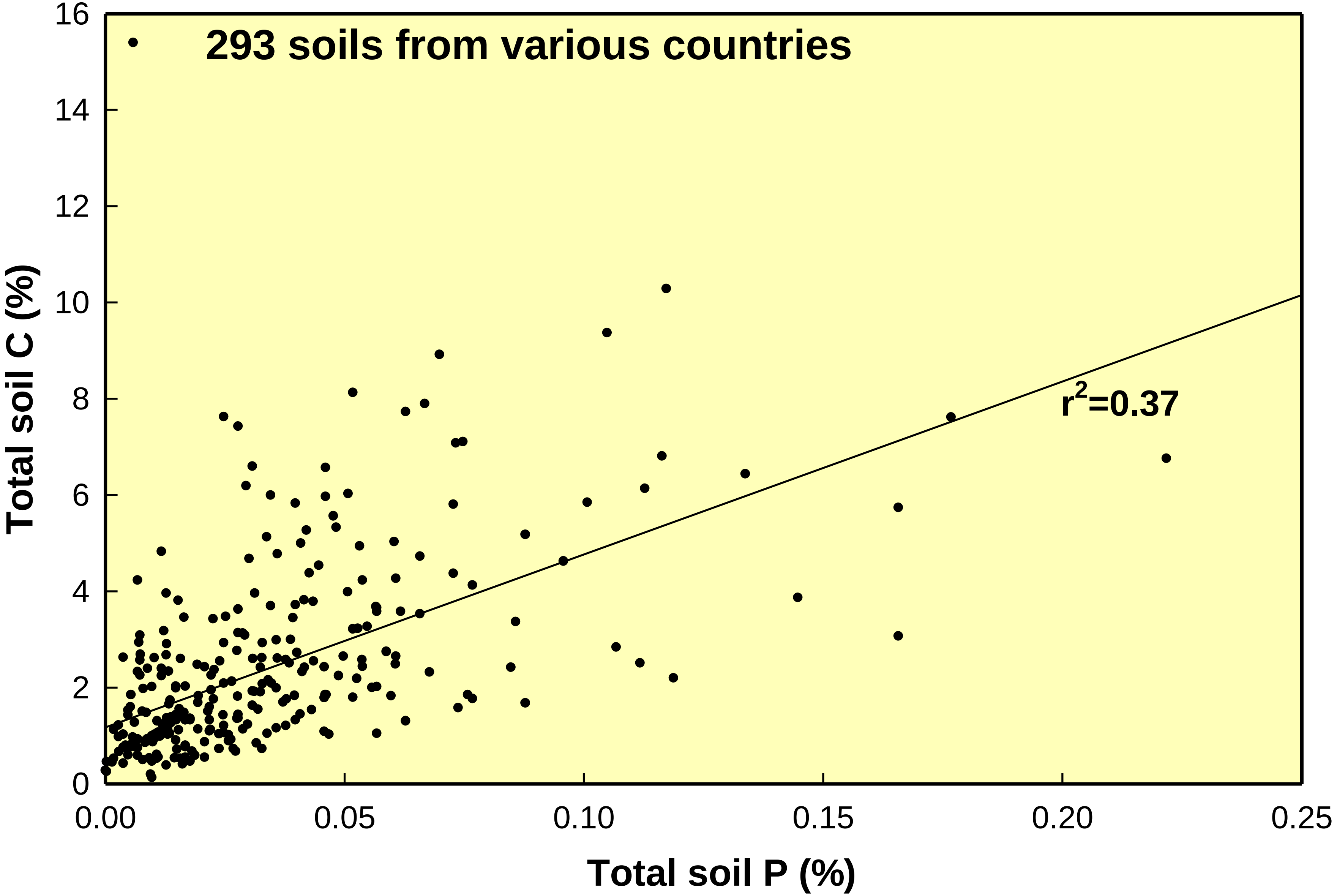


CSIRO

Total soil C:S

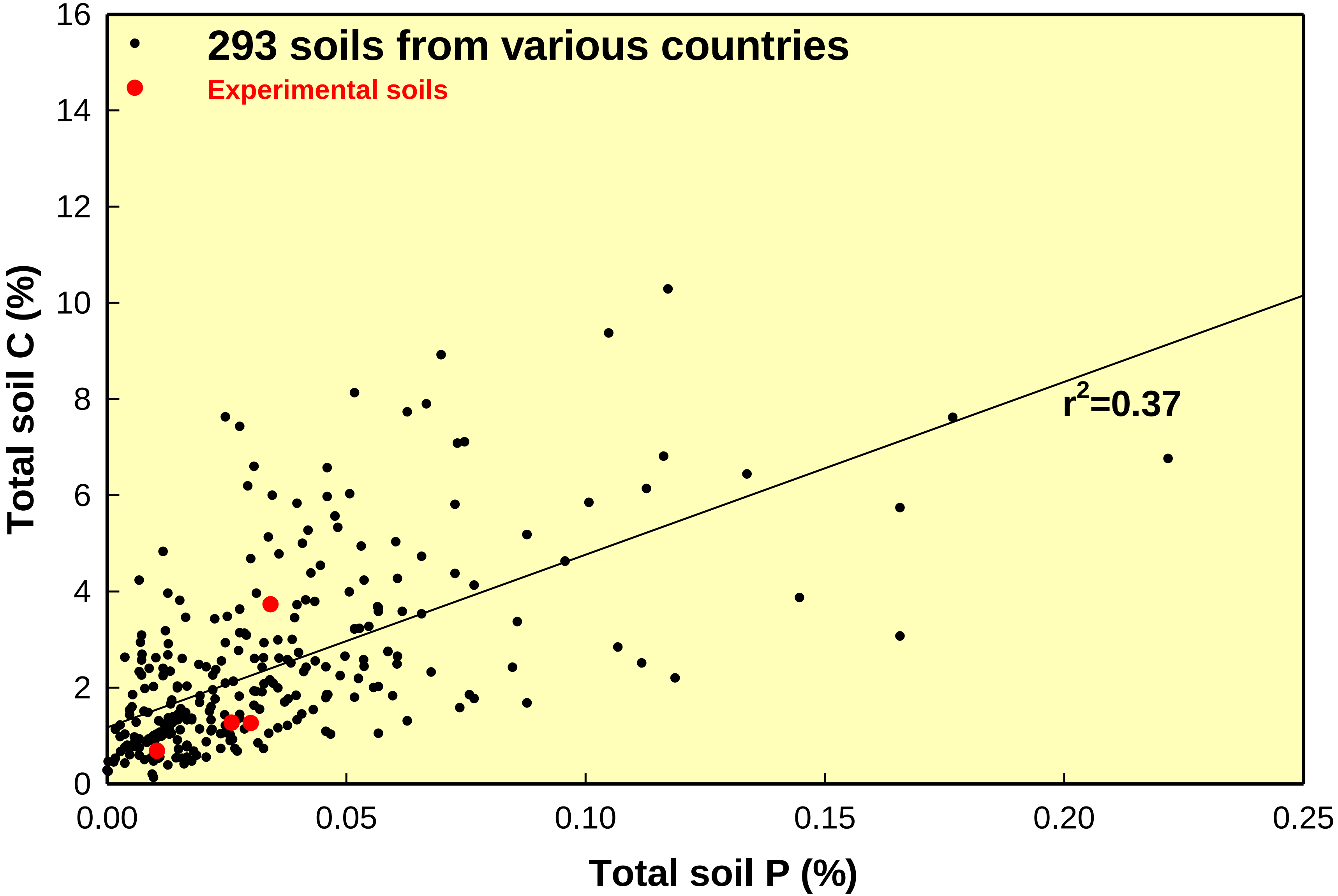


Total C:P



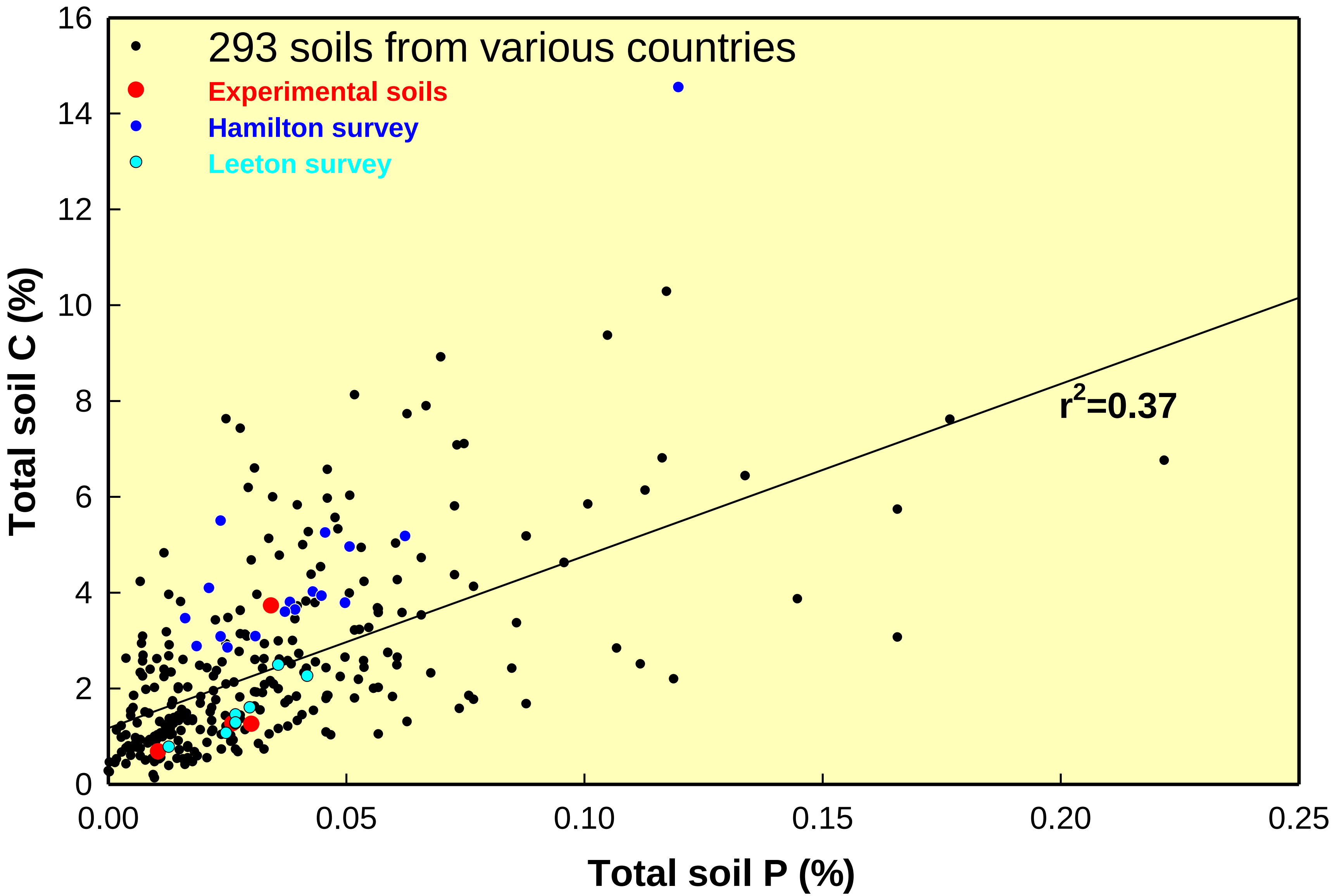
293 soils from various countries
r^2=0.37
Total soil C (%)
Total soil P (%)
0
2
4
6
8
10
12
14
16
0.00
0.05
0.10
0.15
0.20
0.25

Total C:P



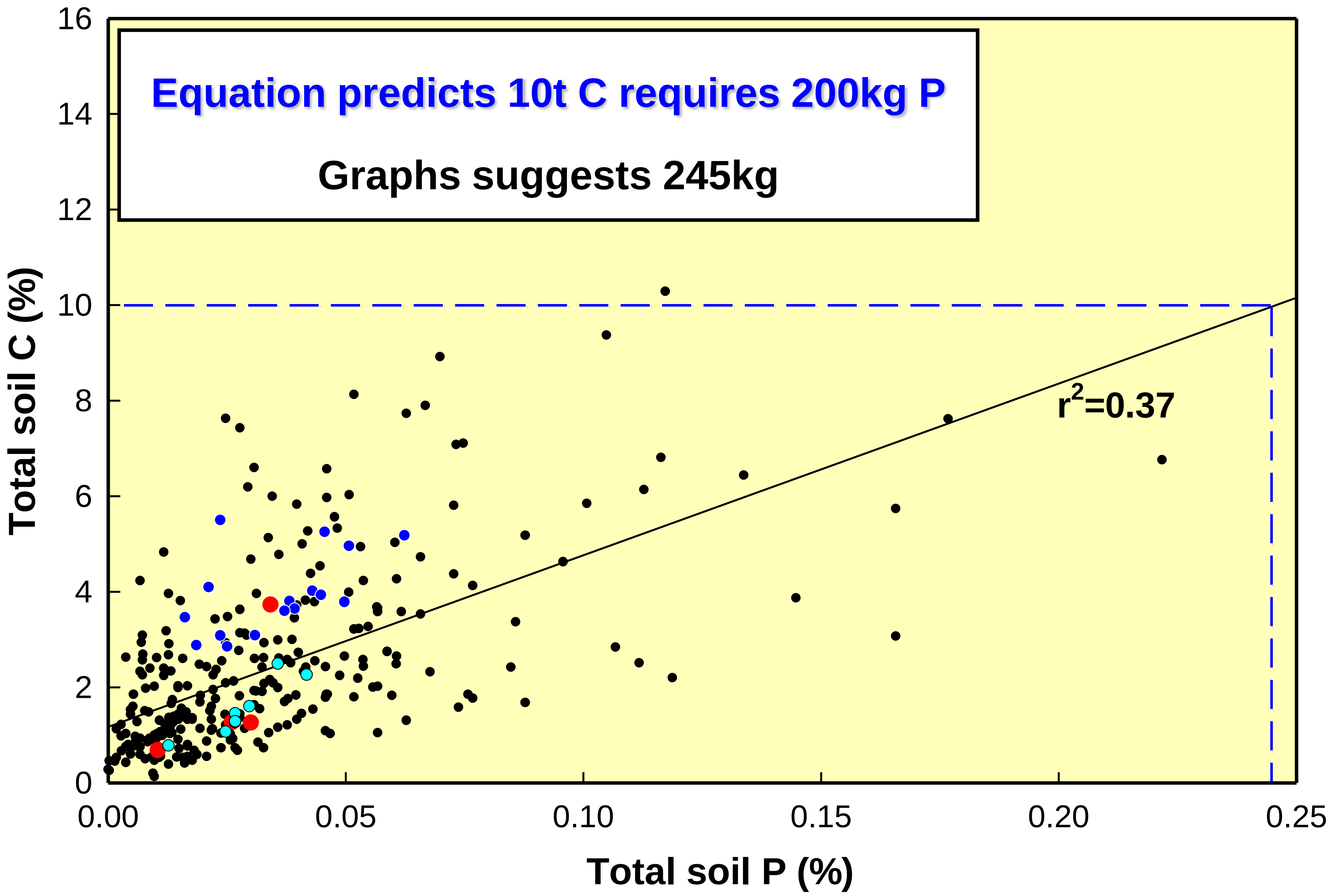
CSIRO

Total C:P



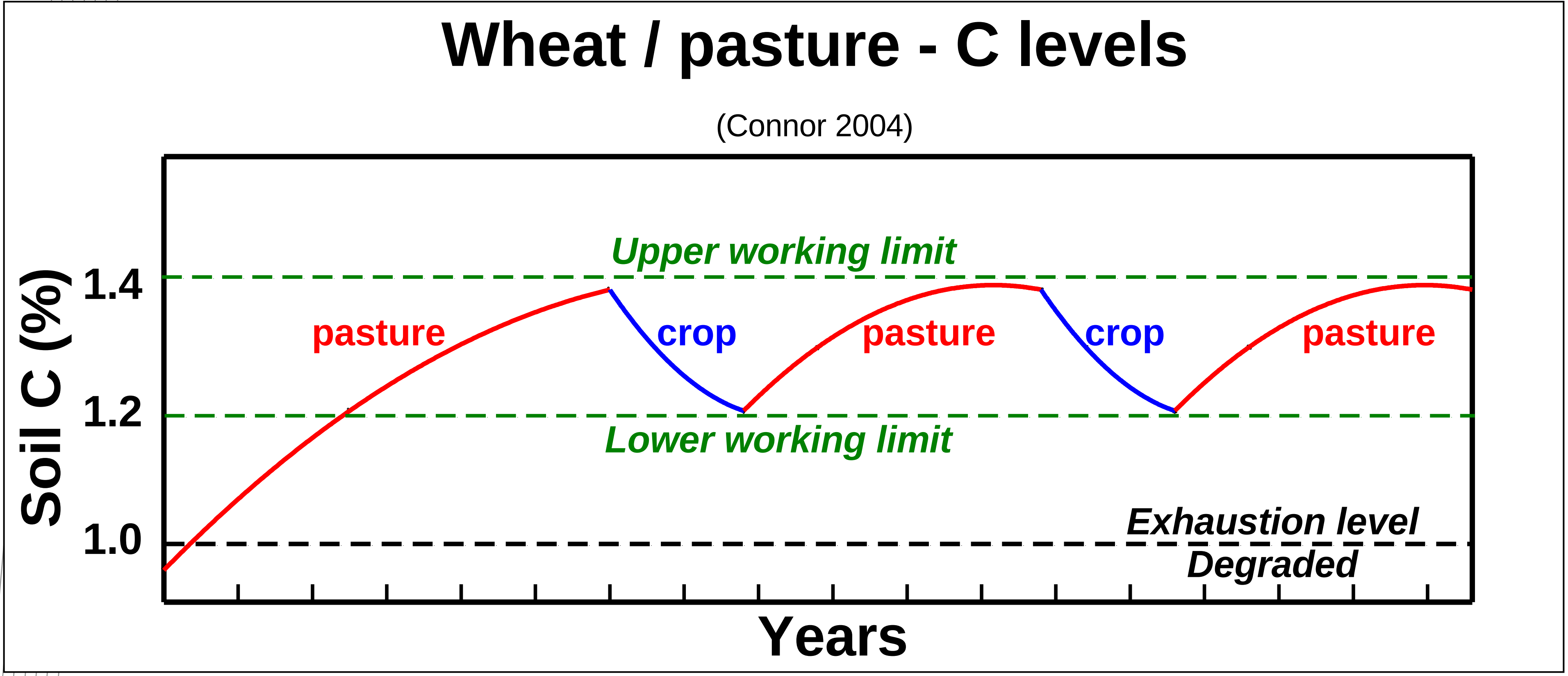
293 soils from various countries
Experimental soils
Hamilton survey
Leeton survey
r^2=0.37
Total soil C (%)
Total soil P (%)
0
2
4
6
8
10
12
14
16
0.00
0.05
0.10
0.15
0.20
0.25

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

CSIRO

%C %N C:N ratio

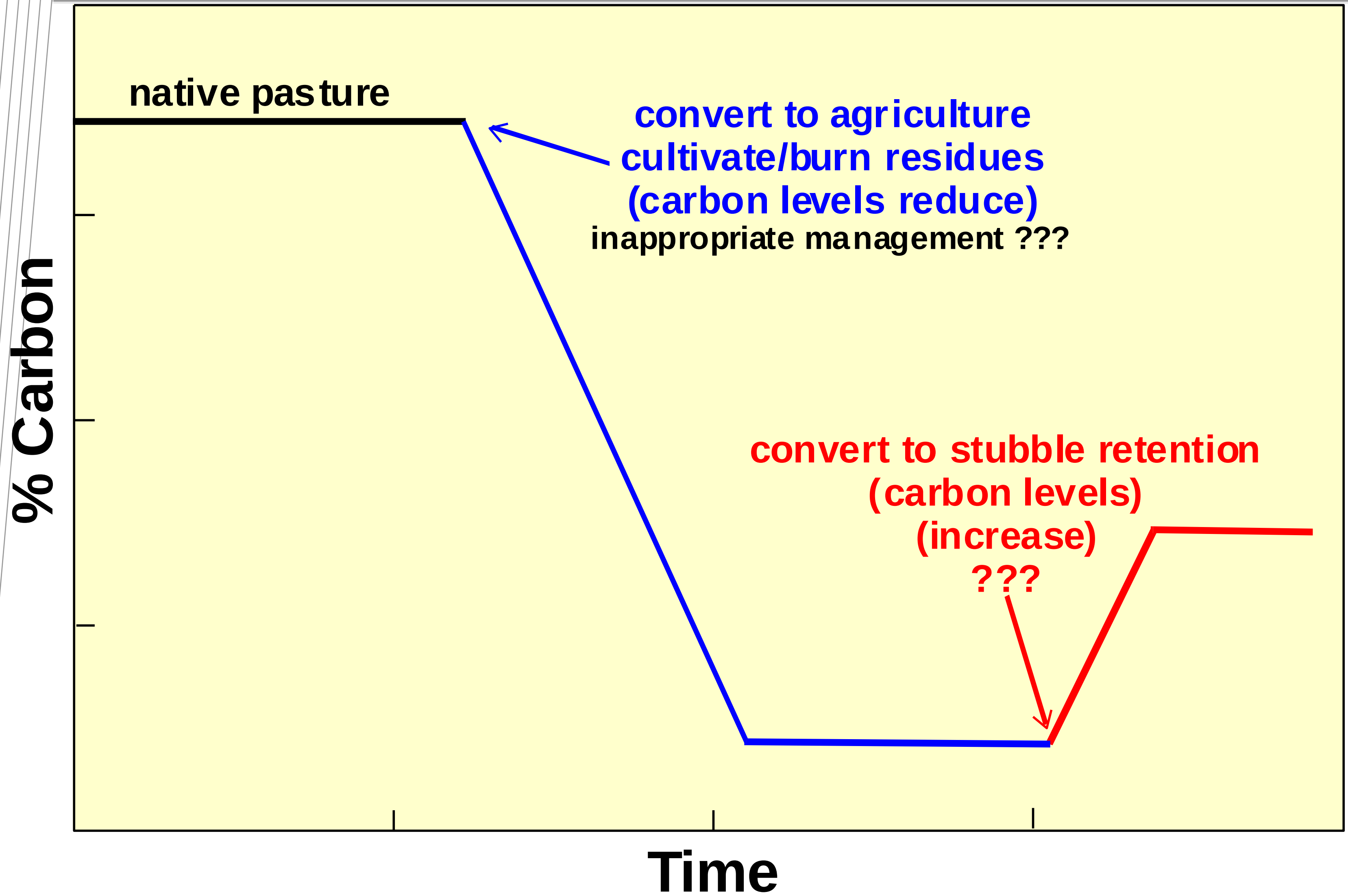
For virgin, pasture or continuous crop

("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

CSIRO

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

CSIRO

Crop vs Adjacent Virgin soil