Soil carbon, soil sampling and site characterisation

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Global carbon pools

(IPCC 2001; Field and Raupach 2004)

- ~38000 Pg C in the world's oceans.
- ~ 5000 Pg C in the earth's crust as fossil fuel and carbonates,
- ~ 3000 Pg C in the thin layer of soil on the terrestrial landmass,
- ~ 700 Pg C in vegetation growing on this soil, and
- ~ 500 Pg C is currently stored in the atmosphere.

Soil holds the majority of terrestrial ecosystem C

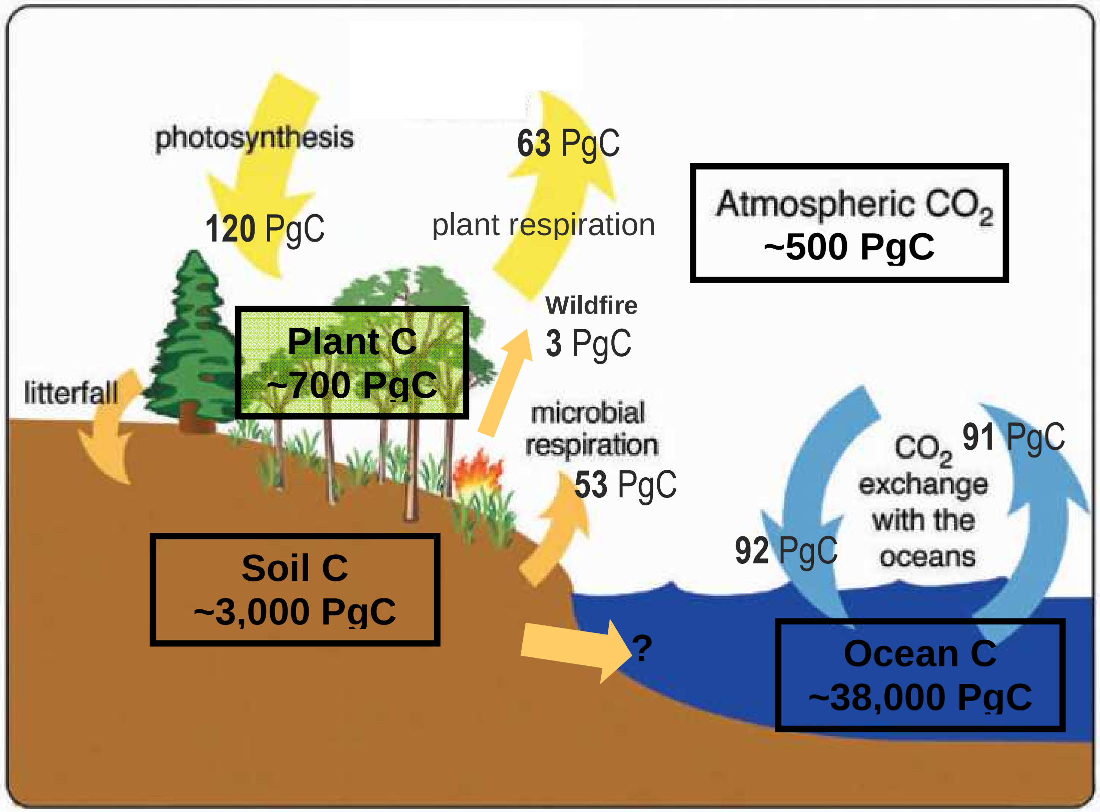
Ecosystem	Area (10^6 km^2)	NPP (PgC y^{-1})	Plant C (PgC)	Soil C (PgC)
Tropical forests	17.5	20.1	340	692
Temperate forests	10.4	7.4	139	262
Boreal forests	13.7	2.4	57	150
Arctic tundra	5.6	0.5	2	144
Mediterranean shrublands	2.8	1.3	17	124
Crops	13.5	3.8	4	248
Tropical savanna & grassland	27.6	13.7	79	345
Temperate grasslands	15.0	5.1	6	172
Deserts	27.7	3.2	10	208
Wetlands	–	–	–	450
Frozen soils	25.5	–	–	400
TOTAL	–	57.5	652	3194

Field and Raupach 2004; Jobbagy and Jackson 2000; Saugier et al. 2001

Soil in the Global C cycle

As a proportion of C pool size, terrestrial vegetation is the most dynamic, closely followed by the soil.

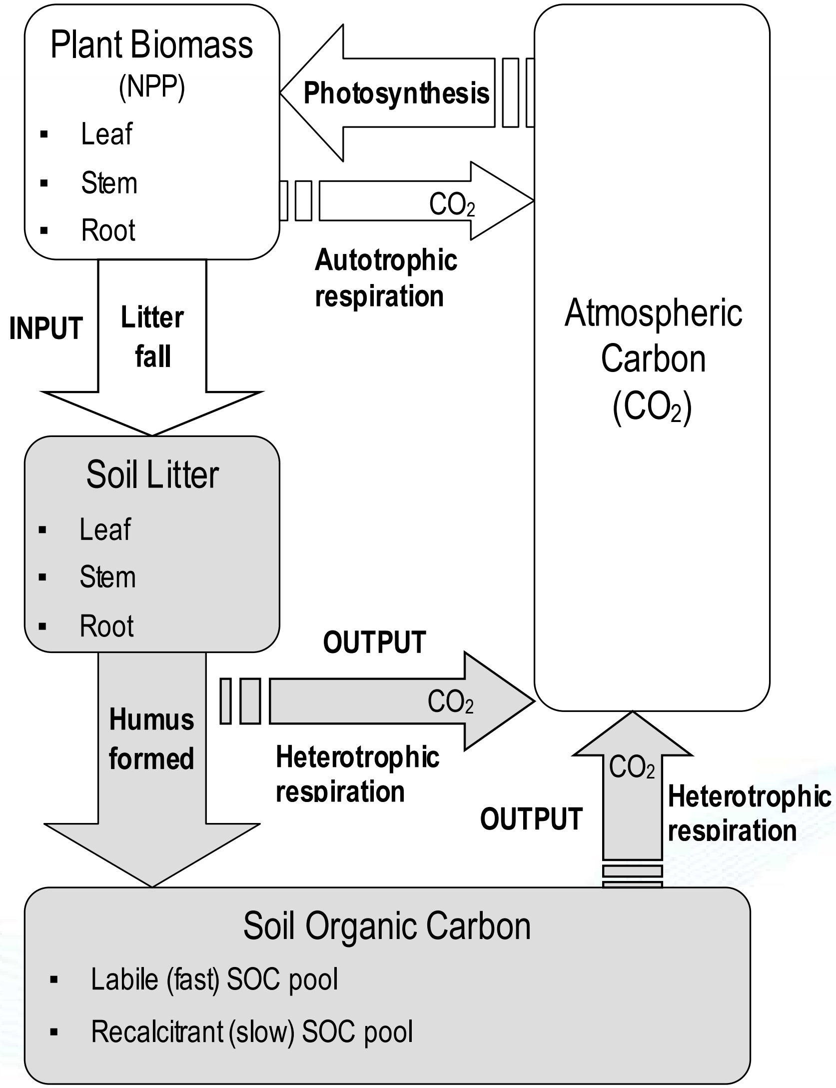
The ocean exchanges only a small proportion of what it holds.



Adapted from (Field and Raupach 2004; Foley et al. 2003).

Balance between C inputs & outputs

The amount of SOC at a point in time is a result of the long-term balance between **INPUTS** and **OUTPUTS**



Other SOC output pathways:

- fire,
- erosion and
- dissolved organic carbon (DOC) loss

BUT, their importance varies and their occur episodically.

Soil characterisation

Soil profile characterisation is performed to enable:

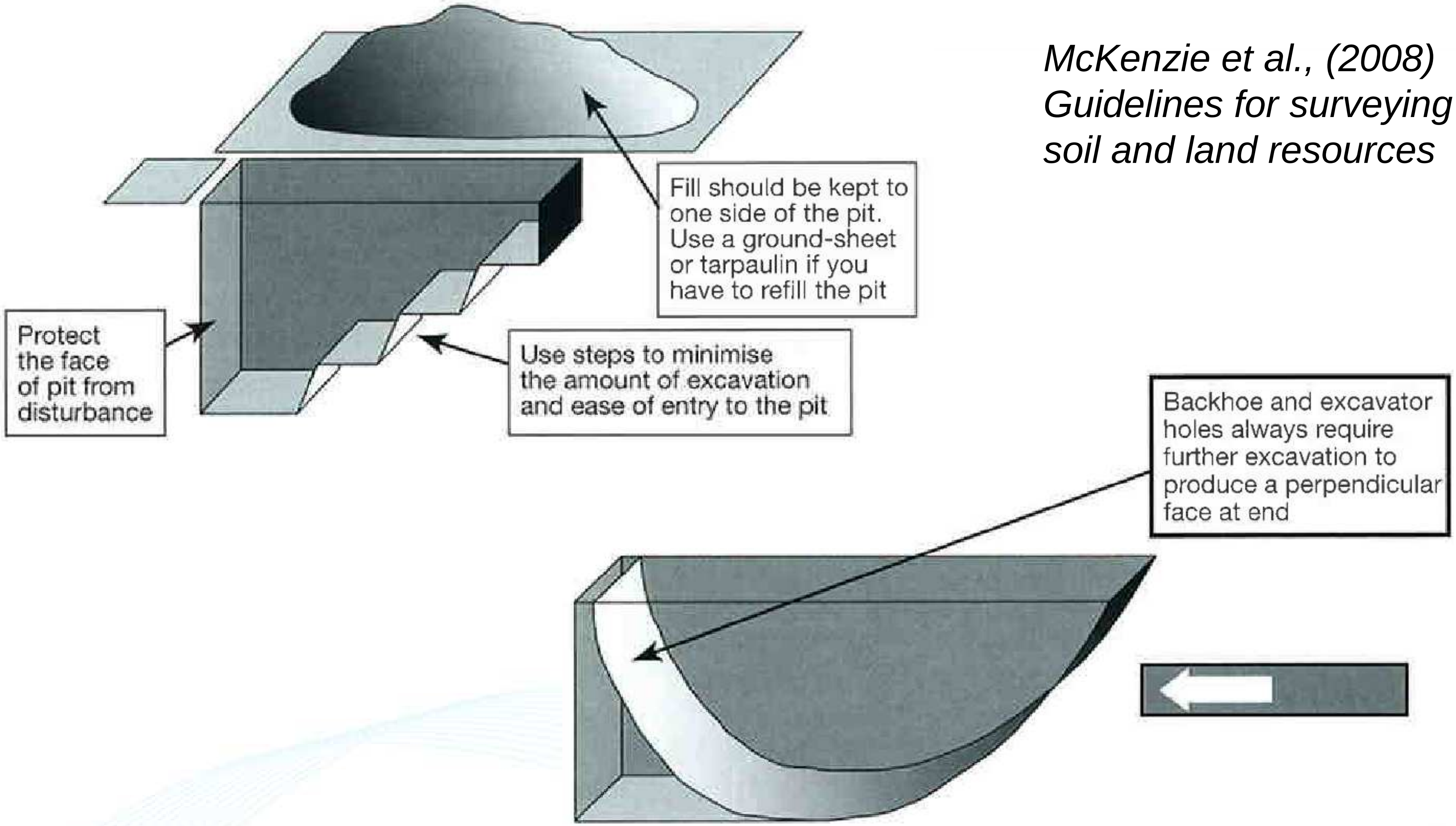
- Selection of appropriate / typical soil type
- Extrapolation to other similar soils
- Stratification within a network of soil plots
- Insight into anomalous results

Variable	Variable
Site	**Chemical properties**
Lithology	pH in CaCl2 and water
Substrate	Organic carbon
Landform element	Exchangeable cations and CEC
Slope	Electrical conductivity
Vegetation structural formation	
Floristics	**Physical properties**
Land use	Particle size distribution
	Bulk density
Morphology	Water retention
Soil horizons	Hydraulic conductivity
Soil texture	Aggregate stability
Colour	
Structure	**Taxonomic class**
Coarse fragment volume	Great group – Aus. Soil classification
Segregations of pedogenic origin	

Source: (McDonald and Isbell 2009; McKenzie et al. 2000; McKenzie et al. 2002b)

Pit soil characterisation

McKenzie et al., (2008) Guidelines for surveying soil and land resources



Sampling for soil change / difference

Statistical thresholds

- Conkling et al. (2002), set a statistical target to detect:
  - a 20% change in the state of Georgia's forest SOC (Mg ha-1)
  - over a 10-year period (2% per annum)
  - to a >80% confidence level
  - with a 33% level of uncertainty (relative error).

- Oliver et al. (2004) set a statistical target to measure:
  - a 10% change in SOC in *Pinus radiata* plantations in New Zealand
  - to a 95% confidence level
  - with 10% level of uncertainty (relative error).

Clearly setting statistical thresholds dictates the number of soil samples required and the type of sampling design required.

Spatial scale and variability (%CV) dictate realistic statistical thresholds

Sampling for soil change / difference

- Forest soils are highly spatially variable due to:
  - parent material,
  - understorey,
  - topography,
  - climate,
  - disturbance events (fire, windthrow, harvesting)
  - time since disturbance,

(Belanger and van Rees 2007; Palmer 2003).

- Too many sampling points wastes time and money.
- Too few sample points leads to a lack statistical certainty.
- Once %CV for SOC has been determined or decided, the level of confidence and acceptable level of uncertainty (relative error) should be calculated.

A 10% level of uncertainty (relative error) is normal in SOC studies:

- as uncertainty at t_1 and t_2 would be greater than possible SOC change.
- a 10% change in SOC represents a huge soil-atmosphere flux of C *(Ellert et al. 2007).*

Minimum sample number required

- The selected level of uncertainty (relative error) is the maximum difference between the observed sample mean and the true population mean and can be calculated from:

$$d = t^2 \frac{s}{\sqrt{n}}$$

where *d* is the relative error,
t is the student factor for a given level of confidence (generally 95%),
s is the CV as a percentage of the mean value, and
n is the sample number *(Belanger and van Rees 2007; Ellert et al. 2007)*

- Rearranged this can determine the number of samples required (n_{req}) to provide estimates to a level of confidence and uncertainty (relative error):

$$n_{req} = \frac{t^2 s^2}{(d \times mean)^2}$$

Sampling for soil change / difference

- The number of samples required to estimate a parameter mean to a specified level of confidence and uncertainty (error) for given %CV

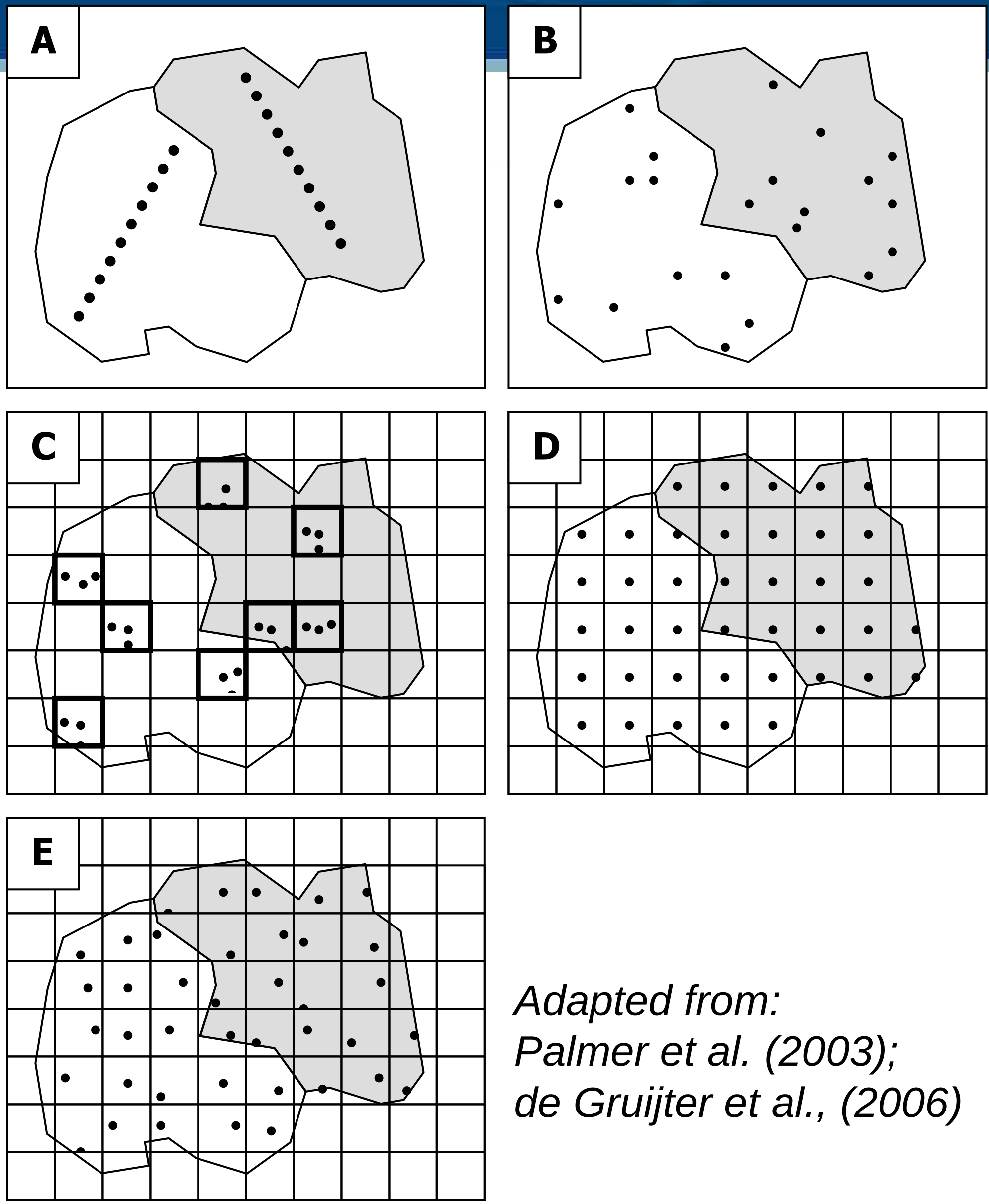
Confidence level	Relative error (d_r) (uncertainty)	% Coefficient of variation (CV)					
		10	20	40	50	100	150
0.80	0.10	2	7	27	42	161	370
	0.25			6	7	27	60
	0.50				2	7	15
	1.00					2	4
0.90	0.10	2	12	45	70	271	609
	0.25			9	12	45	92
	0.50				2	13	26
	1.00					2	8
0.95	0.10	4	17	63	97	385	865
	0.25			12	17	62	139
	0.50				4	16	35
	1.00					9	16

Adapted from Gilbert (1987)

Soil sampling designs

Sampling designs can be:
- transects (A),
- random stratified (B),
- multistage random stratified (C)
- systematic square grids (D)
- systematic grids with random placement (E).

Each sample design shown has stratification into two sub-populations (grey and white).



Adapted from:
Palmer et al. (2003);
de Gruijter et al., (2006)

Sampling for soil change / difference

Soil C sampling should attempt to separate temporal changes in SOC from the inherent spatial variation in SOC –

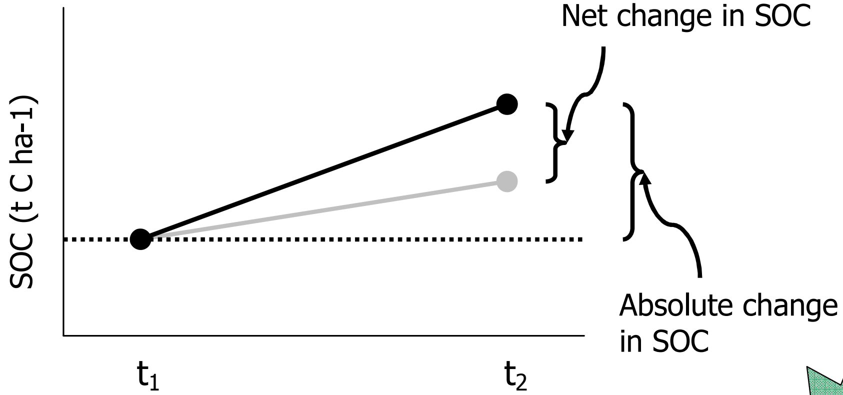
> "Precisely measuring temporal changes in SOC depends on identifying or minimising spatial changes" (Ellert et al. 2007).

There are however several variability or error factors that can mask the detection of real soil C differences or changes (Palmer 2003) :

- *Spatial variability* – ability to sample the same soil twice or more
- *Temporal variability* – episodic change in soil in response to events
- *Measurement variability*
  - sample collection errors
  - sample processing errors
  - sample analysis errors

Coping with soil spatial variability

- **Paired plots** (reference and treatment) e.g. paired native forest and adjacent plantation.

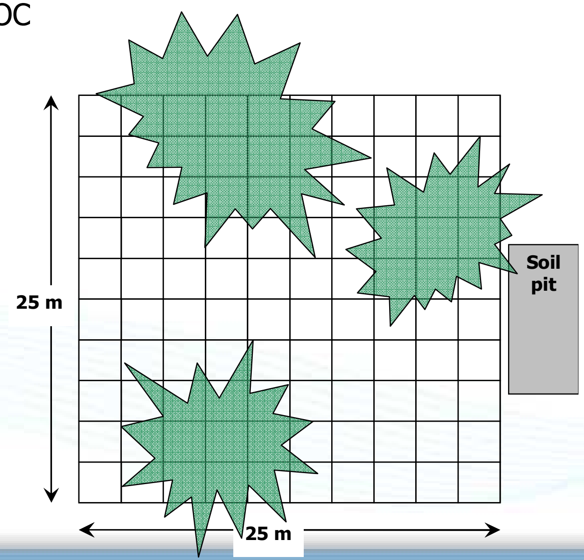


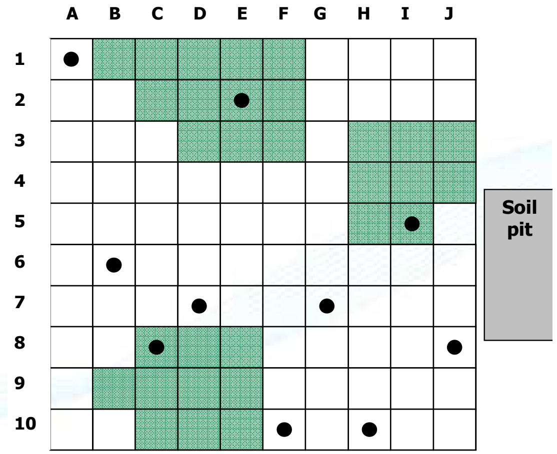
- **Stratification** into sub-populations of lesser variance.

A discontinuous tree canopy ( ) covers 30% (30 of 100, 2.5 x 2.5 m cells).

Three of the ten soil samples should be sampled from cells with >50% tree canopy cover.

Adapted from Wilson et al. (2007)

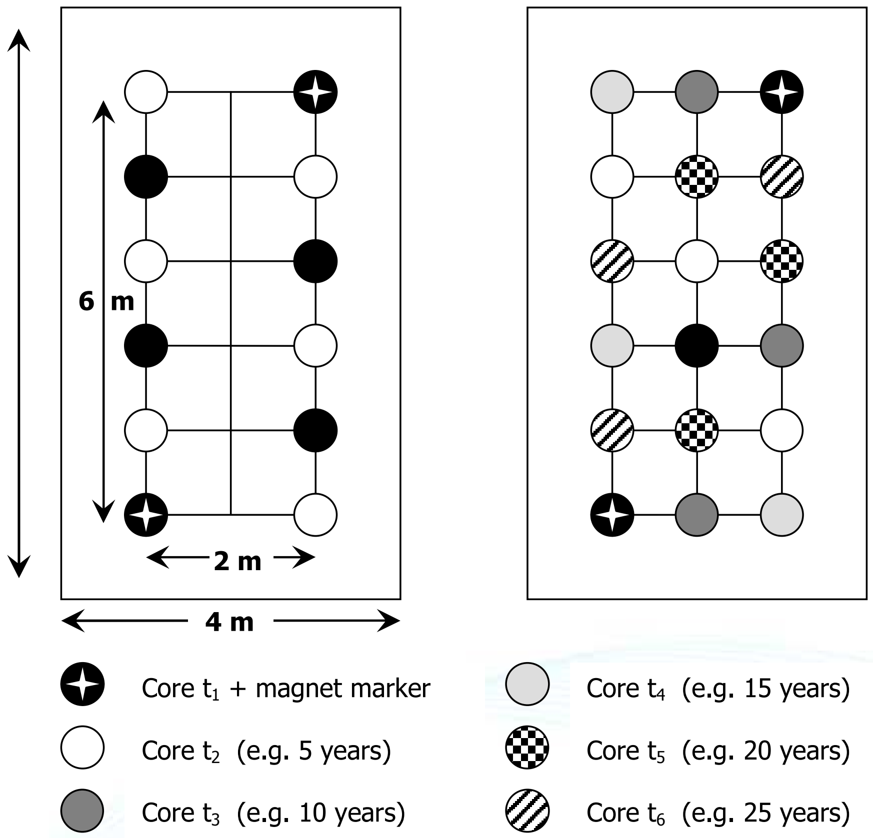




Coping with soil spatial variability

- **Paired re-sampling**

Based on Ellert et al. (2001)



- **Composite sampling**

  Bulking 15 samples can provide estimates of the mean to within 1 SD of the mean value when kept separate *(Carter and Lowe 1986).*

- Composite sampling reduces costs.
- Composite sampling prevents calculation of within plot variability (SD or %CV) of plot mean value.

Coping with temporal variability

- Seasonal variation in SOC may occur due to:
  - litterfall,
  - fine root growth/turnover,
  - plant nutrient uptake,
  - microbial activity

  in response to temperature and moisture.

- Soil sample collection should be timed to occur under comparable environmental conditions.
- In Australia, this is often winter as this is the time of minimal biological activity and soil is most easy to sample

Coping with measurement variability

Factors contributing to measurement variability *(Palmer 2003):*

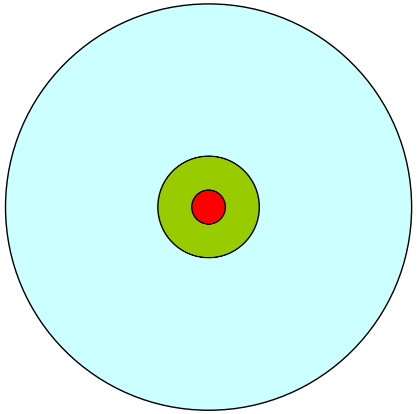
- Inaccurate separation of surface organic and mineral inorganic layers
- Inaccurate sampling of depth layers
- Compaction of soil cores for bulk density calculation
- Contamination between samples during collection or preparation
- Inadequate homogenisation of composites before sub-sampling
- Inadequate grinding
- Baseline noise or drift of analytical equipment
- Inappropriate selection of standards for calibration or drift

Measurement variability can be minimised by:

- establishing and adhering to strict and detailed protocols
- intensive training (preferably one field team and one laboratory team)
- performing regular and random checks for adherence to protocol and QC

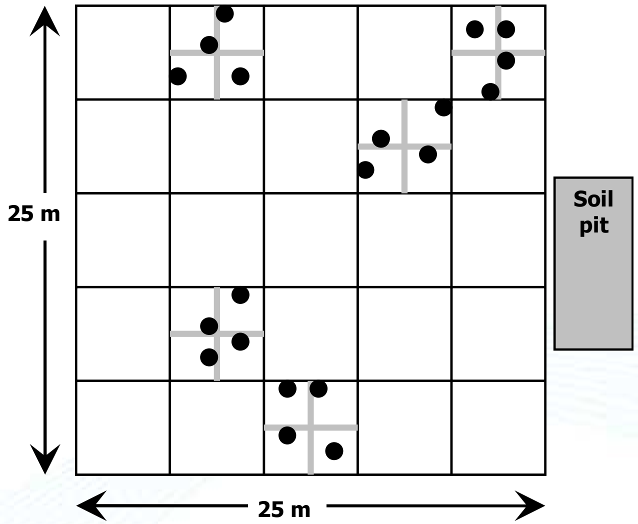
Soil sampling plots

UK / Euro

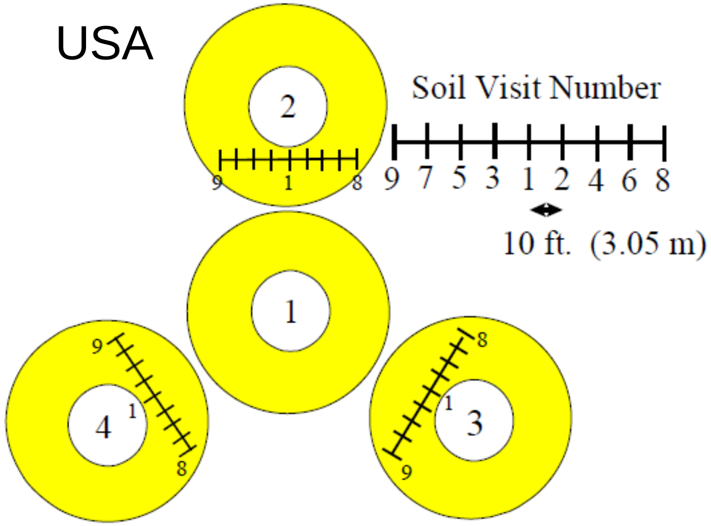


Unit	Shape	Radius / Area
Subplot 1	Circle	3.09 m / 30 m^2
Subplot 2	Circle	11.28 m / 400 m^2
Subplot 3	Circle	25.24 m / 2000 m^2

Australia



USA



Measuring SOC

Forest soil carbon should be separated into (Hoover 2003):

1. forest floor organic carbon, and
2. mineral soil organic carbon

Forest floor organic carbon *(Currie et al. 2003)*

- The forest floor is the organic (O) horizon, consisting of:
  - Litter layer (L) of relatively undecomposed material (alt: fibric)
  - Fragmented (F) and partially decomposed litter (alt: hemic)
  - Humus layer (H) of non-fibrous, dark organics (alt: sapric)

- Surface organic matter > 25 mm in diameter is coarse woody debris (CWD)
- Surface organic matter < 25 mm and > 2 mm is surface litter *(McKenzie et al. 2000):*

Measuring SOC

Mineral soil can contain both organic and inorganic forms of C.

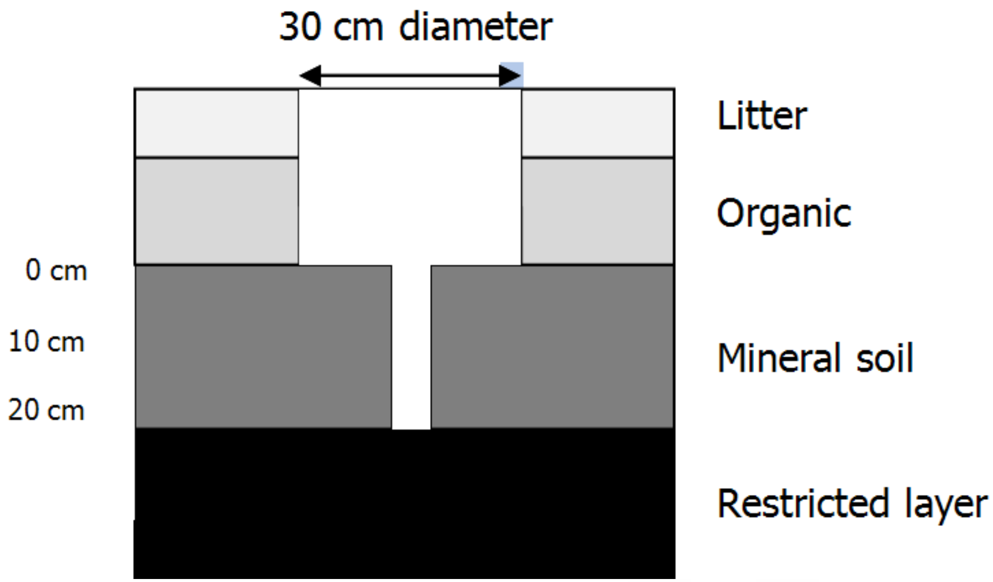
- Soil inorganic C is generally in the form of carbonate ($CaCO_3$) derived from parent materials such as limestone.
- Soil organic carbon (SOC) is the dominant form of carbon in most soils in the upper 100 cm of the profile *(Jobbagy and Jackson 2000).*

- Inorganic C can be removed before analysis using weak acid.

Soil organic matter (SOM) and soil organic carbon (SOC)

- C is the main constituent of SOM, being 48 – 60% of SOM mass *(Rosell et al. 2001).*
- SOC is directly quantified and SOM mass can be estimated using a conversion factor.

Measuring SOC

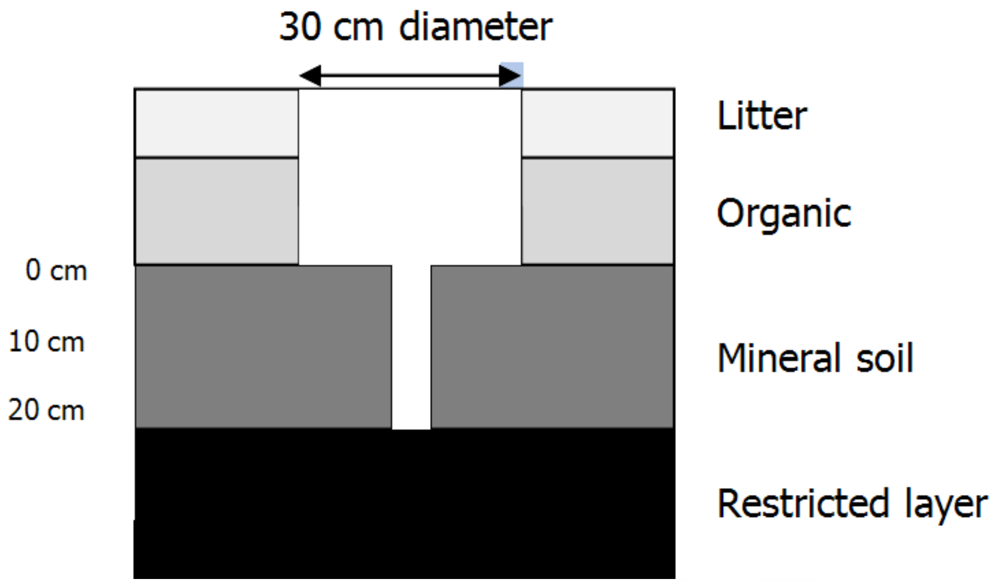


Forest floor organic and mineral soil sampling in the Enhanced US FIA monitoring framework. Source: (Bechtold and Patterson 2005)

Forest floor C density (kg C m^{-2}) measured using:

- collecting a fresh sample from a known surface area, 30 cm Ø = 0.07 m^2
- separate and discard CWD (>25mm Ø)
- sub-sample and oven dry for moisture content,
- determine mass C per unit area on dry weight basis (kg C m^{-2})

Measuring SOC



Forest floor organic and mineral soil sampling in the Enhanced US FIA monitoring framework. Source: (Bechtold and Patterson 2005)

Mineral SOC density (kg C m^{-2}) measured using:

- volumetric cores (50-100 cm Ø) at pre-determined depths.
- soil air-dried, homogenised and sieved (2.0 mm) for archiving,
- sub-sample (<2.0 mm) analysed for soil C concentration.
- Bulk density (g cm^{-3}) and volume coarse stones (>2 mm) needed for calculation

The importance of bulk density

The importance of accurate bulk density cannot be underestimated,

(Lal and Kimble 2001; Page-Dumroese et al. 1999).

Difficult to accurately measure dry soil bulk density in soils with:

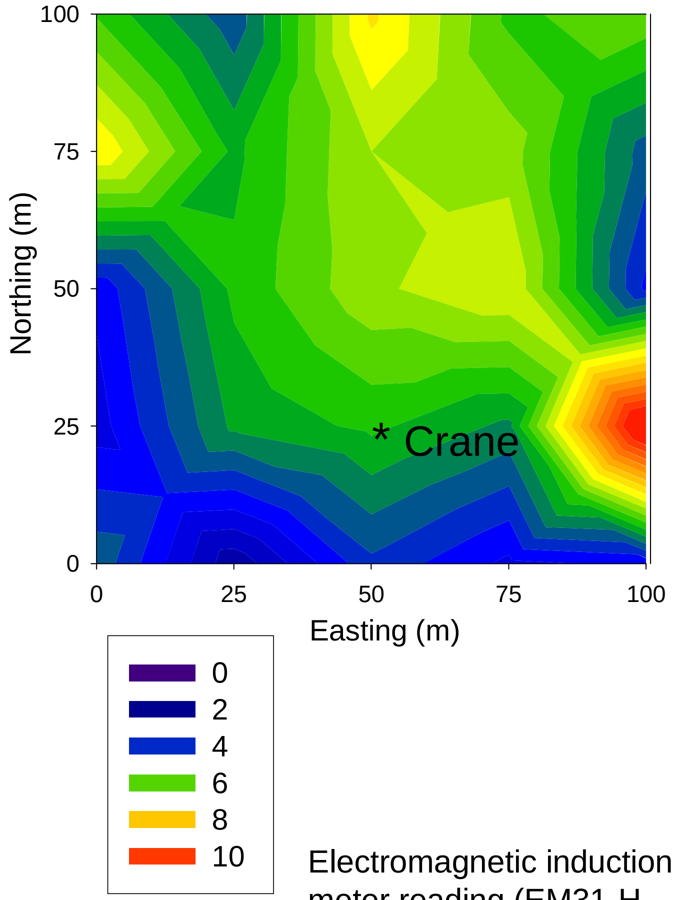
- large rock/stone fractions,
- high organic matter,
- tendency to crack,
- waterlogged or
- sandy.

The pit excavation method may be necessary in such circumstance.

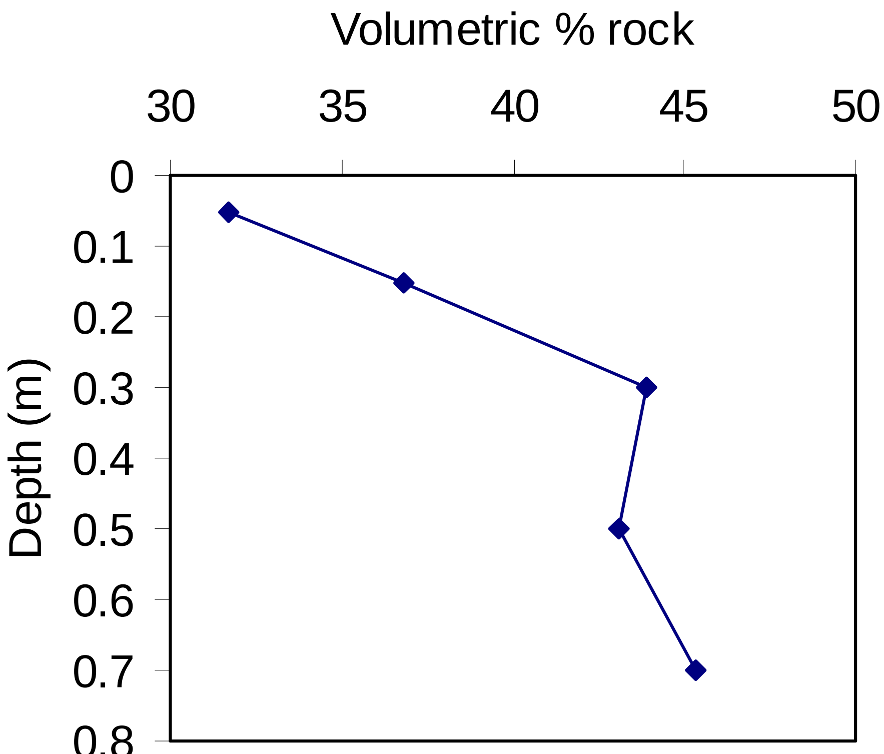
- Excavate a large volume to a set depth, replace with a quantified mass (i.e. volume) or air-dry sand, separate and weigh stones (>2 mm).

SUB-SURFACE CHARACTER

Soil vs rock volume



Electromagnetic induction meter reading (EM31-H, mS/m)



Pit at litter trap 2

The importance of bulk density

A change in bulk density can appear like an increase or decrease in SOC

A field is sampled to 15 cm before and after ploughing.

- Before ploughing, a SOC conc. of 20 g kg^{-1} and BD of 1.6 g cm^{-3}
  - soil C density of 48 t C ha^{-1} to 15 cm.
  -
- After ploughing, a SOC conc. of 20 g kg^{-1} and BD of 1.2 g cm^{-3}
  - soil C density of 36 t C ha^{-1} to 15 cm, an apparent loss of 25% SOC

- The same can occur with forest fire, afforestation, forest harvests.

An **equivalent soil mass** approach is the answer *Ellert et al., (2001 & 2007)*