Soil compaction – Sandra Eady

- Soil compaction is the decrease in soil volume, in particular the air-filled fraction. It can be expressed by bulk density, pore volume, porosity, void ratio or soil strength.
- Soil compaction alters soil structure, limits water and air infiltration and impedes root penetration. Hence, it is an important consideration for soil function and good plant growth.
- Quantifying soil compaction would encompass gathering information on types and dates of field operations, machine mass and tyre width, the surface area affected and soil characteristics (water content, bulk density, soil texture, plastic limit of the soil, below cultivation depth, zero tillage, controlled traffic which purposely compacts, can increase n2O emissions, SOM not a good indicator, some get rid of livestock to get rid of compaction, industry specific like for cotton, horticulture row traffic.).

Source: Garrigues et al. 2013. Development of a soil compaction indicator in life cycle assessment. International J Life Cycle Assessment 18:1316.

Soil compaction – Sandra Eady

- Quantifying soil compaction would encompass gathering information on types and dates of field operations, machine mass and tyre width, the surface area affected and soil characteristics (water content, bulk density, soil texture).
- It is likely to need models of soil water and bulk density e.g. APSIM for soil water, COMPSOIL bulk density every 5 cm from 0 to 50 cm deep. Other models? International consistency?
- It could be regionalised using GIS layers for key data.

Source: Garrigues et al. 2013. Development of a soil compaction indicator in life cycle assessment. International J Life Cycle Assessment 18:1316.

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Soil erosion dynamics proxied by lateral cover

Dr. Adrian Chappell

Life Cycle Assessment workshop; April, 2014

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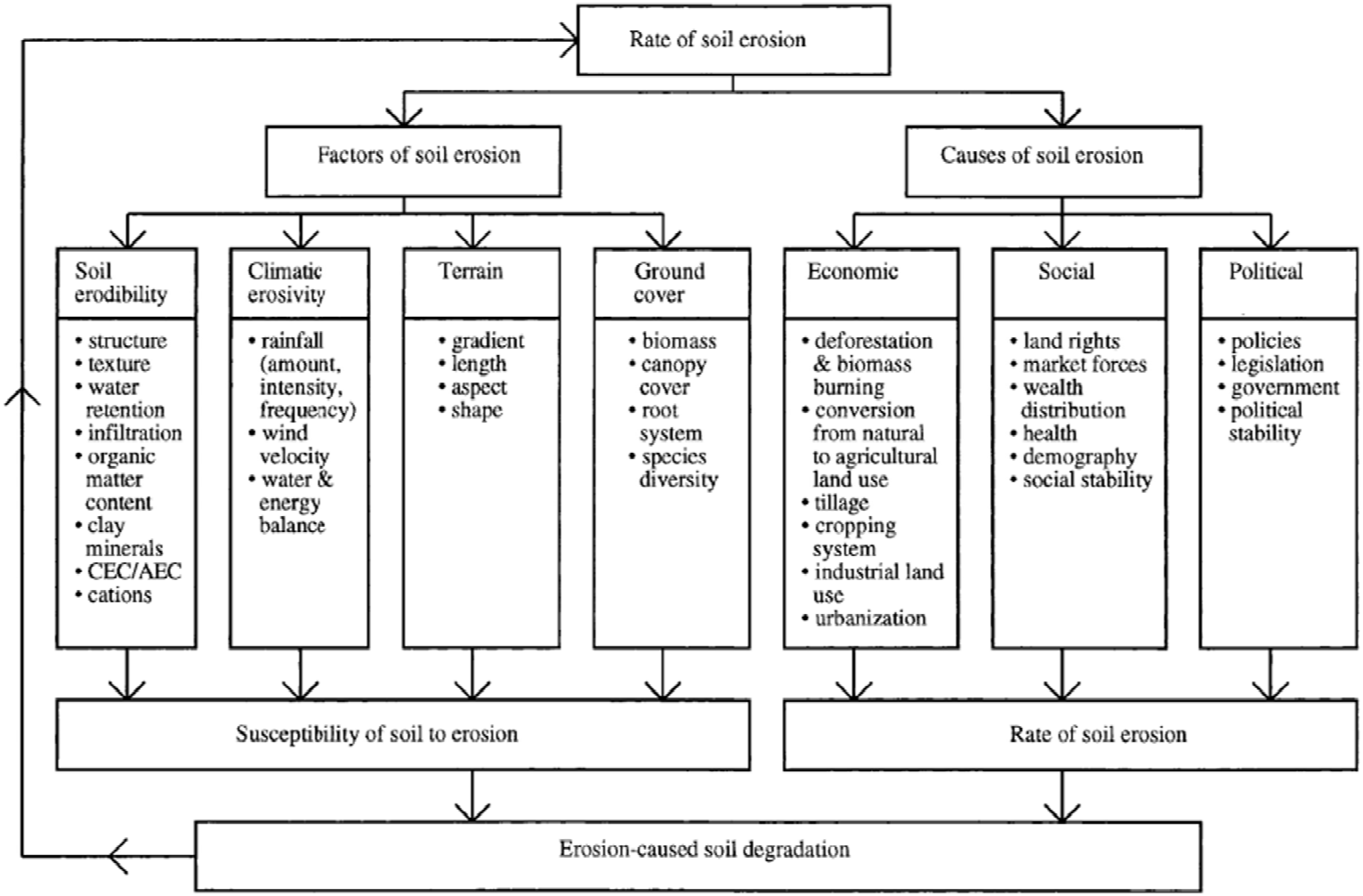
Soil erosion: factors, causes and interactions



Lal (2001) Land Deg & Develop

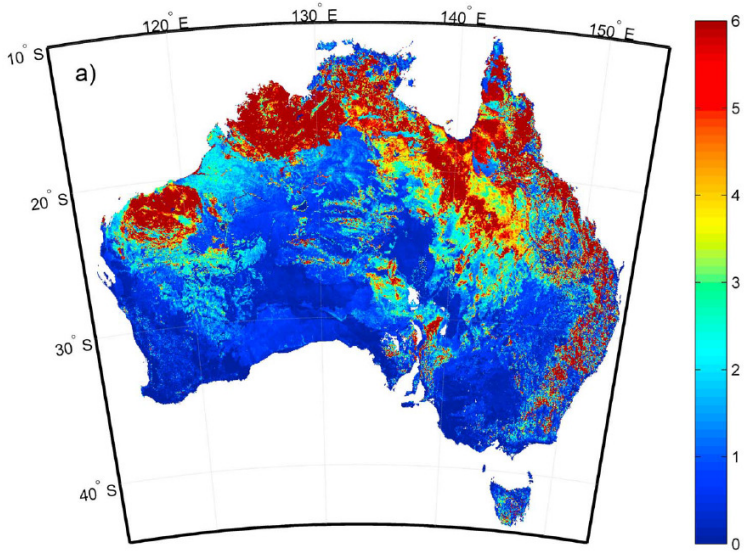
Factors controlling soil erosion

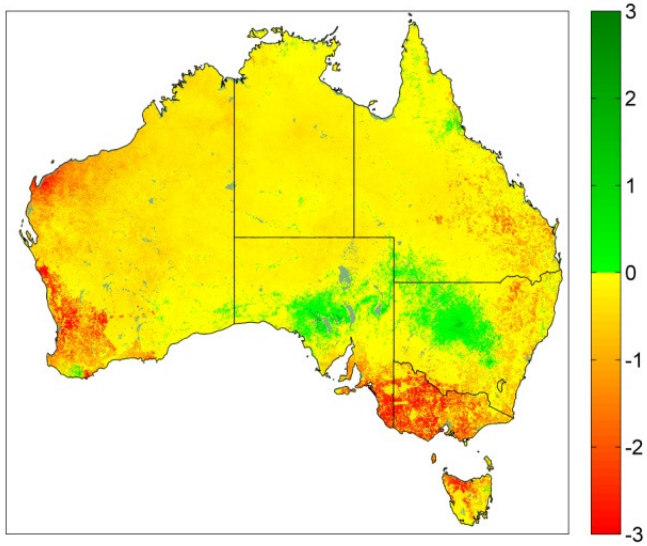
- Universal Soil Loss Equation (USLE)
  - Plot and rainfall simulator experiments;
  - Average annual soil loss (*A*) includes rainfall erosivity (*R*), soil erodibility (*K*), topographic (*L* and *S*) and cropping and management factors (*C* and *P*)
  - $A = RKLSCP$
- Focus on soil erodibility?
  - Index based on soil particle size, OM content, soil structure and profile permeability (Wischmeier)
- Interface between erosivity and erodibility?
  - Aerodynamic / fluid roughness

Australian soil erosion (t ha^{-1} y^{-1})

- Gross (time period unspecified) hillslope water erosion (Lu et al. 2003 AJSR)

- ^{137}Cs-derived net (1950s-1990) soil redistribution (erosion and deposition) by all processes (wind, water and tillage; Chappell et al. 2011 JGR)





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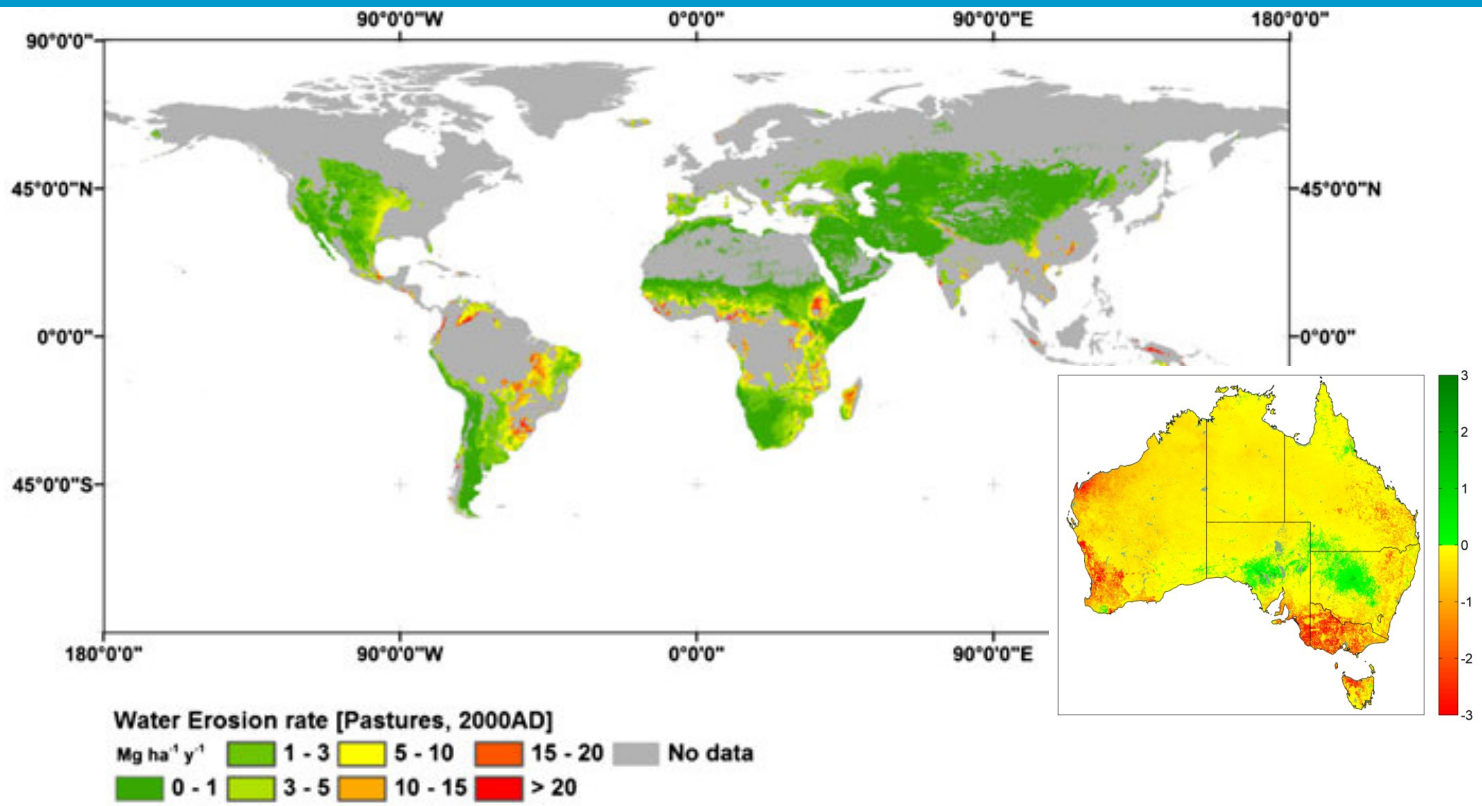
Global soil erosion estimates



- Oceania gross water erosion (year 2000): cropped = 0.3 Pg y^{-1}, pasture = 0.5 Pg y^{-1} (Doetterl et al., 2012)
- Australian net (1950s-1990) soil redistribution (all processes): cropped = 0.079 Pg y^{-1}, rangeland = 0.15 Pg y^{-1}
  - Gross water erosion larger - but pasture / rangeland dominated by wind erosion - similar for wrong reason?

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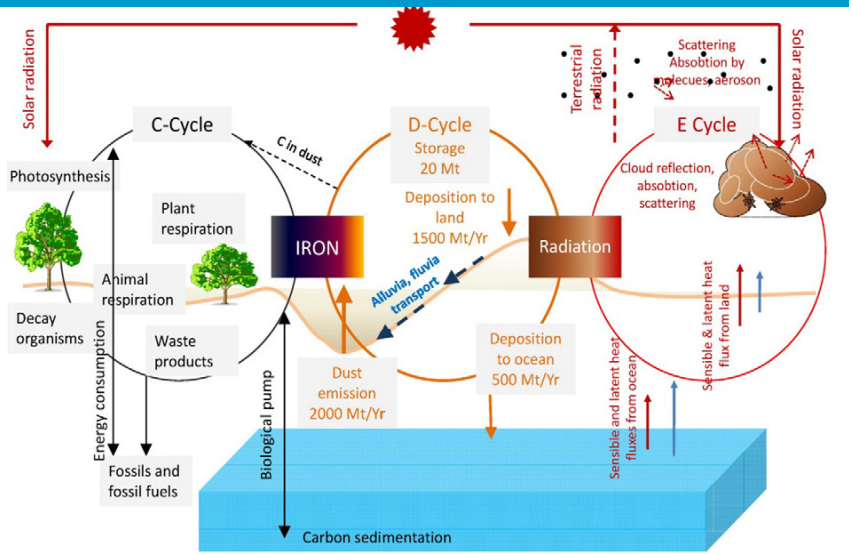
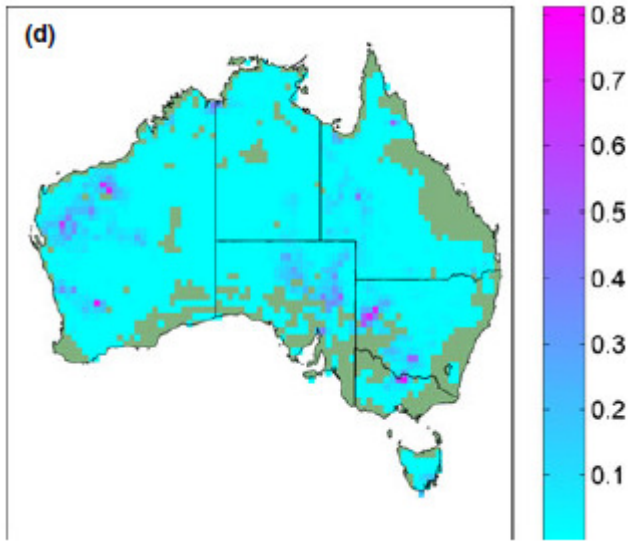
…and wind erosion (dust emission)

- Efficient, selective and rapid 'conveyor' from terrestrial ecosystem of flows.
- Dust cycle interrelated with C and energy cycle



- Australian dust emission (2000-2010)
  - Cropland - larger rate, small area, small total 0.004 Pg y^{-1}
  - Rangeland – smaller rate, large areas, large total 0.1 Pg y^{-1}
- Rangeland gross water erosion unreliable?



Chappell, et al., (2013) Global Change Biology

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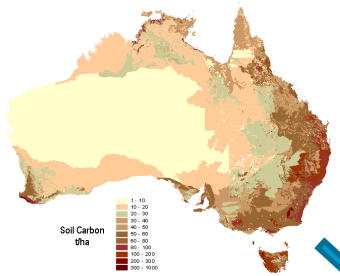
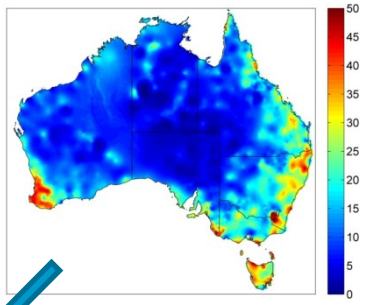
Conveyor (C, N, P…) dynamics



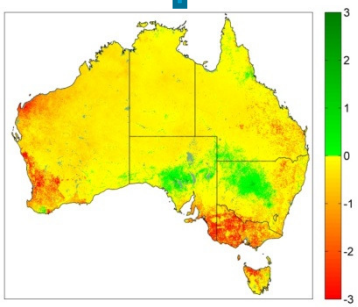
Native or recent?

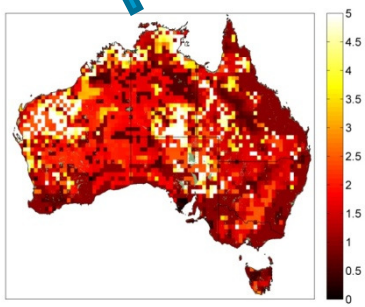


$$C_{eros} = E \times OC_e \times P_e$$

(tC ha^{-1} y^{-1})

Enrichment:
- Property dependent
- Typically approx





Erosion rate dynamics:
- Pre-European,
- Ag expansion,
- Ag stabilisation?

Chappell, Webb, Viscarra Rossel & Bui (submitted) Biogeosciences

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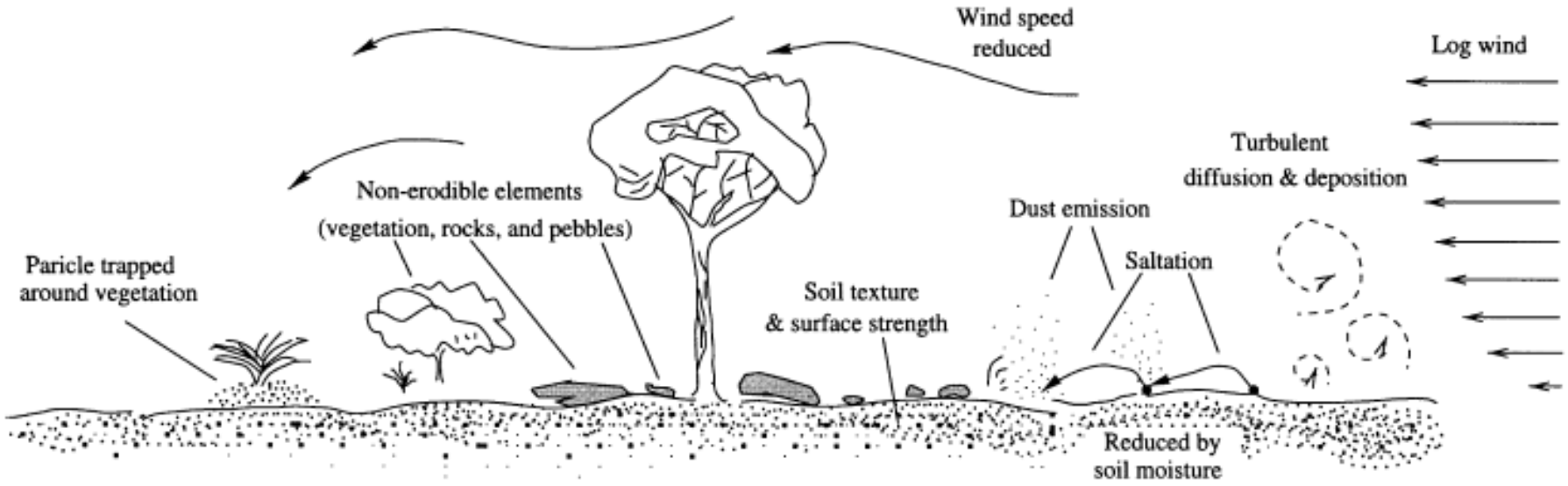
Soil erodibility

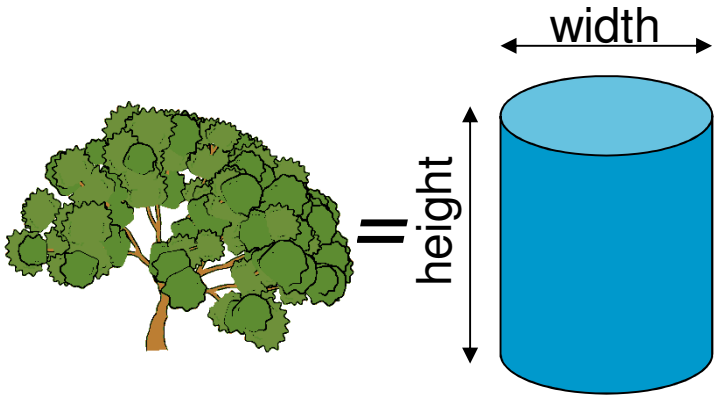
- Soil erosion difficult (expensive) to measure repeatedly over large areas (monitor) – proxy?
- Erodibility - dominated by (aerodynamic / fluid) surface roughness (approximated as lateral cover)

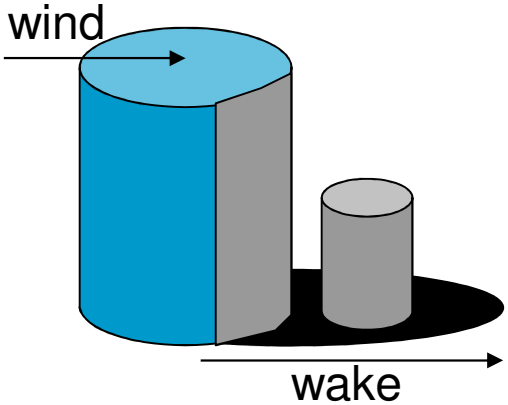


Shao (2001)

Lateral cover (λ)

$$\lambda = n\ b\ h\ /\ s$$

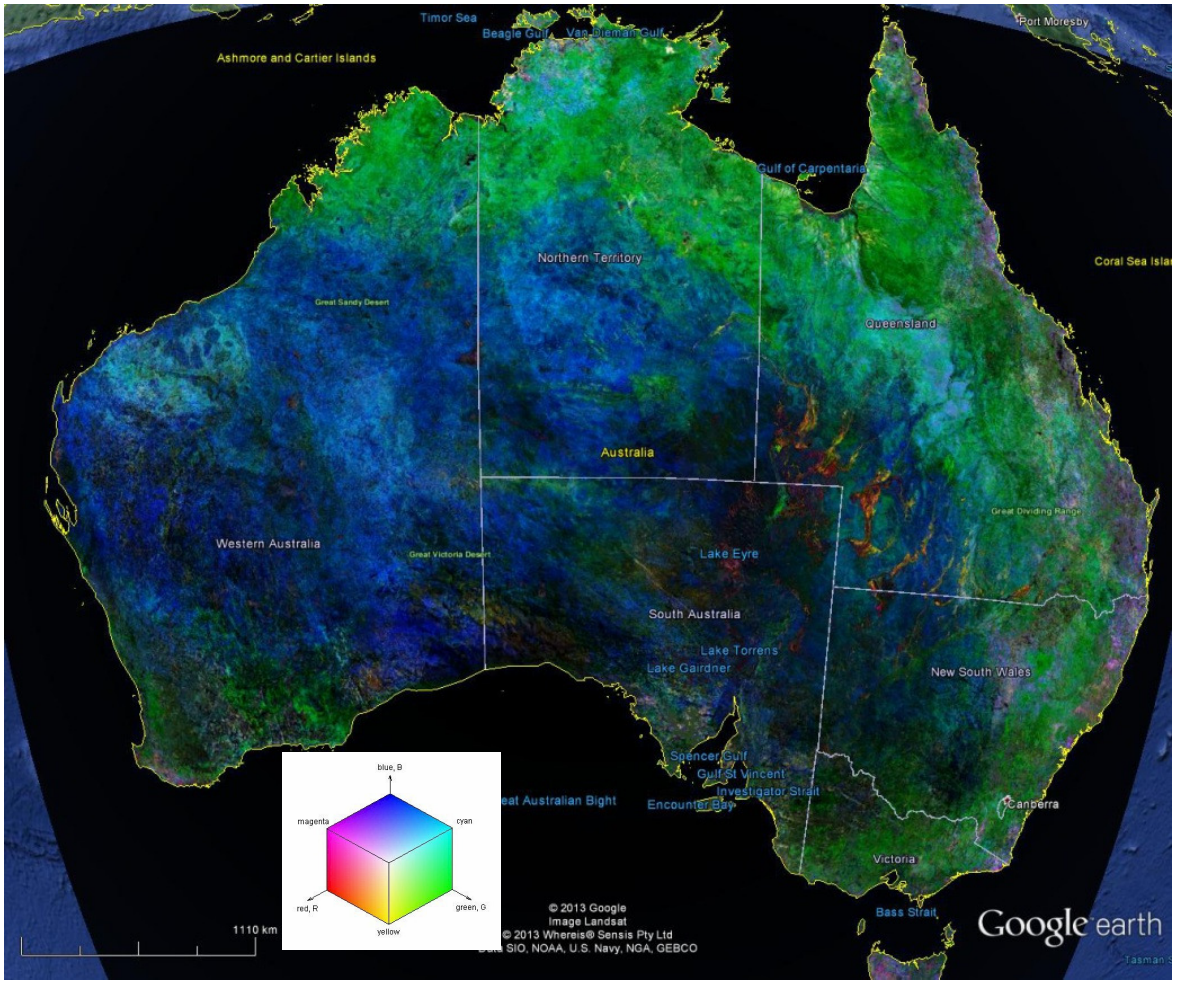




Australian lateral cover (March 2013)

- MODIS RGB
  - R=λ_{SWIR3} (brown veg)
  - G= λ_{NIR} (green veg)
  - B=λ_{BLUE} (bare)

- Every 500 m and 16 days



Using MODIS (albedo) MCD43A3

Chappell, Guerschman et al. (in prep) Remote Sensing of Environment

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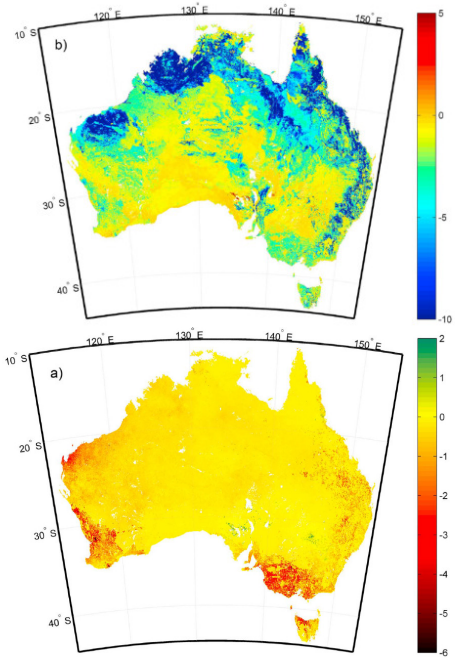
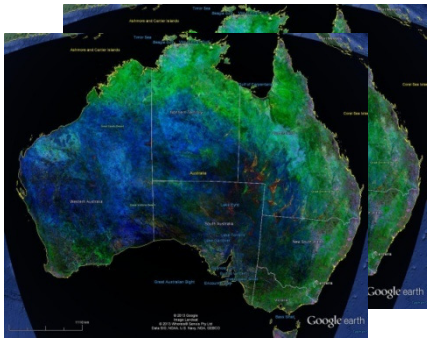
Soil condition (quality indicator) ≈ lateral cover

- Modelling of soil erosion using USLE:
  - Available data layers (local-regional)
  - Water erosion only and uncertain
  - WEQ (never been applied globally)
- Mapped ^{137}Cs-derived net soil redistribution provide baseline 1990
  - Measure ^{137}Cs in SCaRP samples to map difference 2010 (cultivated land only)?
- Replace with lateral cover controlling soil erosion?
  - Clearing, grazing and cultivation can be represented as change in aerodynamic roughness across scales of veg (green), residues (brown) and soil (bare)





Thoughts arising from discussion…

- Uniqueness
  - Misleading (second-order) focus on Australian soil
  - Replace with commonality to maximise applicability
- First order
  - Land use change and management fundamentally changed soil condition from native to current
  - Second-order indicators cannot explain this fundamental change in soil condition
  - Indicator(s) which explain the first order changes to Australian soil condition are globally significant = soil erosion (lateral cover).
- Dynamics
  - Which erosion rate used in LCA calculation, pre-European settlement, ag expansion, ag stabilisation?
- Conveyor
  - Requirement to quantify loss of e.g., soil nutrients or to more generally indicate change?

Soil contaminants and LCA – Rai Kookana

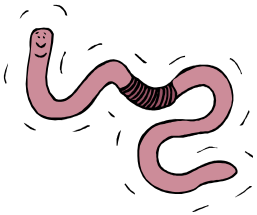
- What are they?

- Salts, heavy metals, metalloids, pesticides, biocides, PAHs, pharmaceuticals, etc.

- How do they get there?

- Irrigation, fertilisers, pesticides, manures, wastewater, biosolids, air, geogenic

- How do they affect soil function?



- Productivity, soil fertility, quality of produce, microbial activity, C & N cycling; ecosystem services

- Measure/ Estimate for regional scale

- Depends on type, Indicators; Surrogates; Not really sure....

Soil contaminants – measures /estimates

- Pesticides and Fertiliser
  - Soil organic matter (non-ionic pesticides)
  - Soil pH, clay + SOM (ionisable)
  - Rate and frequency of application
- Veterinary drugs
  - Ionisable – acidic/basic drugs
  - Soil pH, clay content, SOM
  - Rate and application of administration
- Heavy metals/metalloids
  - Soil pH, mineralogy (iron oxides)
  - Do we know where these hot spots are?
- Acid sulphate soils
  - Geology/Mineralogy, redox status, Soil pH
  - Are these mapped?

Ryan Farquharson – CSIRO

SOIL ORGANIC MATTER

Soil function – what's the end game?

- Support plant growth – think like a plant
  - Nutrient 'bank'
  - Water storage
  - Structure
- Store more (or lose less) soil carbon – think like a carbon containing molecule
  - Protection from agents of decomposition
    - Biological; Physical; Chemical
- Others?
  - Water quality….

Soil Organic Matter

- Once living material in the soil at various states of decay
- Composed of carbon, nitrogen, sulfur, phosphorus….
- Different components have different:
  - chemical composition
  - stability/residence times
  - functions in the soil
- Beware perverse outcomes
  - N_2O, CH_4

Functions of organic matter in soil

- Biological
  - Energy source for microbes
  - Nutrient source microbes
  - Habitat
- Physical functions
  - Structural stability
  - Water dynamics – water retention and infiltration
  - Thermal properties
- Chemical functions
  - Cation exchange capacity
  - pH buffering
  - Complexation of cations

NOTE: functionality is soil type specific, and different components of SOM have different functionality.

Quantification of SOM

- TC, TOC, Fractions
- Physical fractionation, IR-PLS estimates
- Spatial modelling
- Isotopic techniques

Quantification of SOM function

- Not well developed
  - Use of OC in pedotransfer functions for water holding capacity
  - Elemental stoichiometry and nutrient (N) availability
- More work needed…

Ryan Farquharson - CSIRO

MODELLING SOC

Soil Organic Matter Recap

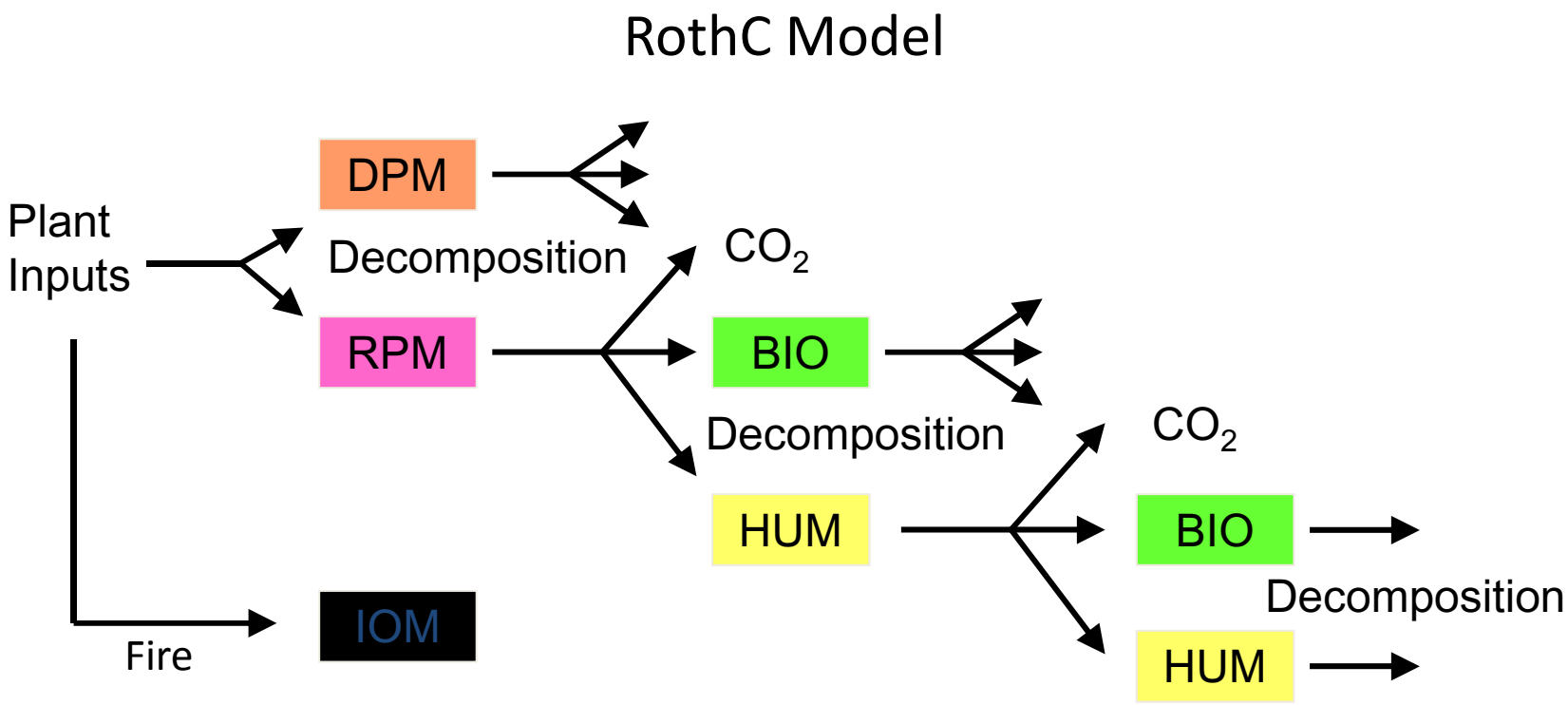
- SOM composed of a range of materials
- Components have different residence times (hours to millenia) and functions:
  - Biological (energy and nutrient source)
  - Physical (structure, water, thermal)
  - Chemical (pH buffering, cation exchange)
- Function is soil type dependent
- Qunatification of SOM:
  - TOC, fractionation, IR estimates, isotopes, spatial modelling
- Quantification of SOM function:
  - Water holding, nutrient availability
  - Needs more work

Compartment models

- Process based (inputs and losses) for a point in space
- Division of OM into compartments
  - Each compartment or ‘pool’ has an inherent decay rate modified by water and temperature
- Assumptions made on microbial efficiency, stoichiometry, protection mechanisms
- Plant production, soil parameters, climate data
- Measured fractions vs conceptual pools
  - Initialisation

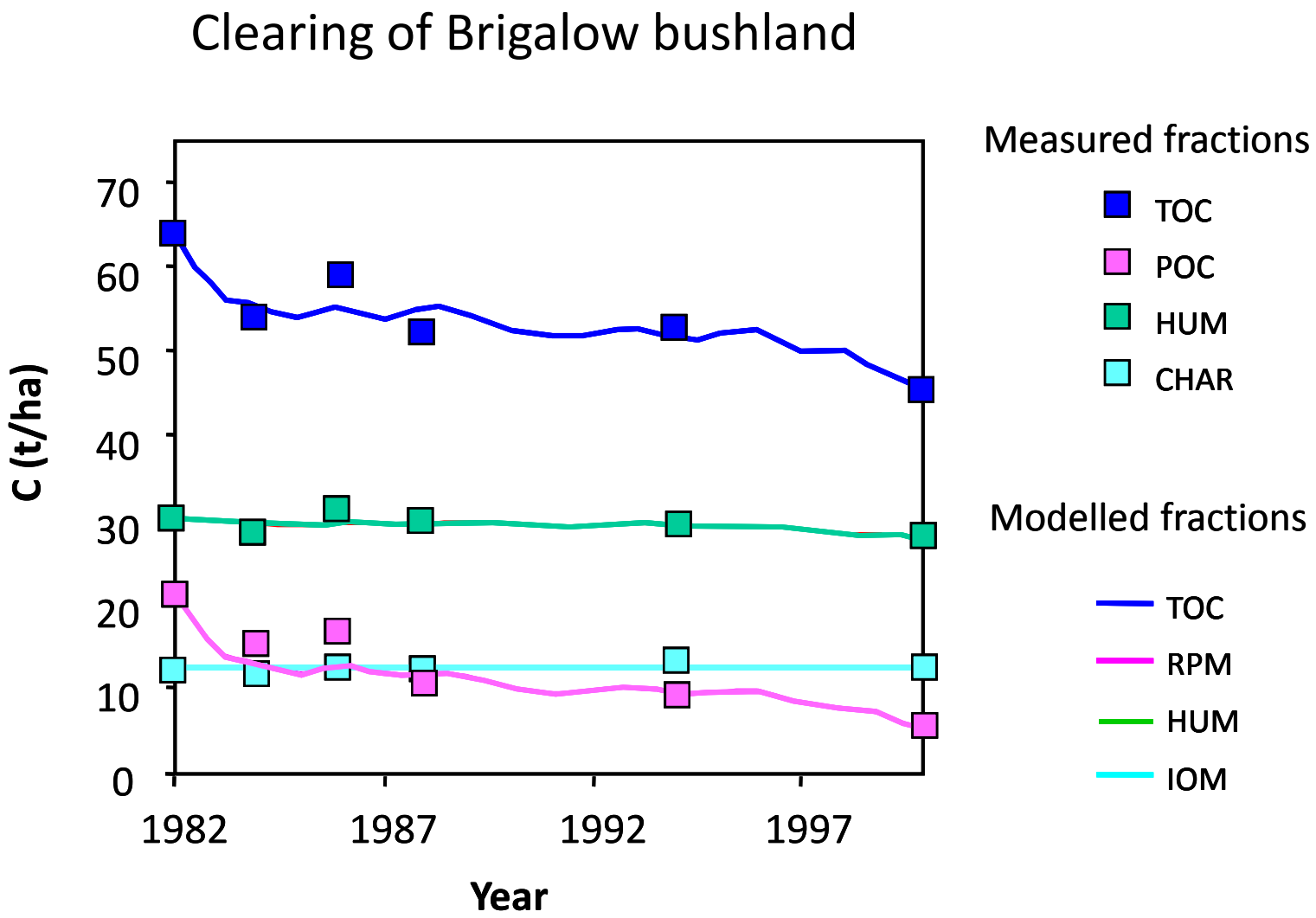
- No functional feedbacks
  - e.g. SOM on water holding capacity and hence productivity

Modelling soil organic carbon – RothC model



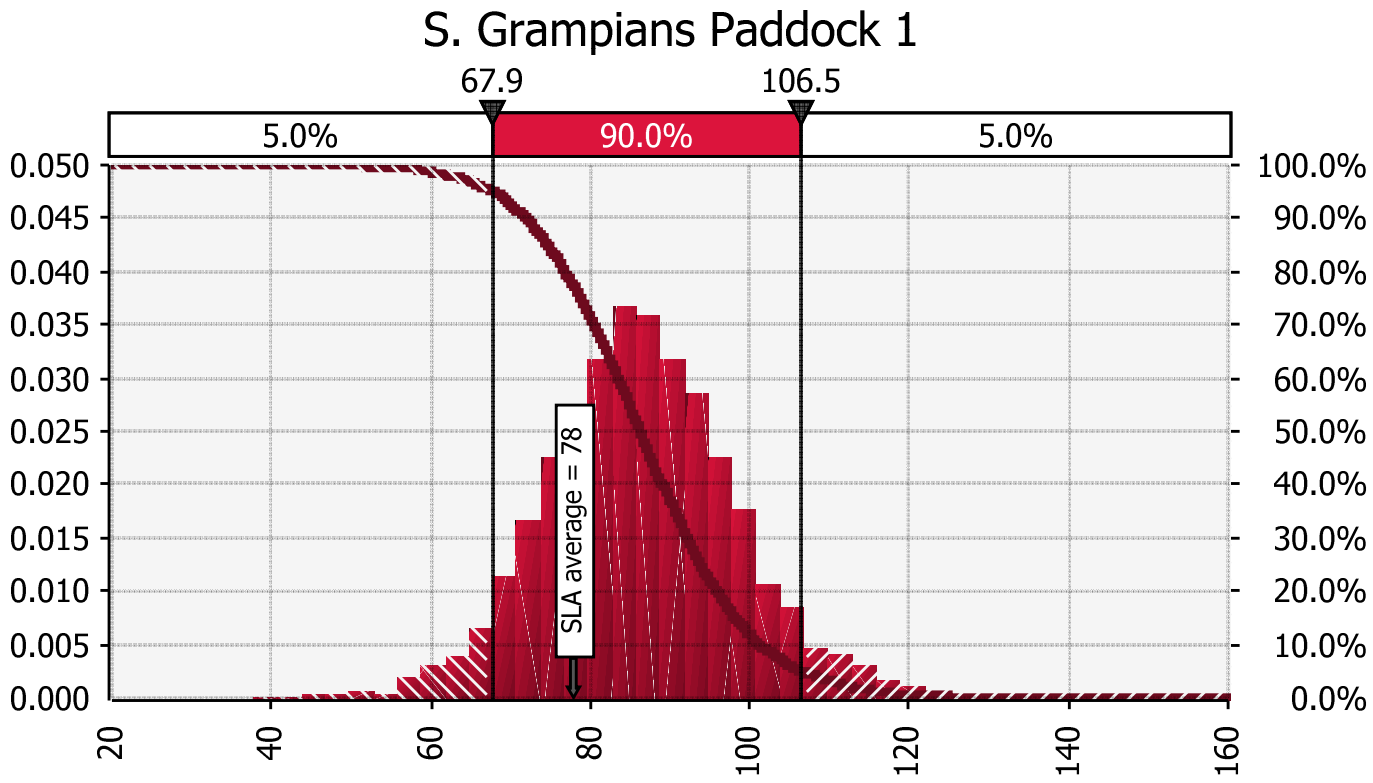
Modelled pool	Measured fraction
Resistant (RPM)	Particulate (POC)
Inert (IOM)	Recalcitrant (ROC)
Humus (HUM)	Humic (HOC)

Calibration of RothC to Australian conditions



SOC modelling for Australian Wool Innovation

- RothC model runs
  - 50 year climate data and plant residue inputs (GrassGro predictions for two paddocks)
  - Variable initial SOC pools
    - sampled from probability distributions of SCaRP SOC fractions
  - Variable clay content
    - sampled from probability distributions of clay content from ASRIS
  - Correlations


S. Grampians Paddock 1
67.9
106.5
5.0%
90.0%
5.0%
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
SLA average = 78
20
40
60
80
100
120
140
160

Where has the carbon gone?

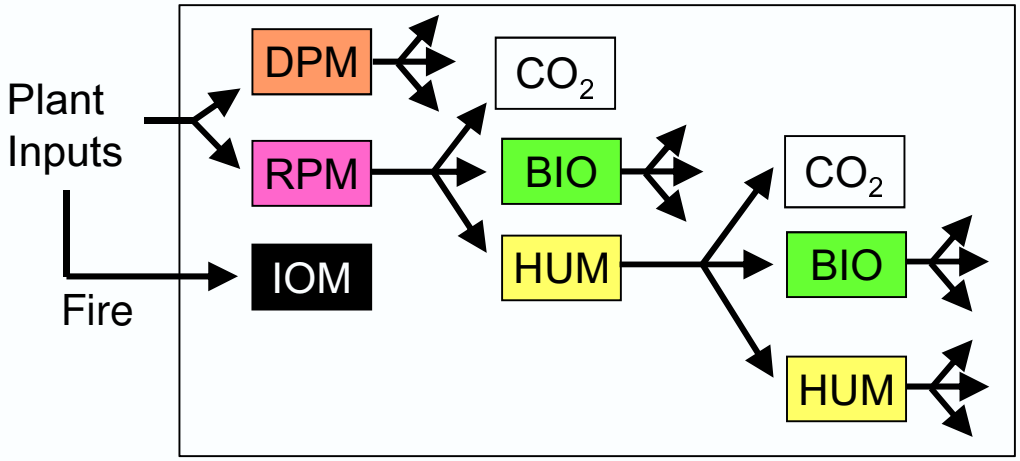
- GrassGro derived plant residue inputs optimistic
- Residue losses prior to entering soil unaccounted
- Default decay constants too slow
- Microbial efficiencies too high
- Erosion losses unaccounted for
- There is potential to increase SOC

Jeff Baldock - CSIRO

MODELLING SOIL CARBON CHANGE

Modelling soil carbon change – important principles: SOC composition and model initialisation

RothC Model

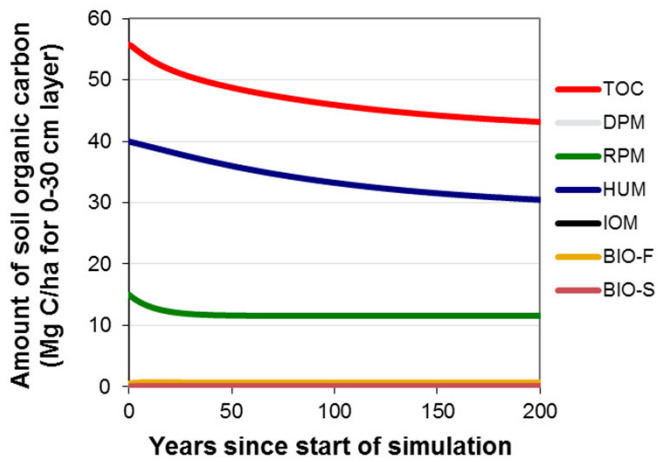


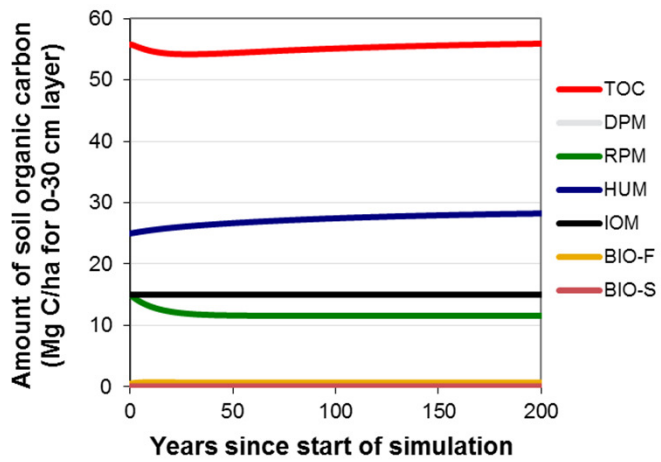
$$C_t = C_0\, e^{-abckt} + A$$

$$C_{loss} = C_0\,(1 - e^{-abckt})$$

Model initialisation

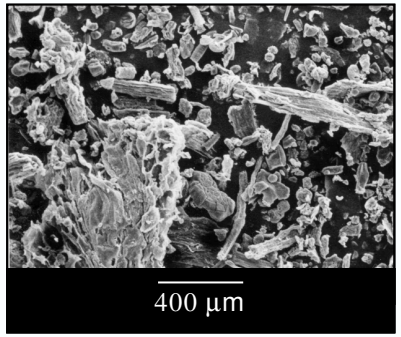
- organic carbon has to be partitioned into components
- Partitioning will alter the rate SOC stock change



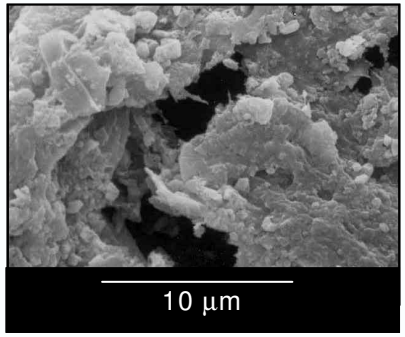


Modelling soil carbon change – important principles to consider: tuning models to measureable fractions

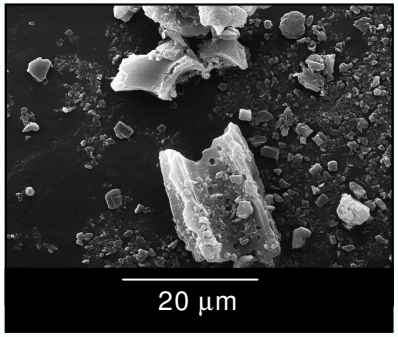
Particulate carbon
(2mm – 0.05 mm)



Humus carbon
(<0.05mm)



Resistant
(charcoal <2mm)

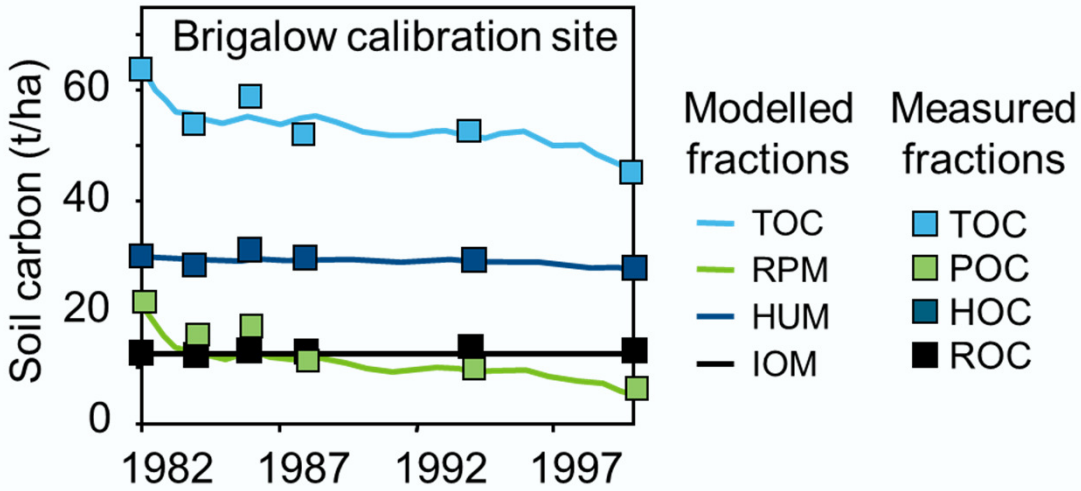


Replace conceptual model pools with measurable fractions

RPM = POC

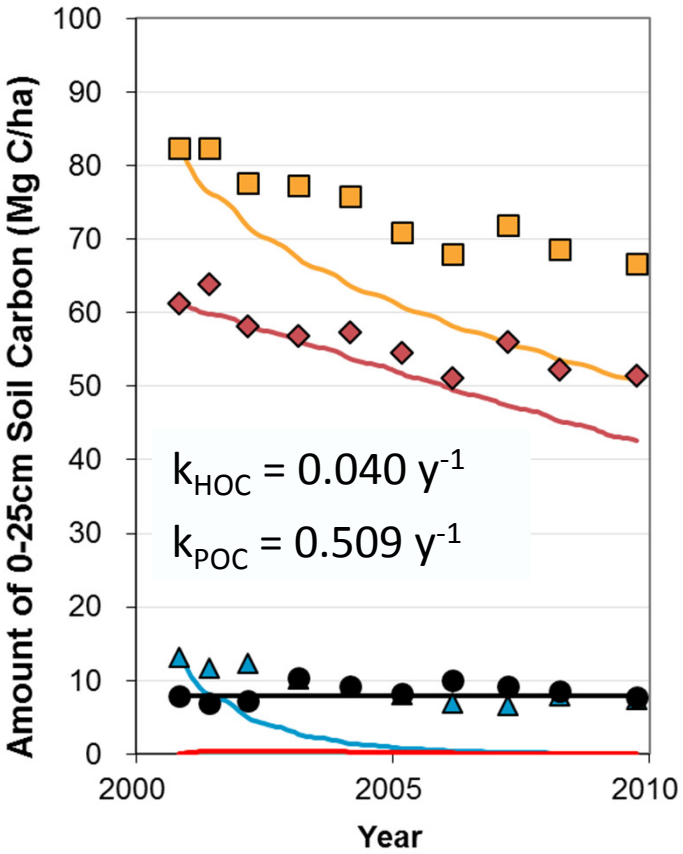
HUM = HOC

IOM = ROC (Charcoal C)

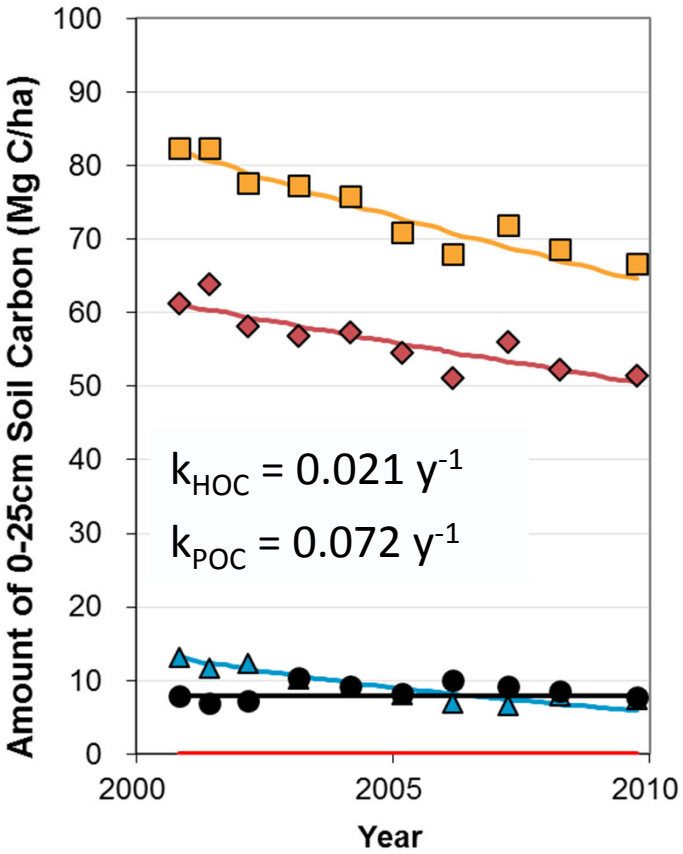


Modelling soil carbon change – important principles: calibration of rate constants

No site specific calibration of k values



After site specific calibration of k values



Modelling Farming Systems Productivity and Environmental Performance - SOC example

Enli Wang, Zhongkui Luo, Jeff Baldock, Hongtao Xing, Peter Thorburn

30 May 2013, Melbourne

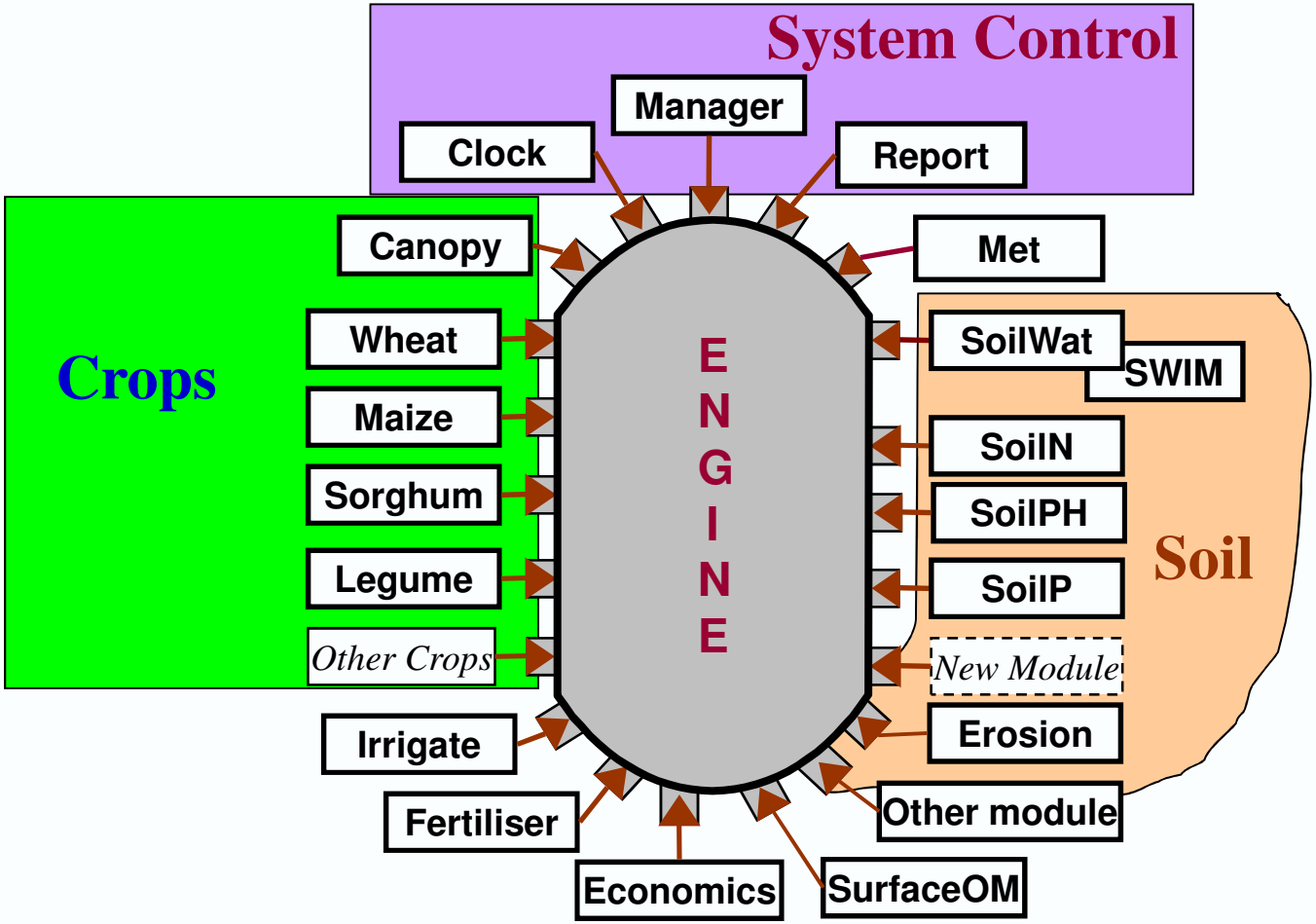
CSIRO SUSTAINABLE AGRICULTURE FLAGSHIP / CSIRO LAND AND WATER
www.csiro.au

Australian Government
Department of Agriculture

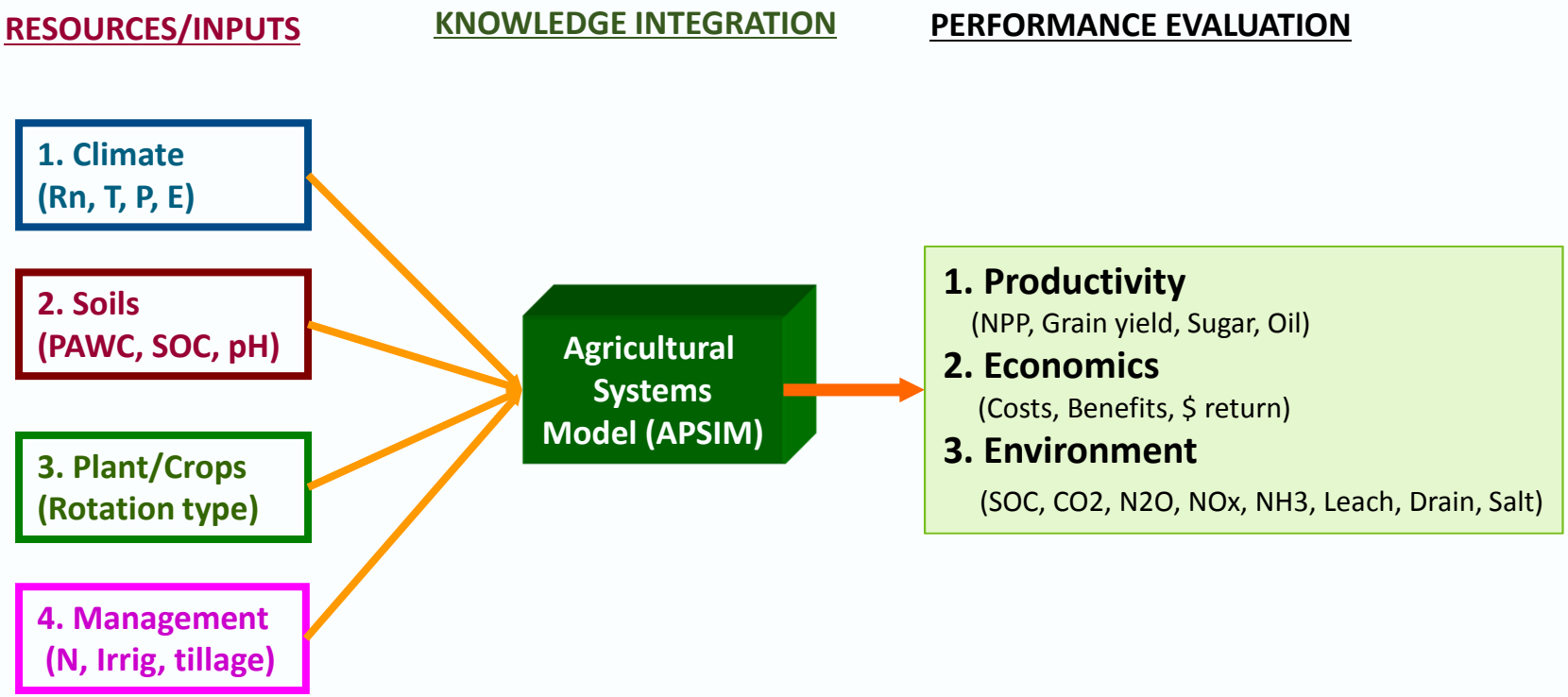
GRDC Grains Research & Development Corporation

CSIRO

TOOL: APSIM- Agricultural Production Systems Simulator

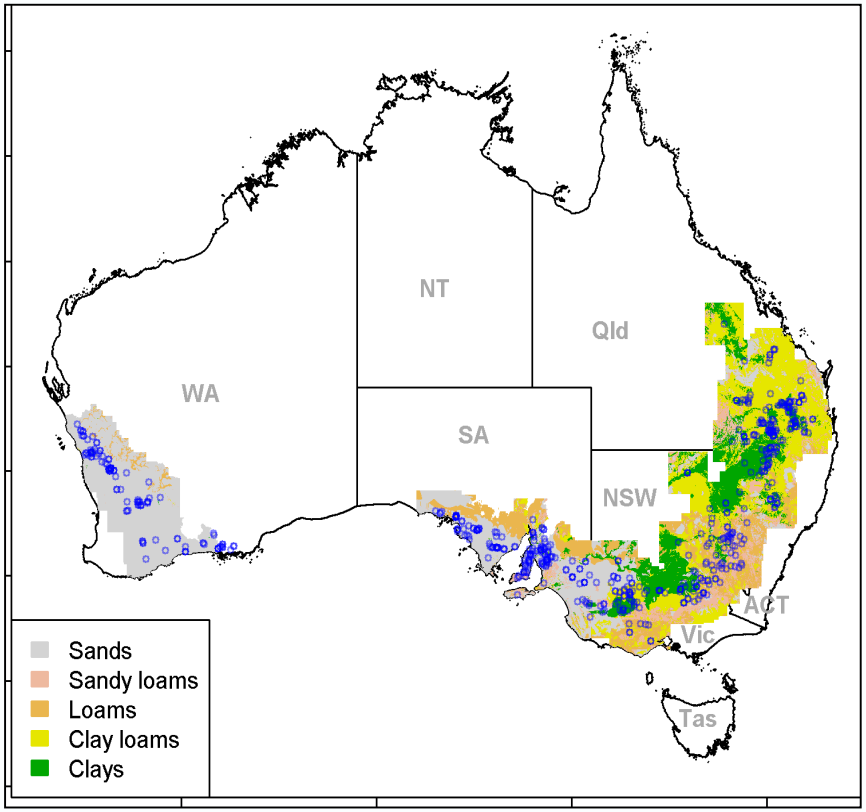


INPUT DATA & systems approach



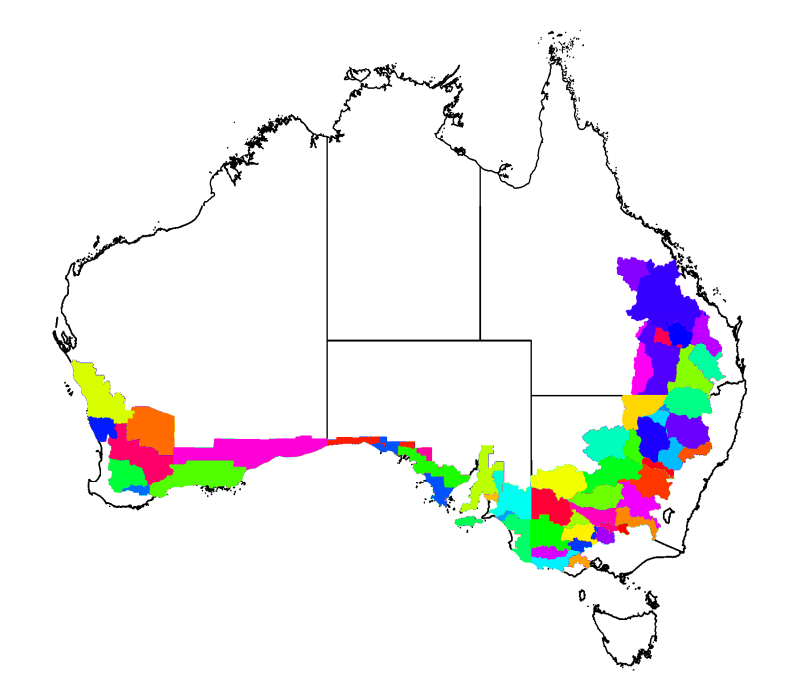
SOIL DATA – APSRU soil profiles + soil classes

Black circles show locations of the 613 APSRU reference sites



- Point simulations at 613 sites
- Point + class data to derive distribution of soil properties
- Metal model to link SOC to driving variables
- Grid prediction using metal model and derived soil properties

Representative rotations

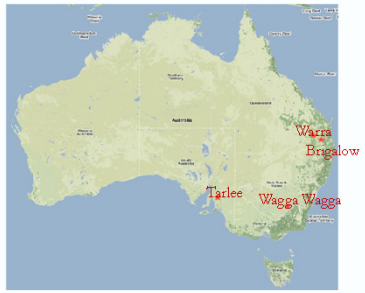


Sub-Regions for refined representative crop rotations & management scenarios

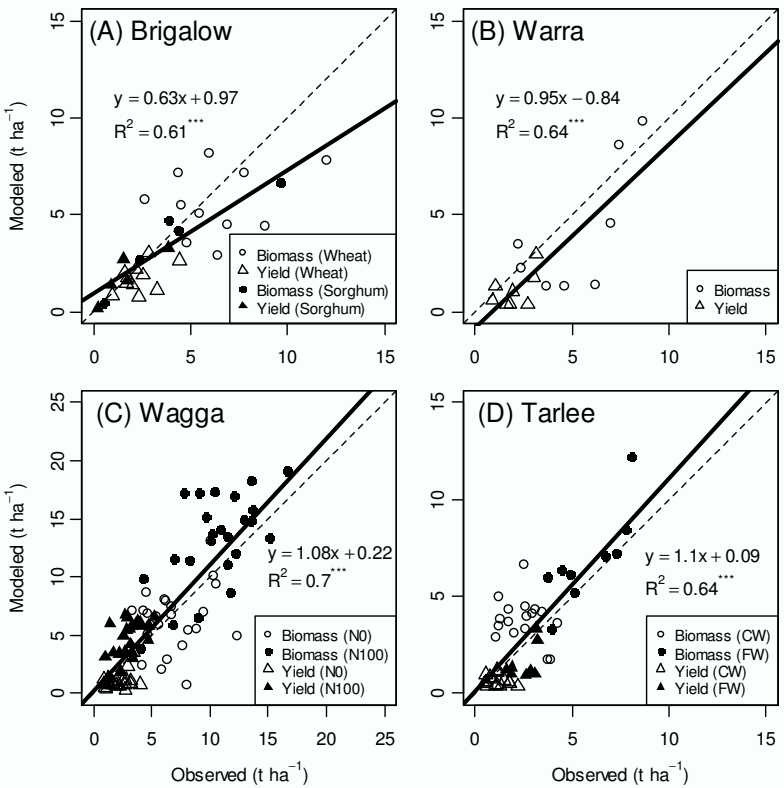
Table 2 Representative crop rotational sequences constructed in each of the GRDC Agro-Ecological Zones

REGIONS	REPRESENTATIVE ROTATIONS
Qld Central	• wheat-chickpea-wheat-sorghum • Wheat-chickpea-wheat • Sorghum-sorghum • Cotton-sorghum • Sorghum-sorghum-chickpea-wheat
NSW NW/Qld SW	• Wheat-Wheat-Wheat-Fallow • Sorghum-Wheat-Wheat-Fallow • Sorghum-Sorghum-Wheat-Fallow • Sorghum-Wheat-Chick Pea-Wheat-Fallow • Wheat-chickpea, fababean, canola-wheat-sorghum, dryland cotton-wheat • Wheat-chickpea-wheat-fababean-wheat-canola
NSW NE/Qld SE	• Wheat-Cotton • Wheat-Canola • Cotton-sorghum-chickpea-wheat • Sorghum-wheat-chickpea-wheat • Wheat-chickpea-wheat-sorghum-wheat • Wheat-wheat-chickpea-wheat-wheat-chickpea
NSW VIC Slopes NSW Central	WEST PART (Plains, 350-500mm Rainfall) • Pasture-Pasture-Chick Pea-Wheat-Wheat-Pea-Barley/wheat • Canola-Wheat-Wheat-Barley-Legume-Wheat-Wheat EAST PART (Slopes, 500-650mm Rainfall) • Pasture x 4-Canola – Wheat-Wheat-lupin/Pea/Fababean-Wheat (Pasture under sown) NSW Central (Wagga Wagga area) • Canola-Wheat-Canola-Wheat-Canola-Wheat-Lupin/Lentile/Pea • PastureX4 -Wheat-Canola-Wheat-Lupin/Pea/Fababen-Canola-Wheat (pasture undersown)
VIC High rainfall	High value pasture – with more crops (wheat) in recent years
SA Wimmera	• Pulse-Canola-Cereal
SA VIC Mallee	• Pulse-Canola-Wheat-Wheat-Barley • Pasture-Canola-Wheat-Barley-Pasture-Legume-Wheat-Barley
WA Northern	• Wheat-Lupin-Wheat-Canola (West Half) • Wheat-Wheat-Wheat-Pasture/Fallow/Canola (Eastern Half)
WA Eastern	• Wheat-Barley-Wheat-Pasture/Fallow/Canola
WA Mallee	• Wheat-Barley-Wheat-Lupin/Canola
WA Central	• Wheat- Barley-Wheat-Canola-Pasture
WA Sand Plan	• Wheat-Lupin-Wheat-Canola

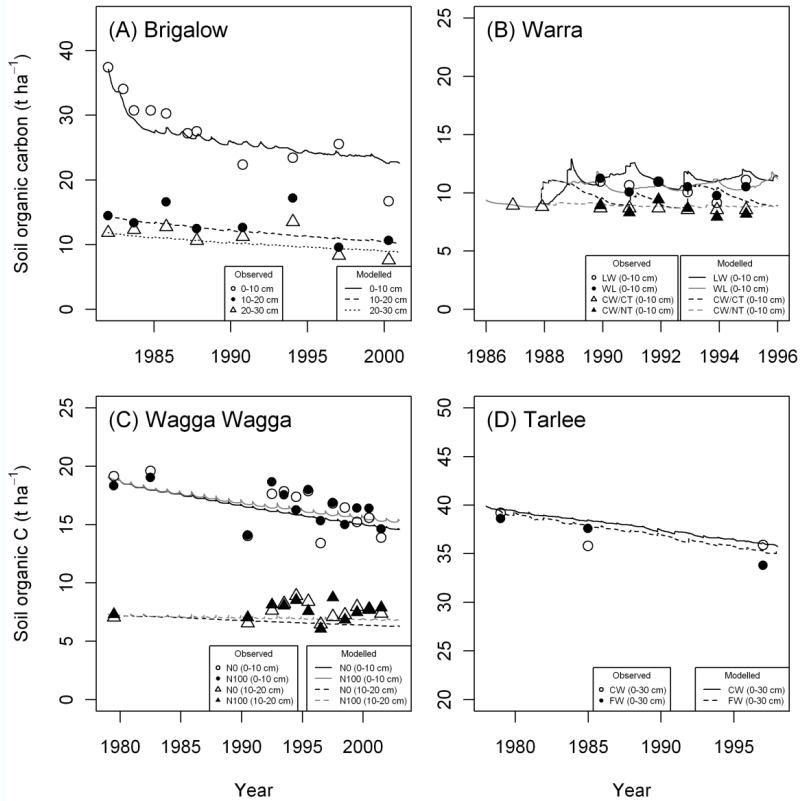
Maturity of technique:
Model performance



Biomass and grain yield

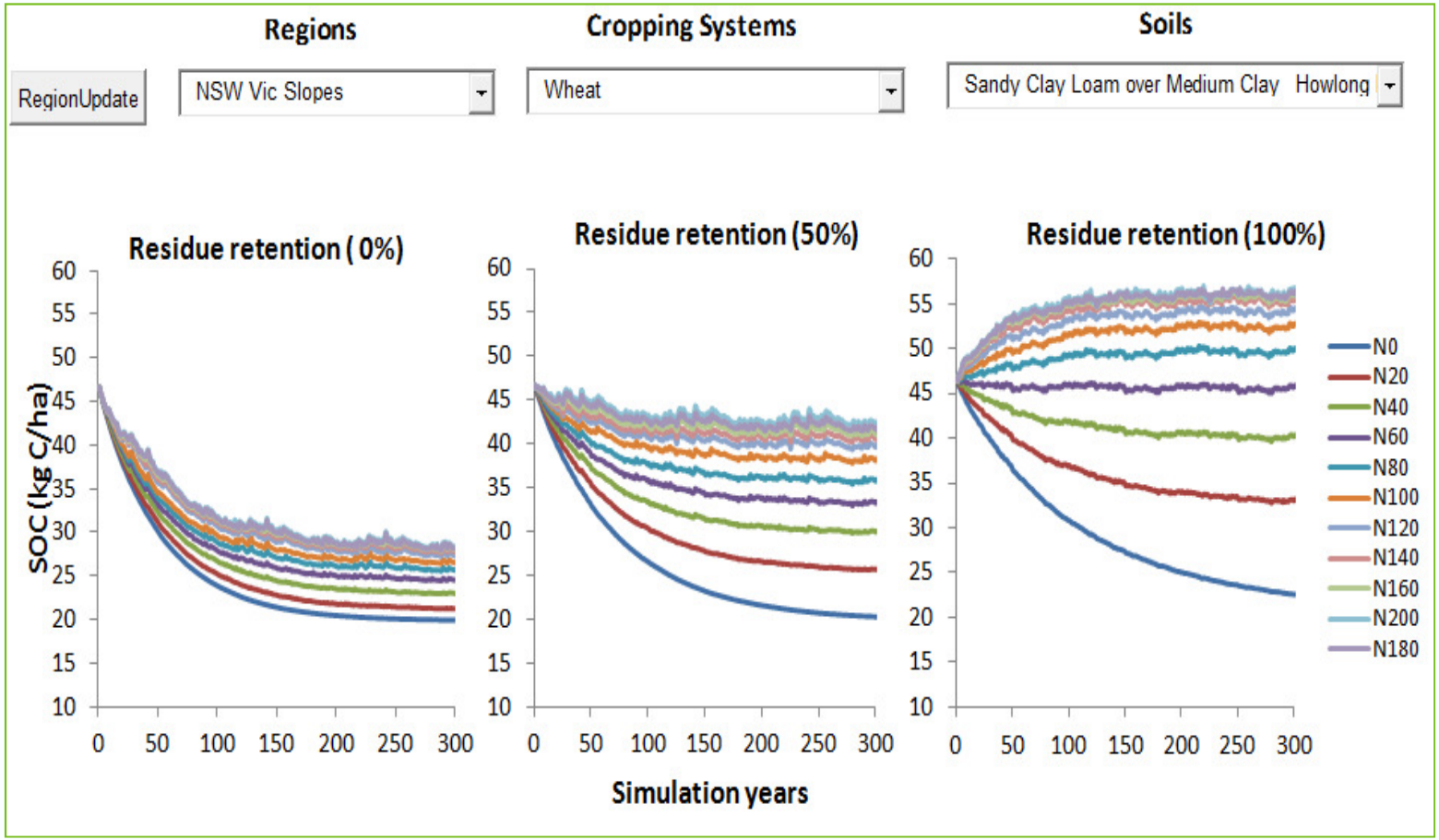


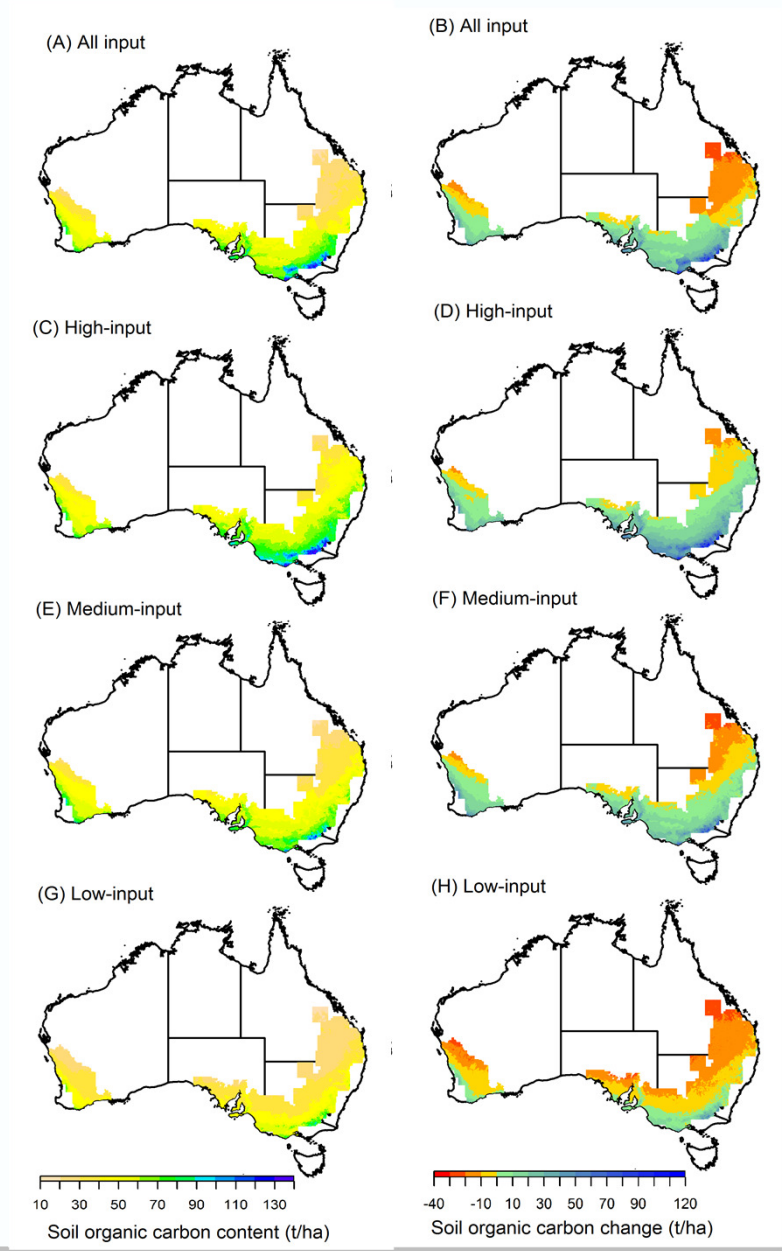
Soil organic carbon



Point Simulations (Scalability):

SOC Potential – Crop, Residue, N application





Scalability:

SOC Potential – regional scale

Representative rotations

Thank you

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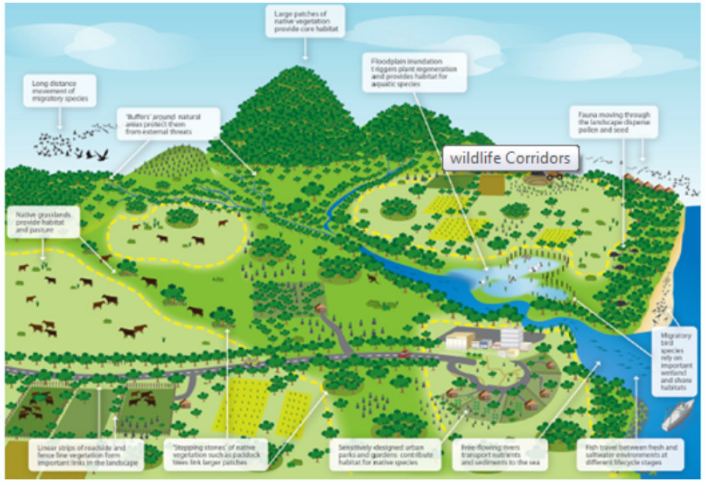
Possible sources of Soil quality indicators in LCA
Keryn Paul - CSIRO

Need a whole-farm/landscape approach to soil quality indicators

Impact of not only efficient rotations/crop management, but also woody veg. (paddock trees, riparian plantings, belts etc.)



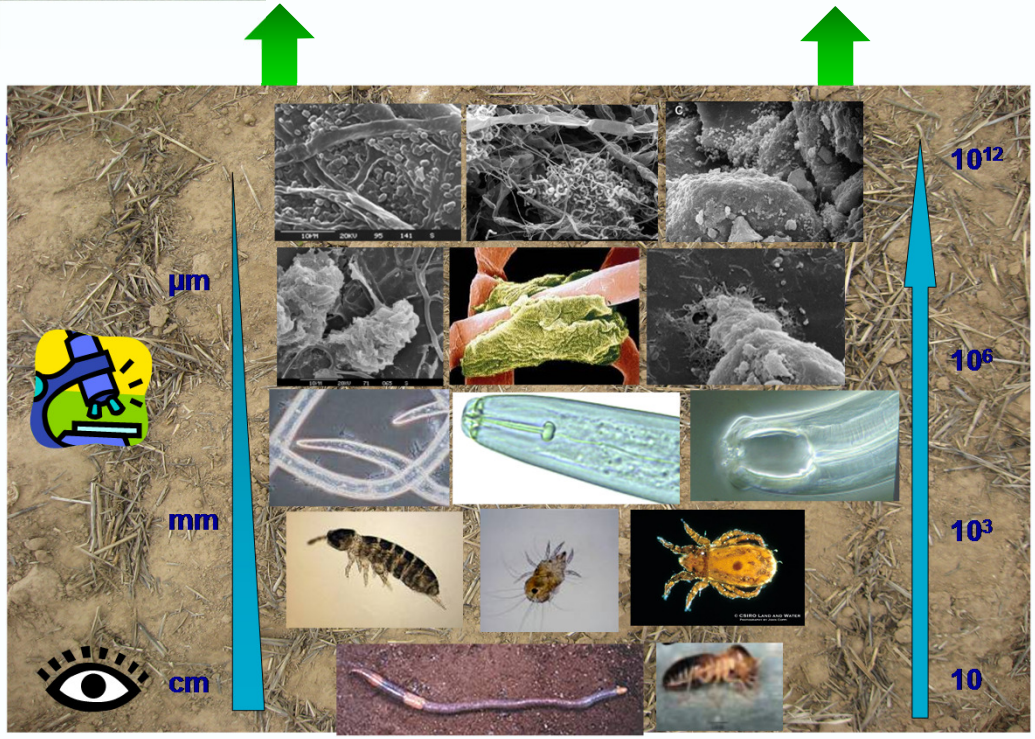
Some examples...

1. Soil carbon: FullCAM-RothC
   - calibrated to 2 plantations, and currently work underway to calibrate it to ~120 environmental plantings in farmlands across Australia.
2. Eutrophication: SNAP model for predictions of avail N under woody veg.
   - calibrated and validated against 17 studies (61 treatments) in southern Aust.
3. Water availability/dryland salinity
   - 3-PG calibrated and validated against 100's of different types of plantations and environmental plantings across southern Australia

Functional (microbial) ecology in terrestrial environments

Below ground diversity/function for impacts Aboveground

Gupta Vadakattu



Environment
Management

- Biota in soil are diverse in terms of size, numbers and habitat requirement
- High phenotypic/taxonomic diversity and functional redundancy contribute to functional capability and resilience
- Habitat heterogeneity and microscale protection influences biota exposure to stress/stimuli and the response
- Key factors – availability of C, moisture, temperature, pH, chemical constraints

Generating inventories for soil biota – Andrew Bissett

- Standardised collection procedures (e.g., as in current soil microbiome projects (BASE, EMP, TERRAGENOME))

- Sequence (amplicons or amplification free)

- Sequence data is USELESS without associated contextual data (edaphic and non-edaphic sample properties)

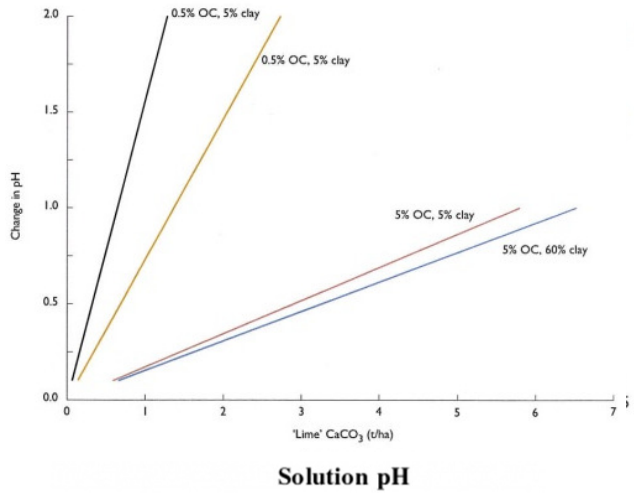
Mike Webb - CSIRO

SOIL ACIDIFICATION

Soil Acidification
(agriculture induced, not acid sulphate soils)

- What is it?
  - the process by which the soil becomes more acid because of agricultural production
  - pH 5.5, 4.8, 4.3 key trigger points

- What does it do?
  - lowers CEC, nutrient uptake, increases toxic elements Al and Mn
  - permanent loss of clay minerals by dissolution (pH 4.3)
  - reduces productivity (pH 5.5; pH 4.8)



- What controls rates of acidification?
  - the amount of acid that is added (NAAR)
  - the ability of the soil to resist pH change (pHBC)

- NAAR
  - nitrogen fertiliser, lime
  - product export

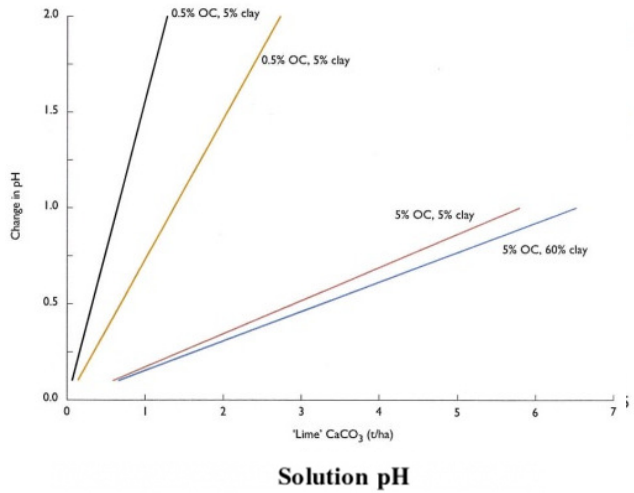
Time to critical pH

- pHBC
  - clay
  - OM

Soil Acidification
(How to monitor or measure)

- pH
  - direct measurement
  - surrogate eg MIR

- pHBC
  - based on clay, OM, (silt)
  - already modelled, could do more



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  - the ability of the soil to resist pH change (pHBC)

- NAAR
  - nitrogen fertiliser, lime
  - product export

- pHBC
  - clay
  - OM

Time to critical pH

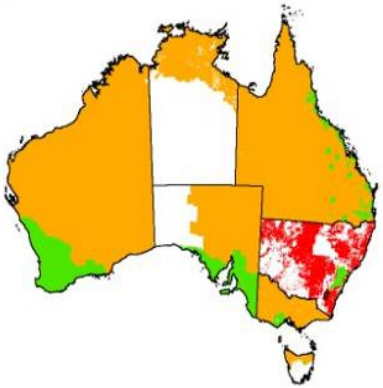
ASRIS: Clay (Layer 1)

Clay (%)

- < 10% Sand, loamy sand or clayey sand
- 10% - 20% Sandy loam
- 20% - 30% Loam, silty loam or sandy clay loam
- 30% - 35% Clay loam, clay loam, sandy or silty clay loam
- 35% - 45% Light clay or light medium clay
- > 45% Medium clay, medium heavy clay, heavy clay

Source

- Level 5 (ASRIS)
- Level 4 (ASRIS)
- 0 - 10cm (NSW DECC)
- No data



0 500 1000

Kilometres

Lambert Conformal Conic

6 August, 2009

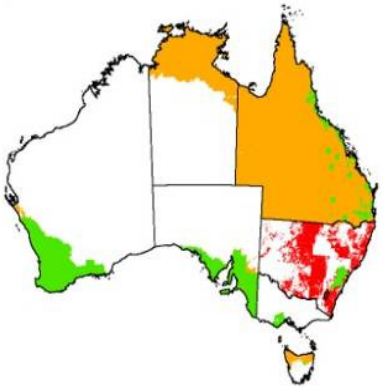
ASRIS: Organic Carbon (Layer 1)

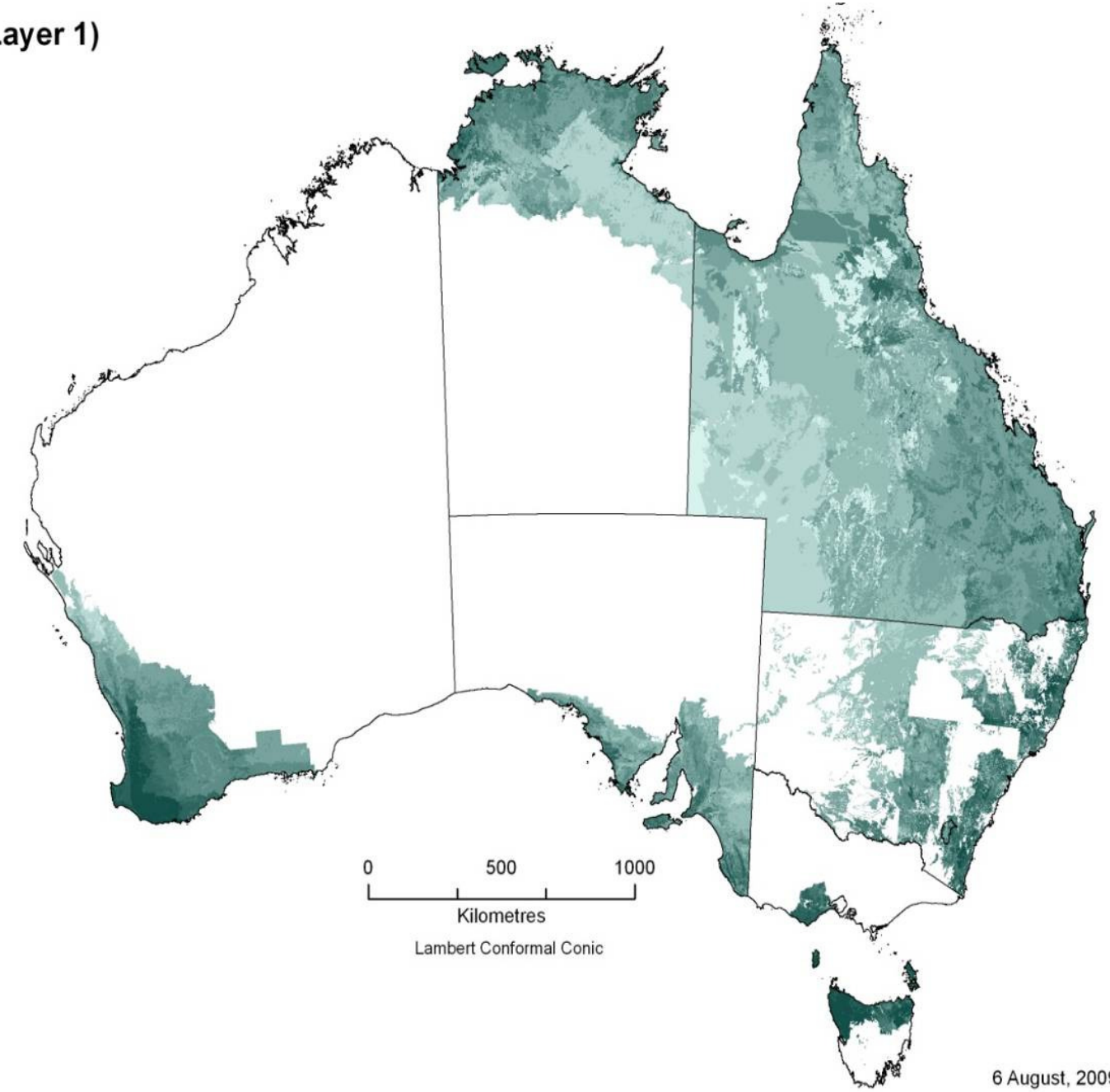
Organic Carbon (%)

- 0.0 - 0.2
- 0.3 - 0.5
- 0.6 - 1
- 1.1 - 1.5
- 1.6 - 2
- 2.1 - 3
- 3.1 - 5
- > 5

Source

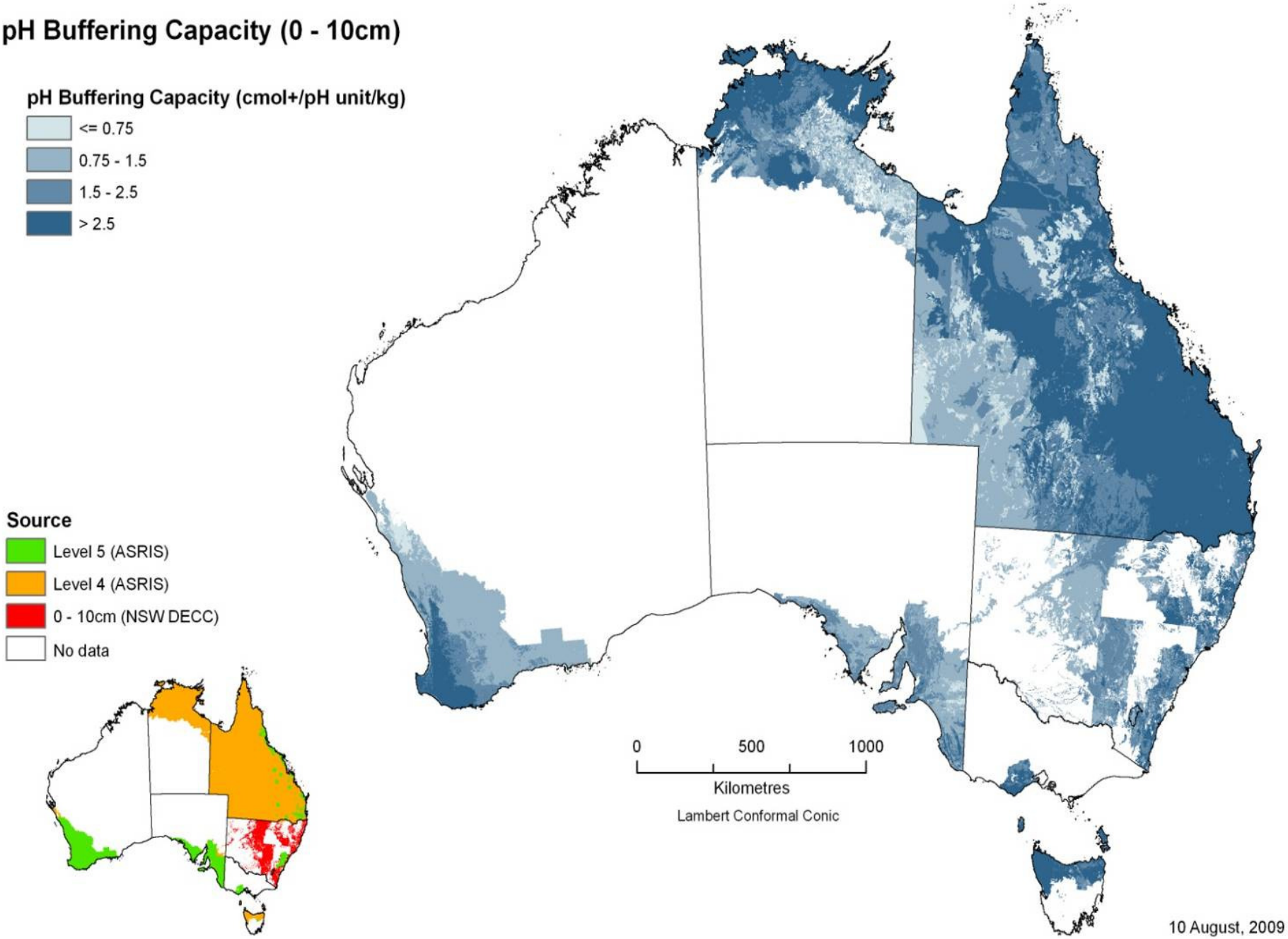
- Level 5 (ASRIS)
- Level 4 (ASRIS)
- 0 - 10cm (NSW DECC)
- No data





6 August, 2009

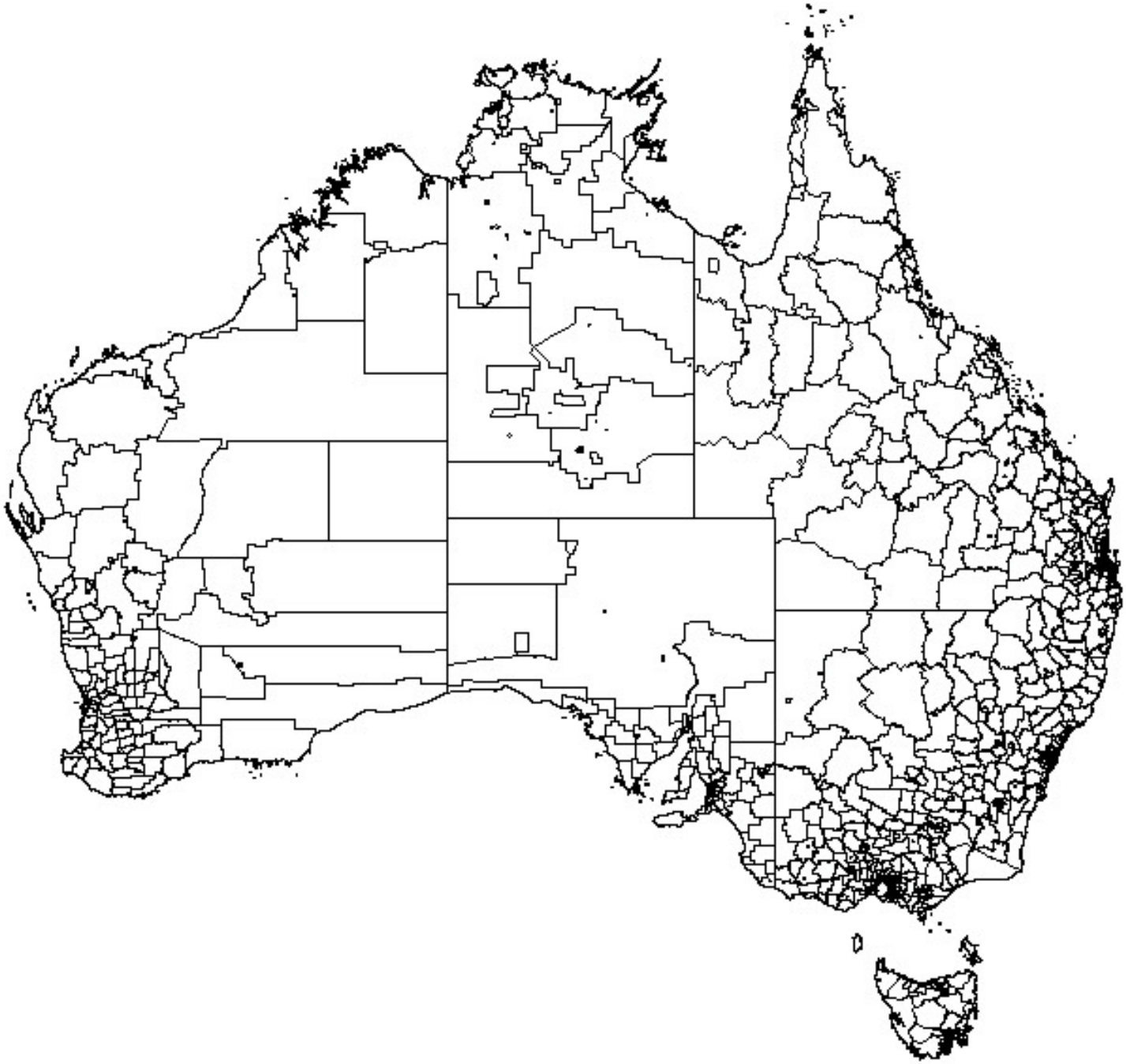
pH Buffering Capacity (0 - 10cm)



Soil Acidification
(How to monitor or measure)

- NAAR

  Based on Statistical Local areas (SLA), which are based on population; some as small as 21 sq km . (usually urban) to 470,000 sq km



Soil Acidification
(How to monitor or measure)

- NAAR

Based on Statistical Local areas (SLA), which are based on population; some as small as 21 sq km . (usually urban) to 470,000 sq km

NAAR = (product exported * ash alkalinity)
+ (FertiliserN x FertiliserFactor)

Product exported (yield/ha) was calculated from rainfall (irrigation) and some crop efficiency factors (Unkovich et al; various publications)

Ash alkalinity from literature Fertiliser factor is the efficiency of nitrate use (Adams 1984)

Product exported is the sum of the different crops or pastures based on SLA data and weighted for the relative area of each crop or pasture.

Thus the scale is that of the SLA,

Nitrogen fertiliser use was calculated from yield of each crop or pasture and the protein content multiplied by an efficiency of uptake factor.

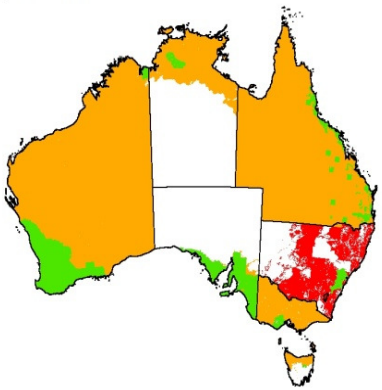
ASRIS: pH (Layer 1)

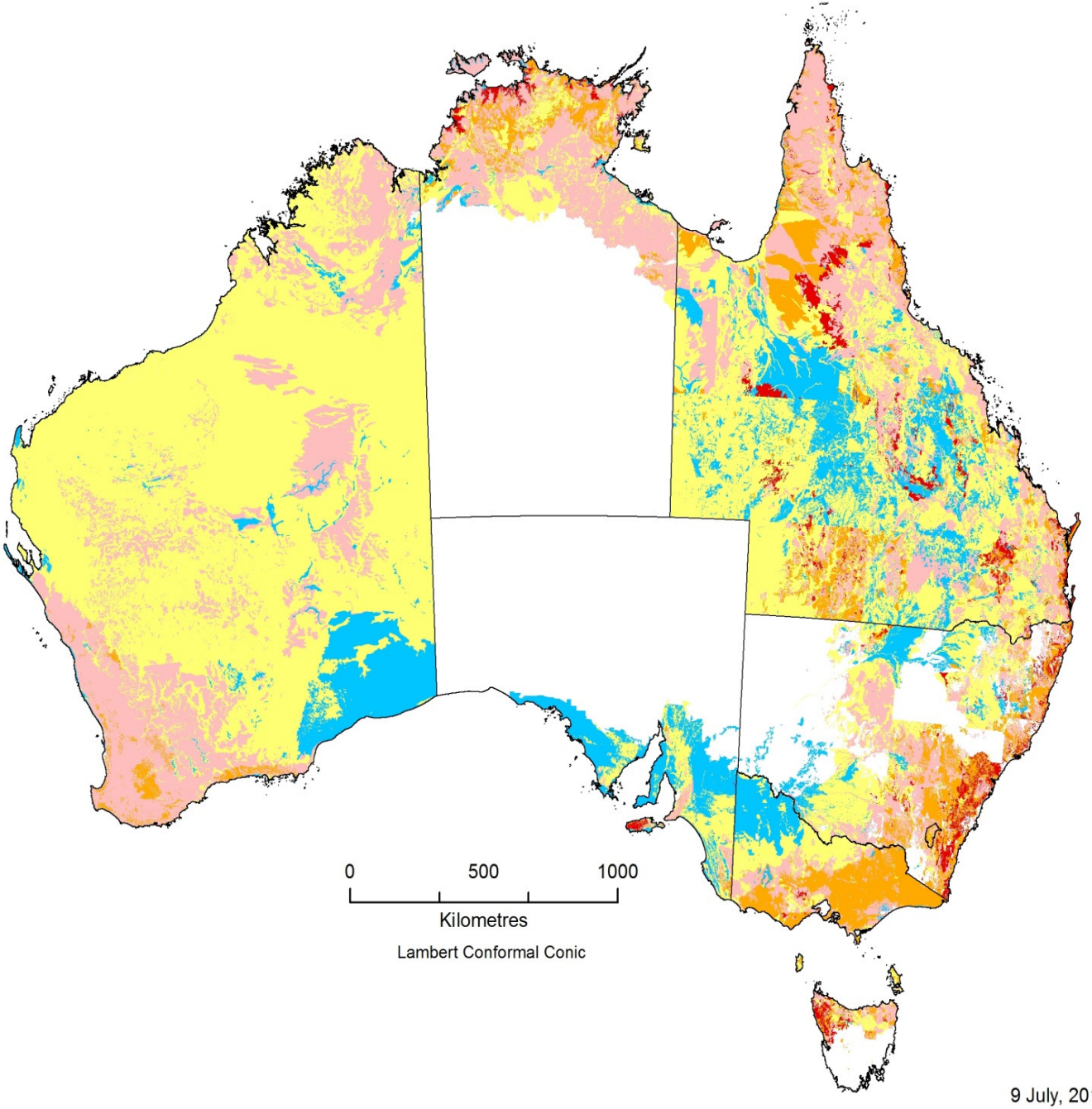
pH ($CaCl_2$ 1:5)

- > 8.5
- 7.1 - 8.5
- 5.6 - 7.0
- 4.9 - 5.5
- 4.4 - 4.8
- < 4.3

Source

- Level 5 (ASRIS)
- Level 4 (ASRIS)
- 0 - 10cm (NSW DECC)
- No data





9 July, 2010

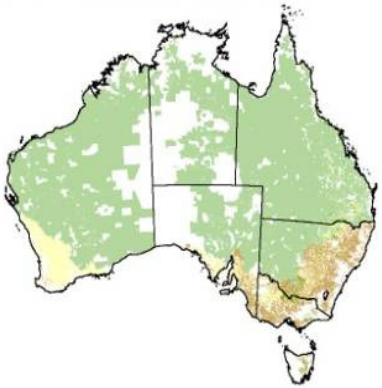
Net Acid Addition Rate (NAAR)

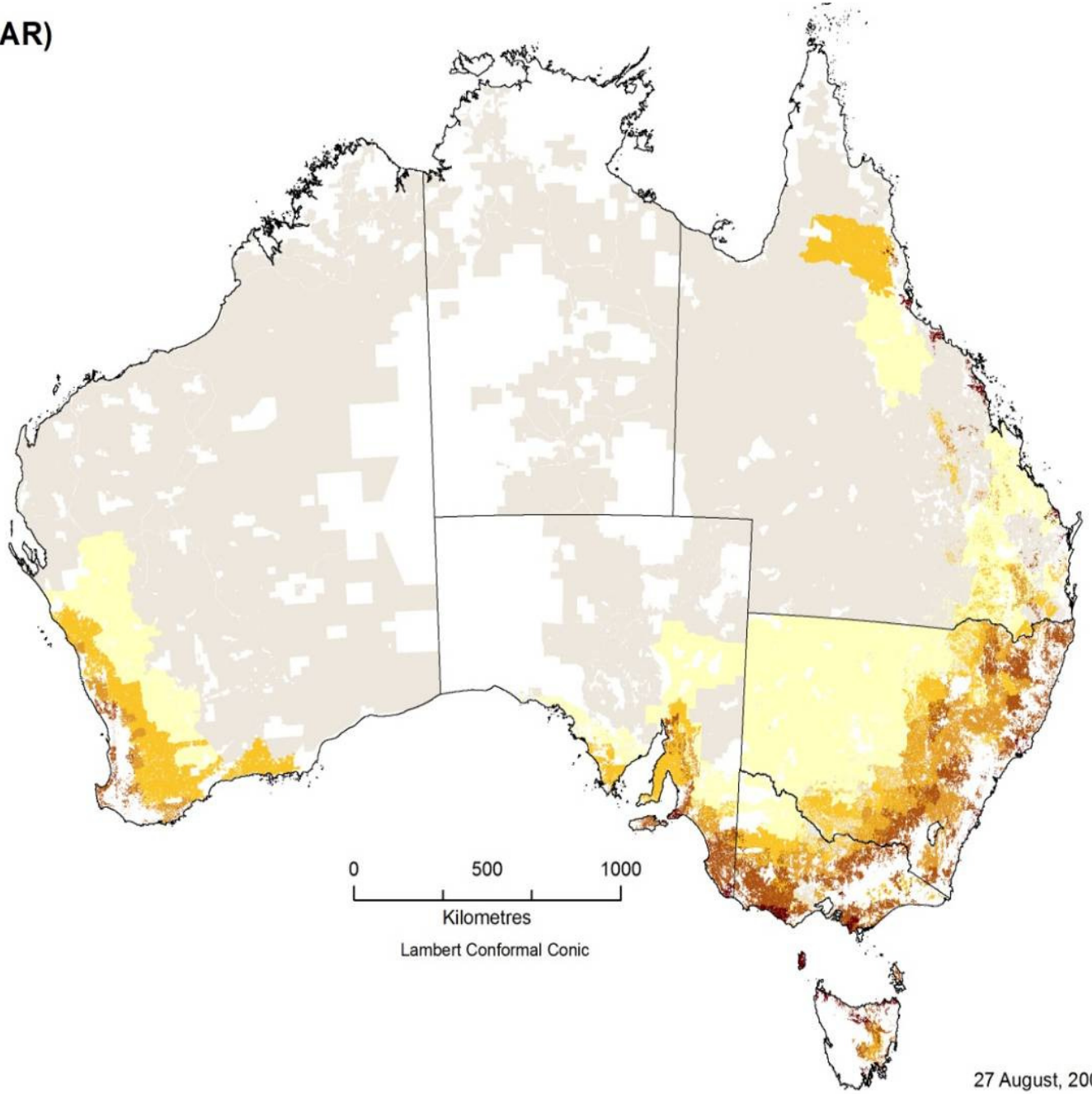
NAAR (eq. Mg CaCO3/ha/yr)

- 0 - 0.05
- 0.05 - 0.1
- 0.1 - 0.15
- 0.15 - 0.25
- > 0.25
- No data
- Other land uses not considered

Catchment Scale Land Use

- Dryland cropping
- Grazing modified pastures
- Grazing natural vegetation
- Irrigated pastures and cropping
- Other land uses not considered





27 August, 2009

Time to critical pH

AR = (pHBC x 5 x Tc x BD) x (Curr pH – Crit pH)
x (1- CF/100)

Time (yrs) = AR / NAAR*PNAAR/100

Time to reach critical pH 5.5 (0 - 10 cm)