Soil Structure, Soil Organic Matter and Soil Health – Lets get back to Basics

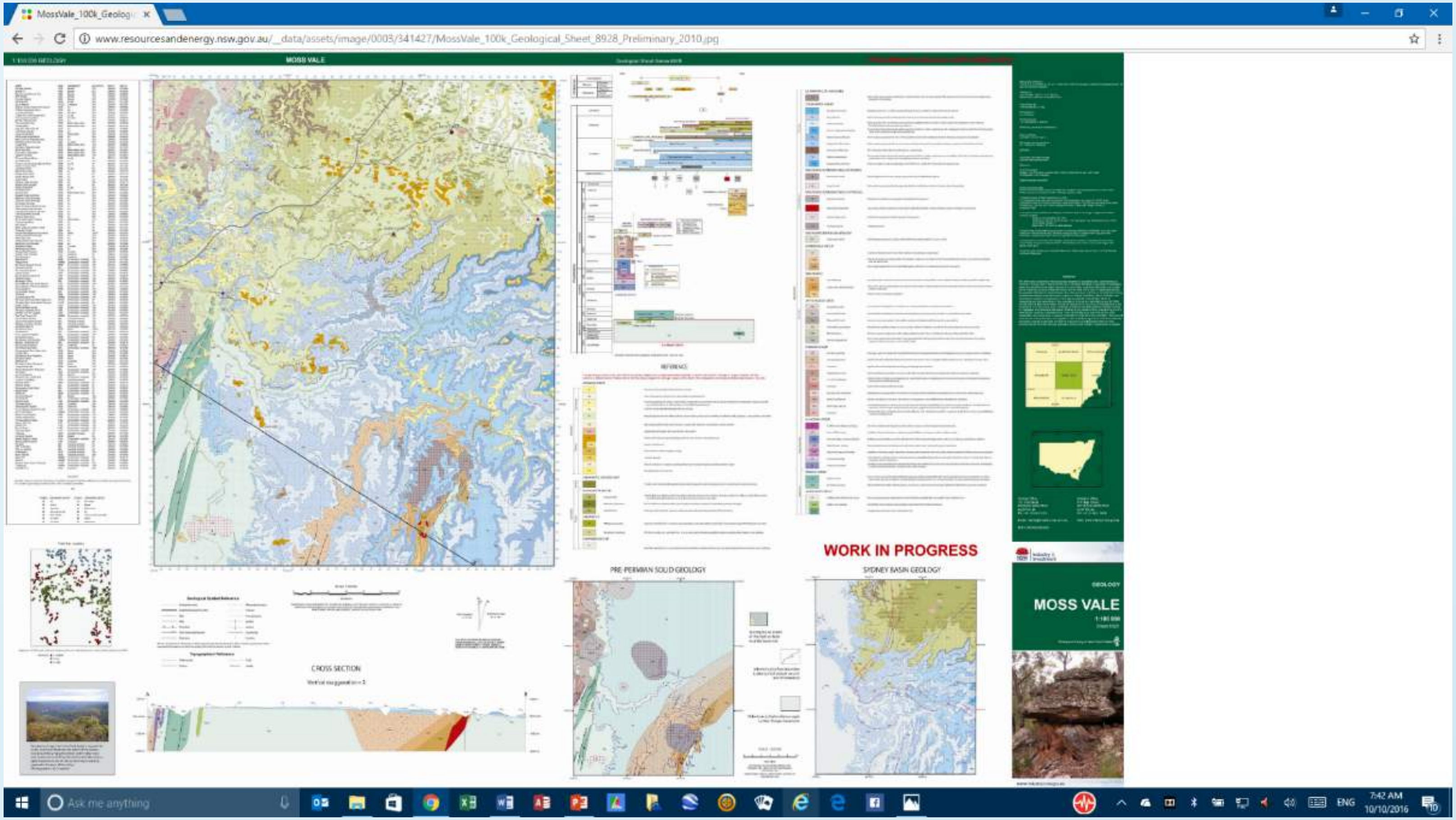
Ian Packer

SOIL KNOWLEDGE NETWORK (Inc.)

Acknowledgements to Brian Murphy and Mark Conyers

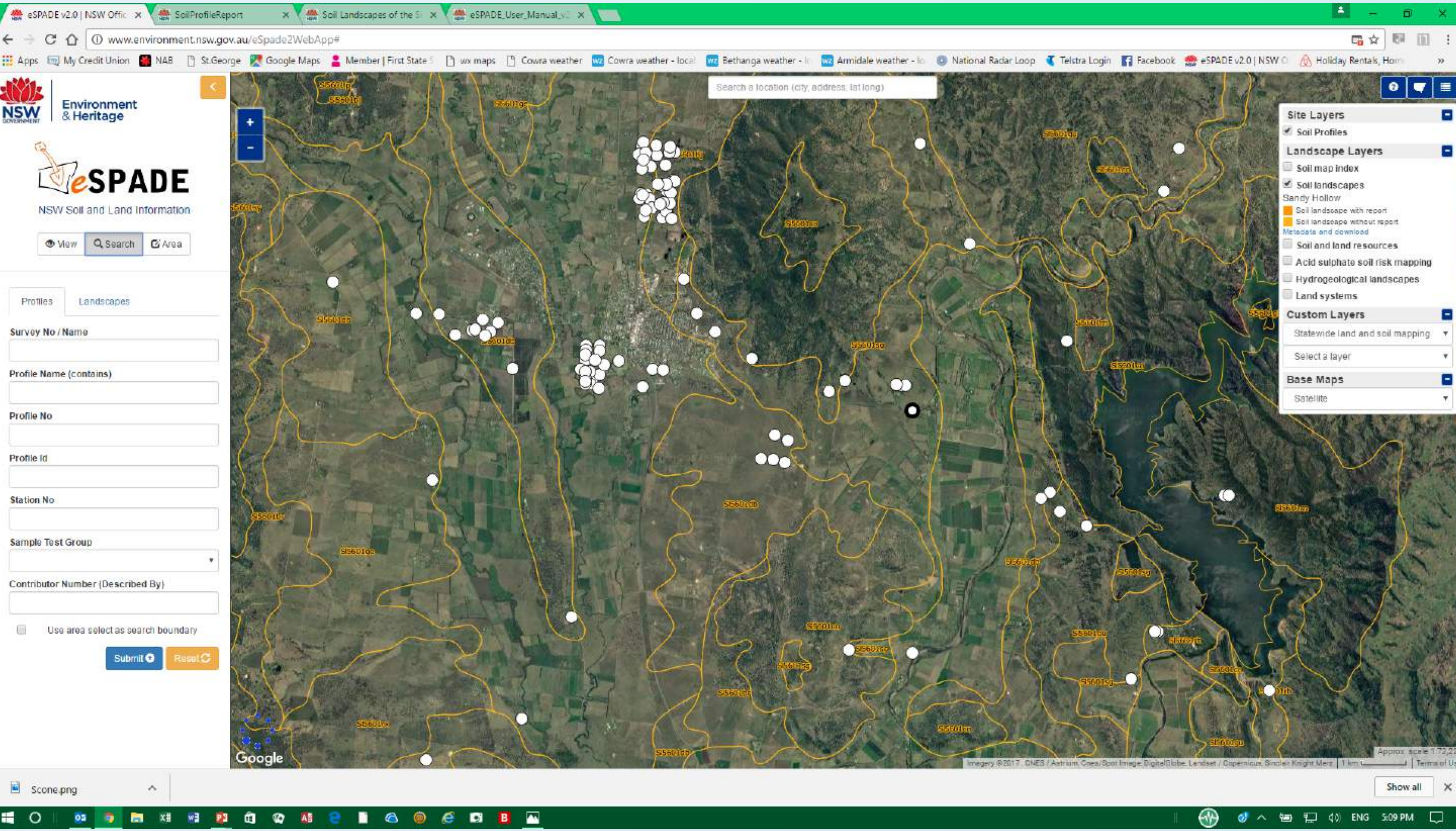
What is my Soil? – Tools in the Shed

- **Identify your geology - http://www.resourcesandenergy.nsw.gov.au/**



- **Use e SPADE - http://www.environment.nsw.gov.au/eSpadeWebapp/ to see what soil profiles have been done in your area and if you are lucky the NSW Soil Landscape maps may have been done**

eSPADE – Soil Profiles with Landscapes



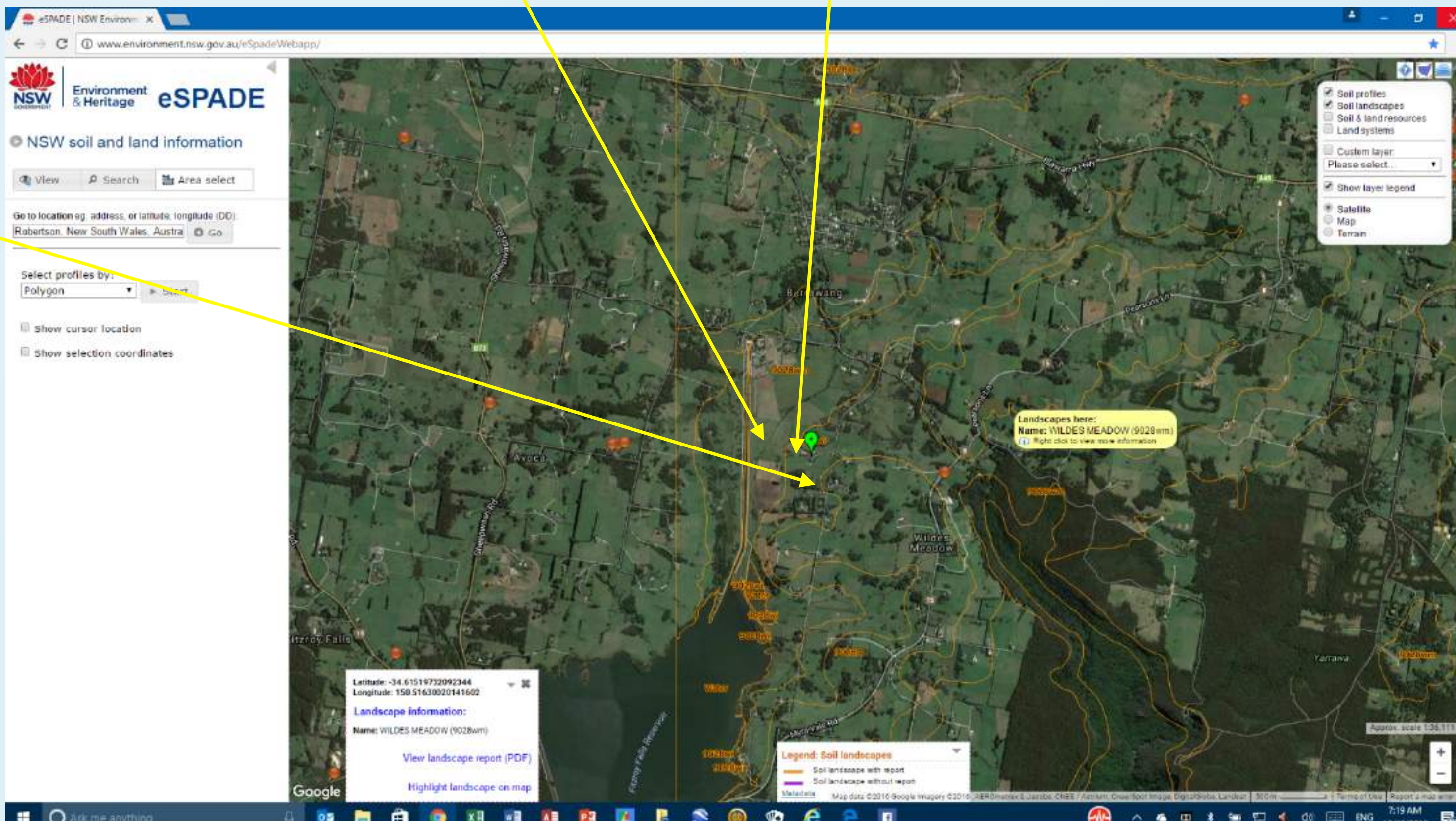
Black round dot is Scone Research Center

At the Farm Level – 150 ha near Burrawang

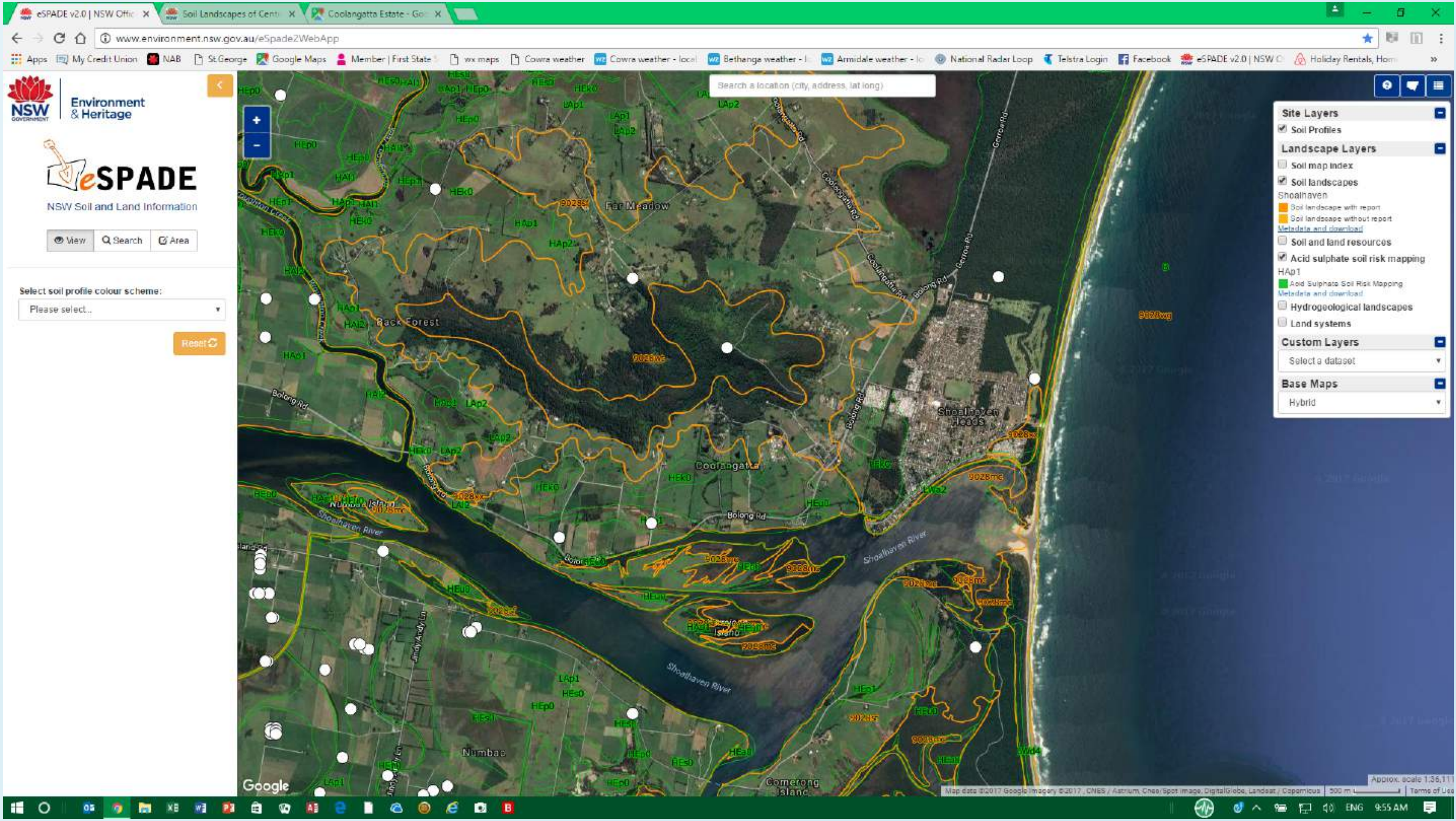
The Wingecarribee soil landscape recent alluvium (quaternary period) deep acid peats in swampy areas rising to gleyed podsolic soils on the flats

The Wildes Meadow soil landscape derived from Bringelly shale (mudstones and claystones). Naturally acid clayey or fine sandy/silt loam topsoils with sandy clay/ mottled yellow clays at depth which are very acid (water pH 3.5 to 4.5).

The Robertson Landscape derived alkaline olivine basalts with yellow ferrosols and red/brown kraznozems with neutral pH clay loam surface texture.



Acid Sulphate Soils – Locate them with eSPADE



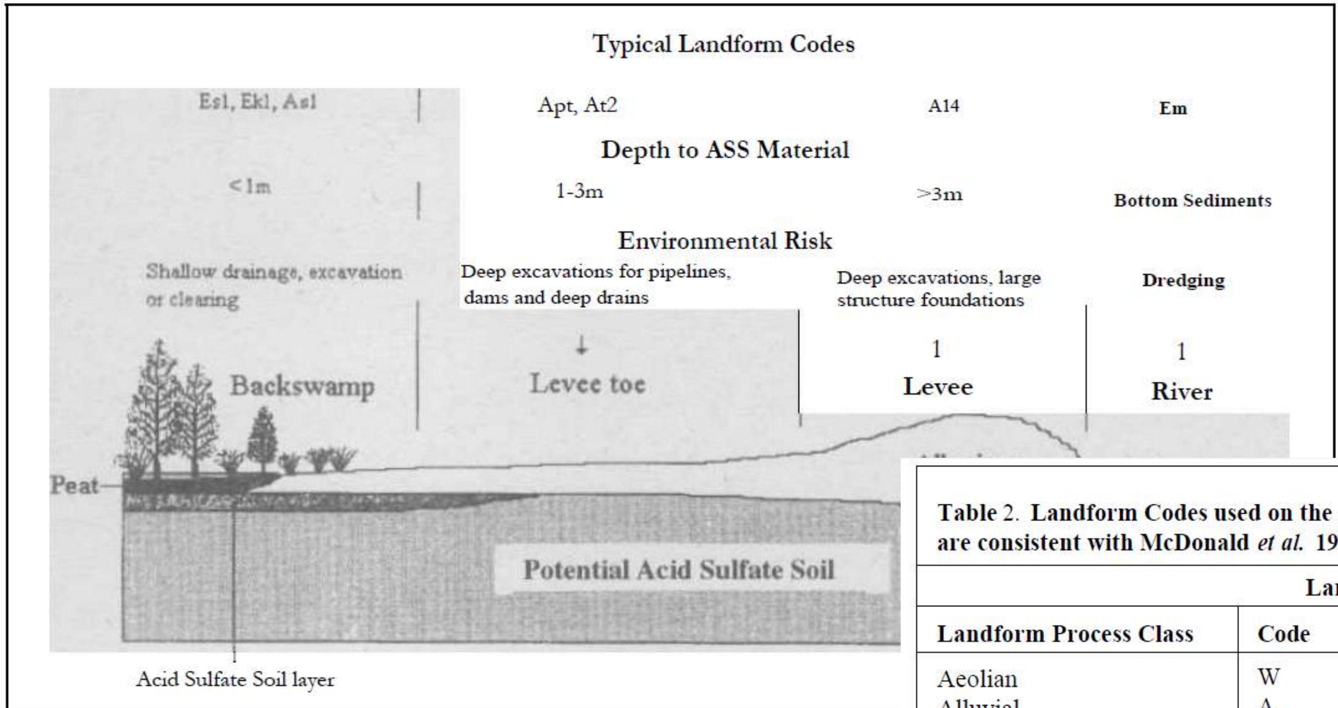


Figure 2 - Schematic cross-section of a lcrce to backswamp landform indicating typical la
and land use activities with an environmental risk.

Table 2. Landform Codes used on the Acid Sulfate Soil Risk Maps (Landform elements are consistent with McDonald *et al.* 1990)

Landform Codes			
Landform Process Class	**Code**	**Landform Element**	**Code**
Aeolian	W	Backplain	b
Alluvial	A	Backswamp	k
Beach	B	Bottom Sediments	m
Estuarine	E	Channel	n
Lacustrine	L	Dune	d
Swamp	S	Interbarrier Swamp	r
Disturbed Terrain	X	Intertidal Flat	i
		Lagoon	g
		Levee	l
		Levee Toe	t
		Ox-bow	o
		Plain	p
		Sandplain	a
		Swamp	s
		Splay	y
		Supratidal Flat	u
		Swale	w
		Tidal Creek	c
Elevation (AHD)	**Code**	**Additional Descriptive Codes**	**Code**
0 - 1 m	0	Pleistocene	(p)
1-2m	I	Acidic Scald	(s)
2-4m	2		
>4 m	4		

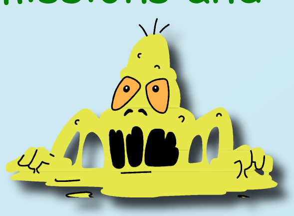
Landform Codes

Why have Healthy Soils?

- **Protect the soil from blowing away or washing away**
- **Buffering the impacts of nutrient leaching and acidification**
- **More soil water and nutrients**

But there other issues to consider in the debate about soil:

- Non renewable resource
- Key to many successful NRM programs – nutrient bulges, grazing, biodiversity
- Main resource for continued farm income and profitability
- Critical resource in addressing climate change, greenhouse emissions and food security



We don't have erosion anymore !!!!! - Causes of Erosion

- **Rainfall Energy and Impact (Erosivity)**
  - causes splash erosion and surface sealing by disaggregating and stirring the soil
- **Wind Erosion**
  - 50% ground cover
  - Fine vs coarse cultivation, stubble
- **Soil Erodibility**
  - influenced by clay, silt & sand content, aggregate stability (organic matter), soil structure & permeability
  - land management
  - slope and steepness
  - crop and pasture management - 70% cover?

- **Soil must be in good condition - cover is not the ultimate answer**

Soil Health and Soil Quality

- **The terms are interchangeable**
- **Soil Health – 'Feel good' concept -** "Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production."
- **Being a scientist I prefer Soil Quality which qualifies soil properties and functions:**
  - Soil Texture
  - Soil Organic Matter
  - Particulate organic matter
  - Microbial biomass / soil enzyme activity
  - Electrical conductivity
  - Cation Exchange Capacity
  - pH
  - Infiltration / runoff
  - Bulk density / porosity
  - Aggregate stability / friability
  - Salinity / sodicity
  - Inorganic and total N,P and K
  - Potentially mineralizible N
- **The list goes on to pin down why a soil is healthy.**

What is Soil Health?

Bad

Good

Soil Structure
Compaction
Porosity /Infiltration

Physical

Soil Quality

Acidity
Cation Exchange Capacity
Electrical Conductivity
Nutrients

Chemical

Biological

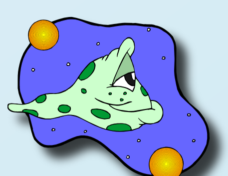
Soil Organic Matter
Soil Biomass
Macro and Micro
Organisms

Soil Productivity

Food Quality and Security

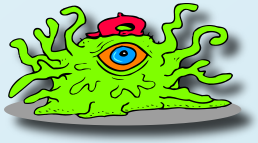
Environmental Quality – Resilience and Sustainability

Health – Humans and Animals



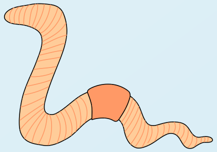
Adapted from Jill Clapperton, 2007

Soil Health



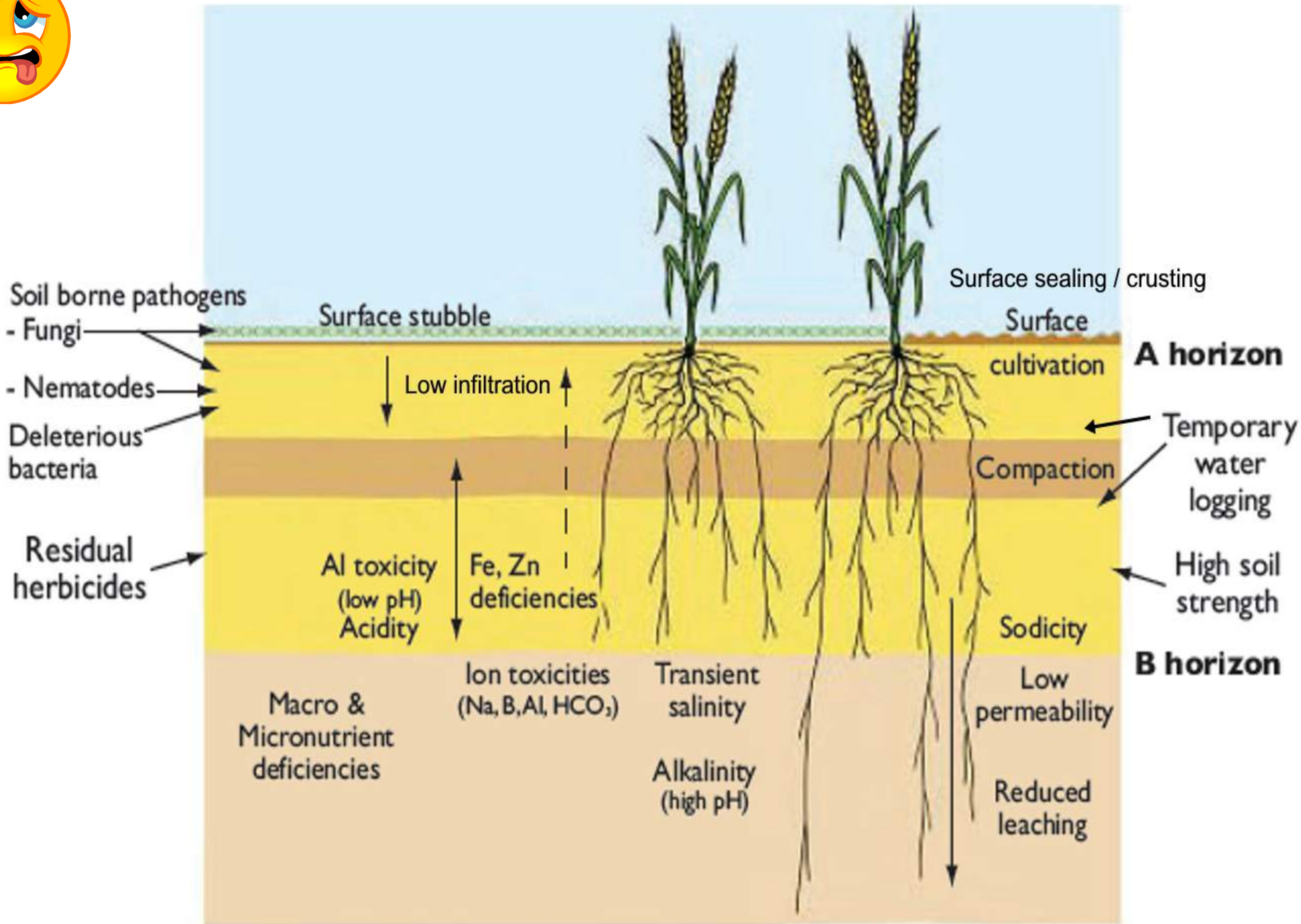
- 'Sustainability' - Improved or maintained not sustained

Soil Organic Carbon – a surrogate indicator



Irrespective of the climate debate, soil quality and its organic matter content must be restored, enhanced and improved. R. Lal, West Lafayette, Indiana (2008)

Surface and Subsurface Soil Constraints
- Physical, Chemical & Biological



Source: © Rengasamy et al. (2003). *Plant & Soil* **257**, 249-260. With kind permission of Springer Science.

Soil Physical Properties

1. Soil Texture

How a soil feels it is the dirt of soil which is composed of

- Dirt – mineral particles derived from the parent material
- Air
- Water
- Soil Biology – organic matter and living micro and macro organisms
- Dissolved nutrients

Important for:

- Estimating the soil water holding capacity
- Assess infiltration rate and soil drainage
- Estimating the amount of lime needed to raise soil pH
- Converting the water extract electrical conductivity to estimate the soil salinity - important for selecting suitable crop and pasture species
- Selecting suitable sites for infrastructure - dams, banks, channels and drains

2. Tillage & Stock Compaction – Soil Bulk Density

- Stock compaction does occur in pasture/crop situations with sheep and cattle exerting the same or more ground pressure than tractors.

- Some static pressures (weight per area of contact) are:

Horses – shod	295 kPa
Cattle	185 kPa
Sheep	82 kPa
Kangaroo	46 kPa
Alpaca	39 kPa
Camel	33 kPa
Tractors	30-150 kPa
Man	95 kPa

- Sheep compaction occurs at about the same depth as ploughpans created by disc ploughs – 10-15 cms

- Cattle compact deeper and pug the soil more leaving the surface rough

Critical Bulk Density Values

Table 1. Average minimum bulk densities that restrict root penetration in soils of various textures.

Texture	Bulk Density g/cc
Coarse, medium, and fine sand	1.80
Loamy sand and sandy loam	1.75
Loam and sandy clay loam	1.70
Clay loam	1.65
Sandy clay	1.60
Silt and silt loam	1.55
Silty clay loam	1.50
Clay	1.40

Bulk Density and Soil Type

Bulk Density (kgs/m^3)	Sandy Soils	Loams	Clay Soils
<1.0	-	Satisfactory	Satisfactory
1.0 – 1.2	-	Satisfactory	Satisfactory
1.2 – 1.4	Very open	Satisfactory	Some too compact
1.4 – 1.6	Satisfactory	Some too compact	Very compact
1.6 – 1.8	Mostly too compact	Very compact	Highly compact
>1.8	Very compact	Extremely compact	Excessively compact

Bulk Density and Air

Gravimetric Moisture Content (%)	Bulk Density to give 10% air (kgs/m^3)
5	2.10
10	1.90
20	1.55
30	1.33
40	1.15

Bulk Density and Penetration Resistance

Penetration resistance (MPa)	Degree of Soil Consolidation	Effect on root growth
<0.50	Loose	Not affected
0.50 – 1.25	Medium	Root growth of some cereal plants may be affected
1.25 – 2.00	Dense	Cereal root growth badly affected
2.00 – 3.00	Very Dense	Very few plant roots penetrate the soil
>3.0	Extremely dense	Root growth virtually ceases

Tillage Compaction - Soil Density

Soil Bulk Density (g/cm^3)

	Permanent Pasture	Direct Drilling	Reduced Tillage	Conventional Tillage
Ginninderra	1.30	1.22	1.36	1.41
Wagga Wagga		1.36	1.34	1.42

Conclusions

- Less soil disturbance in DD treatment at Ginninderra – Siroseeder vs full disturbance combine
- Longer time period at Ginninderra 8 years vs 4 years
- More grazing impact at Wagga Wagga
- There was a plough pan at 5 cm in Wagga Wagga
- The drier climate at Wagga may have slowed changes

Bulk Density – Junee Tillage Trial

Treatments

* Old lucerne stand with low population (Lb)
* Direct drilled paddock for 4 years. Compared
  - Bare soil surface (DDb)
  - Stubble covered soil surface (DDs)

Bulk Density (g/cm3)

Depth	Lb	DDb	DDs	DD Mean
0 - 4 cm	1.45	1.26	1.29	1.275
4 - 8 cm	1.5	1.47	1.45	1.46
8 - 12 cm	1.65	1.61	1.61	1.61
Mean 0 - 12 cm	1.53	1.45	1.45	1.45

Conclusions

- Direct drilled paddocks lighter surface density
- No effect at depth - plough pan problem
- Reduce density at depth with deep ripping in short term and develop stable biological porosity in the long term

Pasture Studies

CSIRO Grazing Trial at Ginninderra, Canberra (1990 – 1994)

- Established 1989 with conventional techniques.
- Grazed with 10 dse/ha until 1992 and then crash grazed for 3 - 4 weeks to control growth until sampling time
- Treatments were 2 summer active perennial grasses compared to winter active perennial grass

DLWC Research Station Wagga Wagga (1991 – 1993)

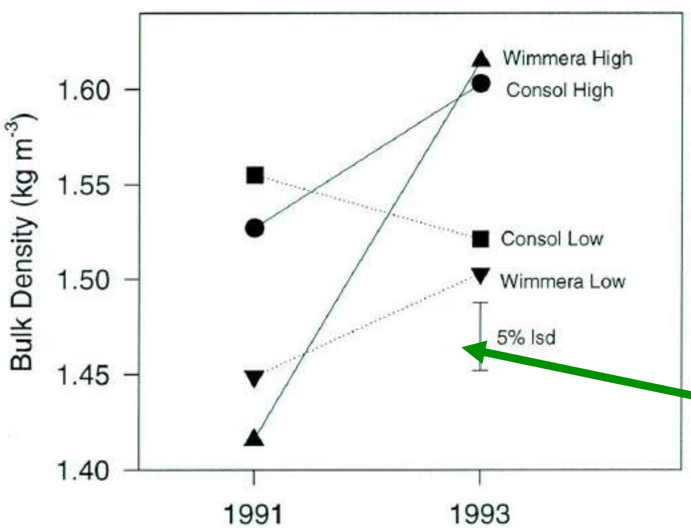
- Established in 1989
- Compared a summer active perennial with a Wimmera ryegrass subterranean clover treatment
- 2 grazing rates – 9 dse/ha and 6 dse/ha.

Soil Measurements

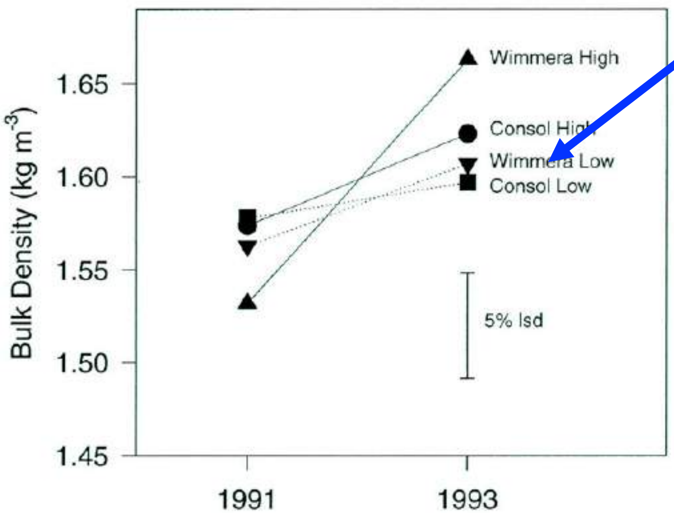
- Change in hydraulic conductivity, runoff (bare soil surface),
- Sediment loss and bulk density.

Some Results

Change in Bulk Density (0-4 cm) at Wagga - Species by Stocking Rate Effect



Change in Bulk Density (8-12 cm) at Wagga - Species by Stocking Rate Effect

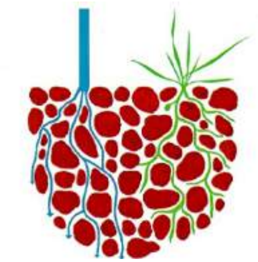


- Soil physical properties significantly declined whether winter or summer active species or grazing rate – infiltration amount went from 56% in 1991 to 39% in 1993
- Infiltration rates from 25 mm/hr to 5 mm/hr
- High grazing rates compacted the soil
- Compaction occurred at 8 - 12 cm
- Similar results both at Canberra and Wagga Wagga
- Infiltration rate was impeded by actively growing plants and roots – needed to create channels from dead roots

3. Porosity and Infiltration

- Infiltration is controlled by the amount and size of big pores in the soil

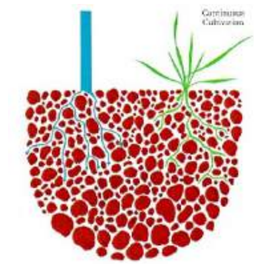
Water Flow = (Pore Radius)^4



Good Soil Structure

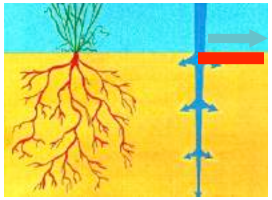
Compared to a 0.50 mm pore:

- a 1 mm pore carries 16 times more water
- a 2 mm pore carries 256 times more water
- a 3 mm pore carries 1296 times more water (worm hole)
- a 5 mm pore carries 10,000 times more water (lucerne root)

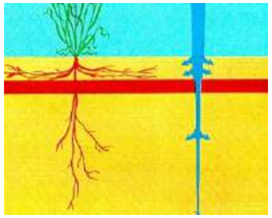


Bad Soil Structure

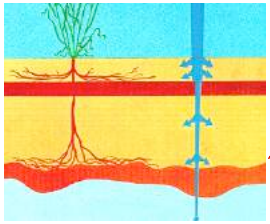
* Infiltration is also controlled by surface sealing or crusting and compaction layers in the soil



Surface Sealing or crusting formed from low organic matter and surface stability, no cover and raindrop impact or surface compaction/pulverisation. Increased runoff and erosion



Plougpans or compaction zones usually at 10 to 15 cms . Formed from excessive stock compaction or overcultivation. Significantly reduce infiltration rate especially to depth. Can be deeper in clay soils

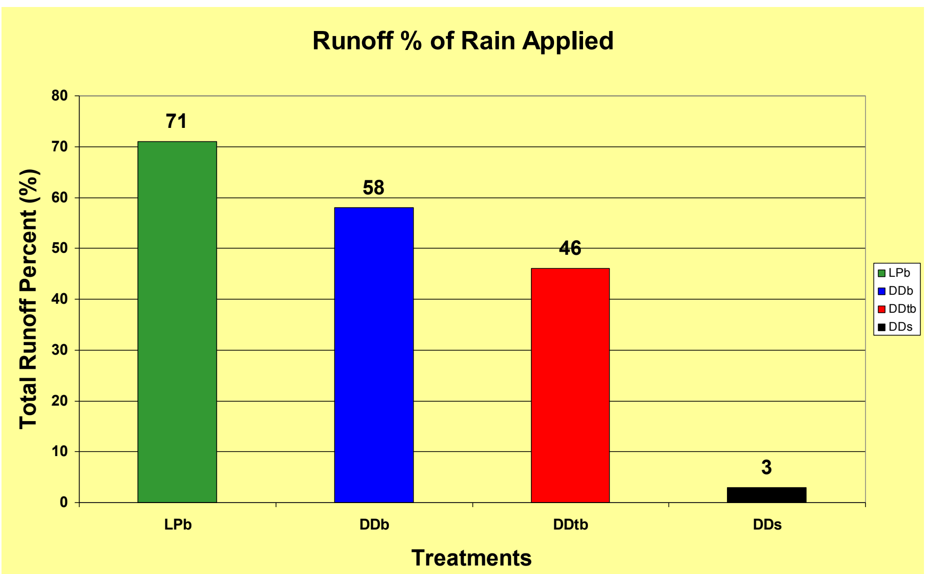


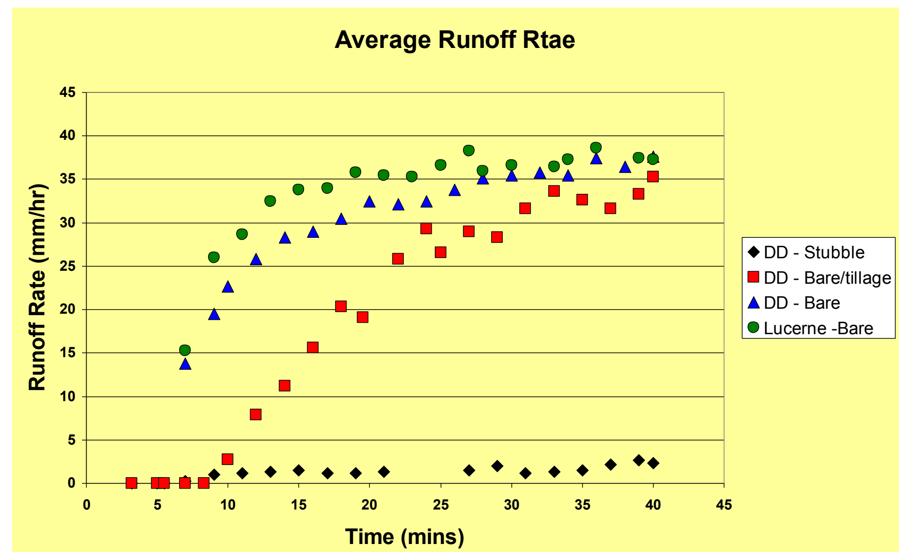
Natural Pans – caused from cementation of leached agents such as silica. Often too deep to address so just have to recognise

4.Water Erosion and Infiltration - Junee

Rainfall simulation study on paddocks that had:

- * Old lucerne stand with low population (LPb)
- * Direct drilled paddock for 4 years. Compared
  - Bare soil surface (DDb)
  - Bare cultivated soil surface (DDtb)
  - Stubble covered soil surface (DDs)





- **Cultivated soil only effective for 7 mins sealed then reached same RO rate as other bare treatments**
- **Fragility of soil improvements**
- **Stubble DD RO rate remained at < 5 mm/hr**

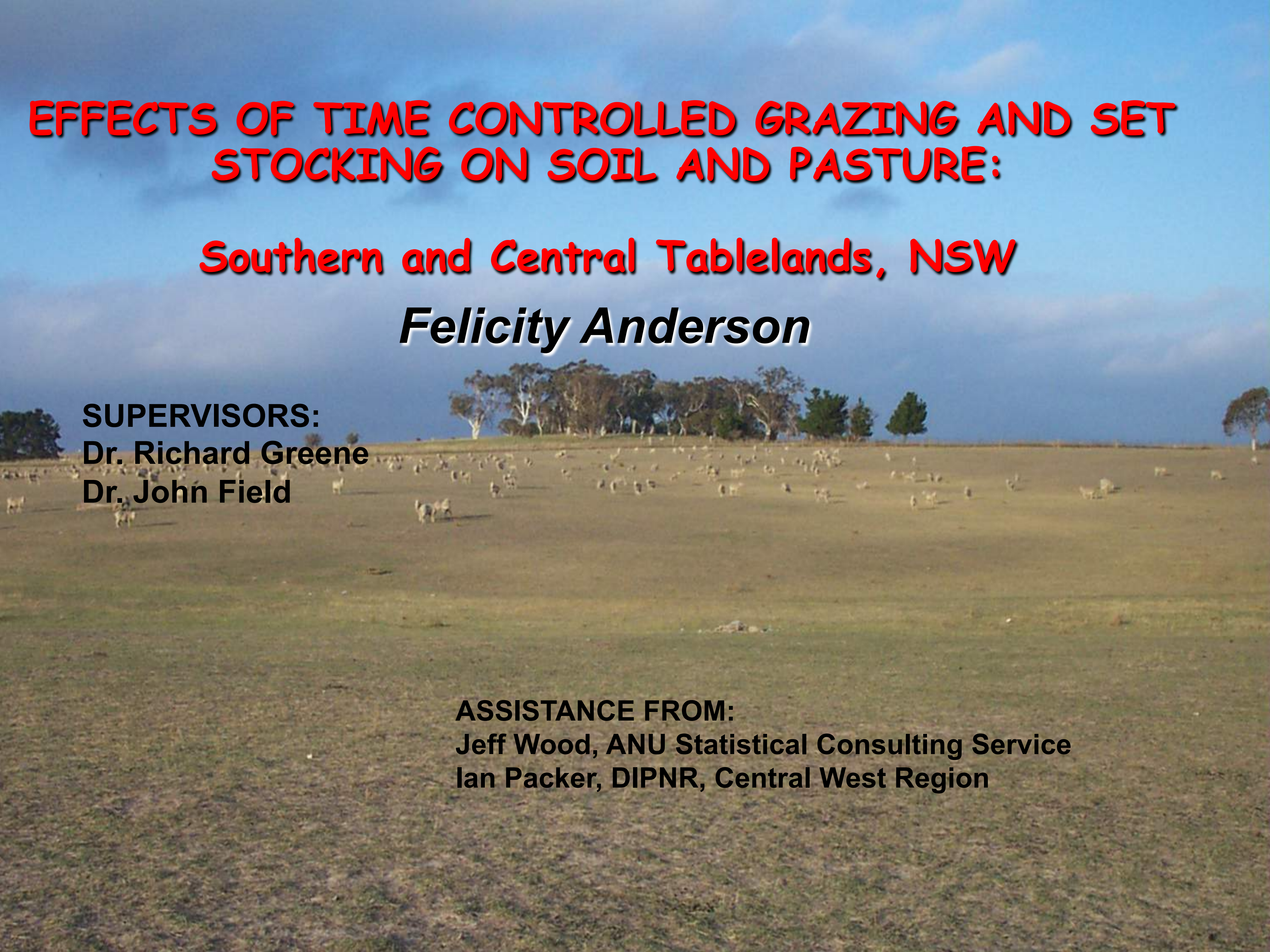
Erosion in Pastures

Erosion in pastures does occur

- poor ground cover - nutrition, pH, overstocking
- surface pulverisation
- subsurface compaction - restricts infiltration

Addressed by Conservation Grazing

- controlled ground cover management - Prograze
- time controlled grazing/cell grazing techniques
- pasture types for conditions - native grasses
- trees - riparian zone, windbreaks etc.
- strategic earthworks



EFFECTS OF TIME CONTROLLED GRAZING AND SET STOCKING ON SOIL AND PASTURE:

Southern and Central Tablelands, NSW

Felicity Anderson

SUPERVISORS:
Dr. Richard Greene
Dr. John Field

ASSISTANCE FROM:
Jeff Wood, ANU Statistical Consulting Service
Ian Packer, DIPNR, Central West Region

Background

- **MLA,2000, Cullen *et al.* 2003, The Wentworth Group, 2002 identified that agricultural systems in the tablelands High Rainfall Zones) was unsustainable - so what about sustainable grazing systems**
- **Grazing in the High Rainfall Zones lead to:**
  - soil acidification
  - pasture degradation
  - Salinity
  - Soil erosion and runoff of nutrients
- **Time Controlled Grazing (TCG) proposed as a sustainable alternative grazing method (Savory, 1999)**
- **Investigated the impact into TCG as a method of rotational grazing in its own entity**

Some Results

- Less runoff and erosion
- Decreased rate of soil acidification
- Potential to decrease deep drainage through increased water usage by perennial plants
- Increased ground cover under TCG due to increased perenniality
- Increased sustainability of production

5. Available Water

Total Available Water (TAW) (-8 to -1500 kPa}, mm per cm of soil profile

Texture	Sand size	Compacted 0% CF	Not Compacted 0% CF	Compacted 20% CF	Not Compacted 20% CF	Compacted 40% CF	Not Compacted 40% CF	Compacted 60% CF	Not Compacted 60% CF	Compacted 80% CF	Not Compacted 80% CF
Sand	Coarse	0.20	0.20	0.16	0.16	0.12	0.12	0.08	0.08	0.04	0.04
	Medium	0.45	0.45	0.36	0.36	0.27	0.27	0.18	0.18	0.09	0..09
	Fine	0.60	0.60	0.48	0.48	0.36	0.36	0.24	0.24	0.12	0.12
Loamy Sand / Clayey Sand	Coarse	0.55	0.55	0.44	0.44	0.33	0.33	0.22	0.22	0.11	o.1i
	Medium	0.75	0.75	0.60	0.60	0.45	0.45	0.30	0.30	0.15	0.15
	Fine	0.90	0.90	0.72	0.72	0.54	0.54	0.36	0.36	0.18	0.18
Sandy Loam	Coarse	0.55	1.40	0.44	1.12	0.33	0.84	0.22	0.56	0.11	0.28
	Medium	0.80	1.40	0.64	1.12	0.48	0.84	0.32	0.56	0.16	0.28
	Fine	1.40	1.95	1.12	1.56	0.84	1.17	0.56	0.78	0.28	0.39
Loam		1.15	1.95	0.92	1.56	0.69	1.17	0.46	0.78	0.23	0.39
Sandy Clay Loam		1.15	1.60	0.92	1.28	0.69	0.96	0.46	0.64	0.23	0.32
Clay loam		1.00	1.65	0.80	1.32	0.60	0.99	0.40	0.66	0.20	0.33
Clay		0.90	2.10	0.72	1.68	0.54	1.26	0.36	0.84	0.18	0.42

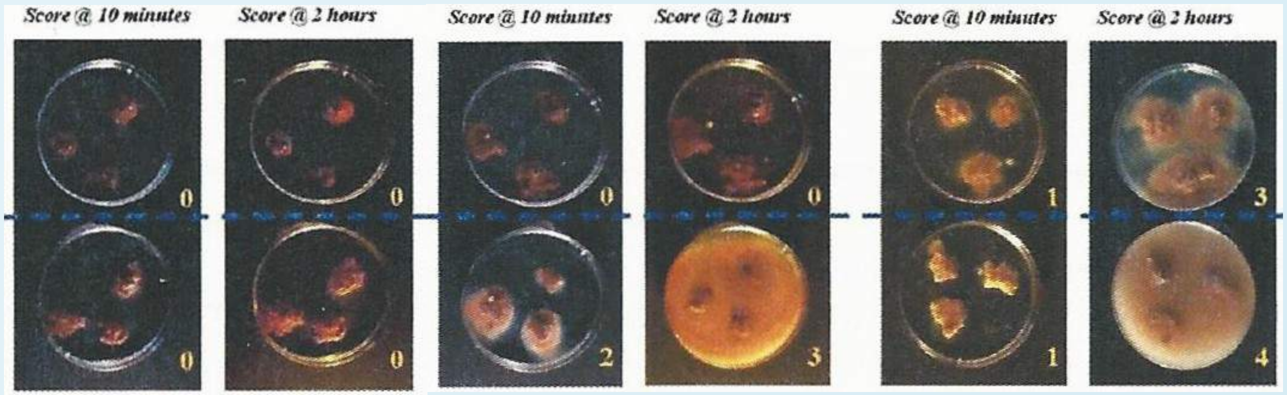
Readily Available Water (RAW) (-8 to -60 kPa}, mm per cm of soil profile

Sand	Coarse	0.20	0.20	0.16	0.16	0.12	0.12	0.08	0.08	0.04	0.04
	Medium	0.40	0.40	0.32	0.32	0.24	0.24	0.16	0.16	0.08	0.08
	Fine	0.44	0.44	0.35	0.35	0.26	0.26	0.18	0.18	0.09	0.09
Loamy Sand / Clayey Sand	Coarse	0.43	0.43	0.34	0.34	0.26	0.26	0.17	0.17	0.09	0.09
	Medium	0.48	0.48	0.38	0.38	0.29	0.29	0.19	0.19	0.10	0.10
	Fine	0.51	0.51	0.41	0.41	0.31	0.31	0.21	0.21	0.10	0.10
Sandy Loam	Coarse	0.43	0.63	0.34	0.51	0.26	0.38	0.17	0.25	0.09	0.13
	Medium	0.49	0.63	0.39	0.51	0.29	0.38	0.20	0.25	0.10	0.13
	Fine	0.63	0.77	0.51	0.61	0.38	0.46	0.25	0.31	0.13	0.15
Loam		0.57	0.77	0.46	0.61	0.34	0.46	0.23	0.31	0.11	0.15
Sandy Clay Loam		0.57	0.68	0.46	0.55	0.34	0.41	0.23	0.27	0.11	0.14
Clay loam		0.54	0.69	0.43	0.55	0.32	0.42	0.21	0.28	0.11	0.14
Clay		0.51	0.80	0.41	0.64	0.31	0.48	0.21	0.32	0.10	0.16

Based an the data of Moore et al. {1998) ond Wetherby {2003)

CF – coarse fragments > 2mm

6. Slaking vs Dispersion – Organic Matter vs Sodicity



Undisturbed Aggregates

Aggregates remoulded when wet

SAMPLE A

SAMPLE B

SAMPLE C

ASWAT score = 0 (0+0+0+0)

ASWAT score = 5 (0+0+2+3)

ASWAT score = 9 (1+3+1+4)

Undisturbed Aggregates

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Management Needs

Stable in water. Keep up the good work.

Avoid energy inputs on wet soil such as raindrop impact, cultivation, livestock trampling, machinery compaction

Add gypsum and/or lime to address dispersion. In the long term increase soil organic matter.