Camboya Landcare Association Inc.

Know Your Soils

A manual describing soil properties and nutrient function

Produced for Clifton State High School, Dalby State High School and Pittsworth State High School

As part of CLG – 1205831–545
Understanding Sustainable Land Management Practices
on Central Darling Downs

Australian Government

Queensland Government

Contents

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Know Your Soil

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Great state. Great opportunity.

Queensland Government

- Soil components
- Important soil properties

Soil Components

- Mineral particles (inorganic fraction) – small particles of rock and other minerals, produced from weathering of rocks (sand, silt, clay)
- Organic materials – humus and the dead and decaying parts of plants and soil animals
- Water – the ‘soil solution’ in which nutrients for plants are dissolved
- Air – which fills the spaces between the soil particles not filled by soil solution
- Living organisms – ranging in size from small animals to viruses

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Why do soils differ?

- Different proportions of the main components
- Components are grouped together in different ways
- Many different types of minerals in the inorganic fraction, and each soil has different proportions of them

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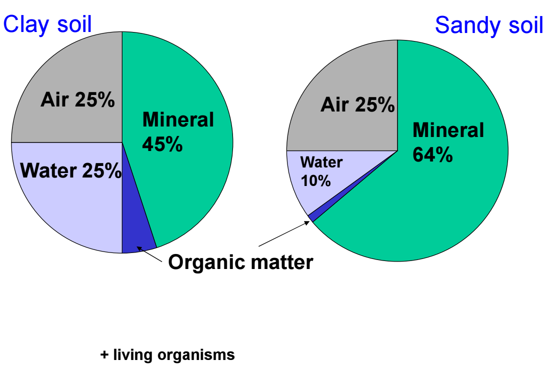
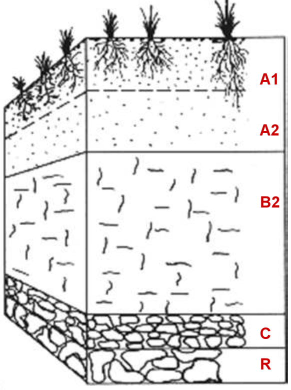
Soil components



- When talking about soils, it’s not just about the surface and what you can see
- Plant roots are not confined to the top 10 cm (they frequently extend below 1 m) – the subsoil is just as important as the surface soil

Soil Profile

Soil horizon = A layer of soil with properties different from layers above and/or below it



Soil Forming Factors

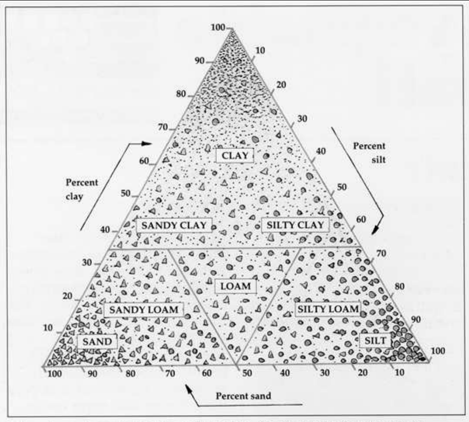
- Parent material (geology, rock type)
  - granite = often sandy, infertile
  - basalt = clayey, fertile
- Climate (rainfall, temperature, wind)
  - influences rate of weathering, plant growth
- Topography (shape, length, grade of slope, aspect)
- Organisms
  - plants, bacteria, fungi, animals, worms, insects
- Time

Important Soil Properties

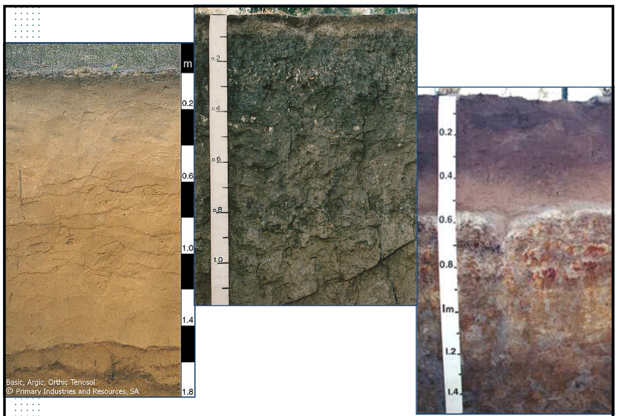
- Texture
- Structure
- Colour
- Chemistry – pH, salinity, sodicity, fertility
- Water and air

Soil Texture

- The proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil
- How a soil 'feels'



Soils can be named according to their proportions of clay, silt and sand using the texture triangle.



Texture influences:

- The amount of water that can be stored in the soil (water holding capacity)
- The rate of water and air movement through the soil (drainage, permeability, aeration)
- Soil nutrient supply (amount and availability)
- Ease of root growth
- Workability, trafficability (potential for compaction)
- Resistance to erosion
- Ability of a soil to maintain a stable pH

Soil Structure

- Soil particles (sand, silt, clay) are usually arranged into larger units (called aggregates or peds)
- Soil structure refers to the size and arrangement of the aggregates, and the pore space between them

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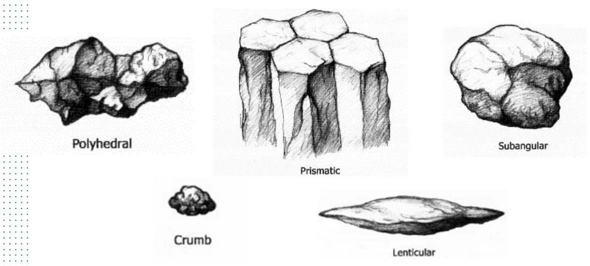
- Structure shape, size and development



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Structure influences:

- Water entry into the soil
- Runoff of water
- Permeability (ease of movement) of water and air in the soil
- Root penetration
- Seedling emergence
- Resistance to erosion
- Workability
- Drainage

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Soil Colour

- Colour may be due to soil forming processes, or inherited from the parent material
- In general, soil colour is determined by the amount and state of organic matter and iron oxides

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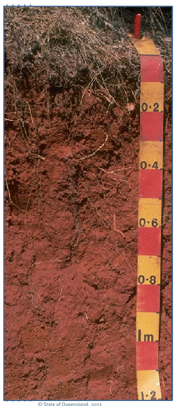
Soil colour gives an indirect measure of other soil attributes:

- Presence/amount of organic matter
- Drainage
- Waterlogging potential
- Degree of leaching

Red



Yellow

Grey/blue grey

Black/dark

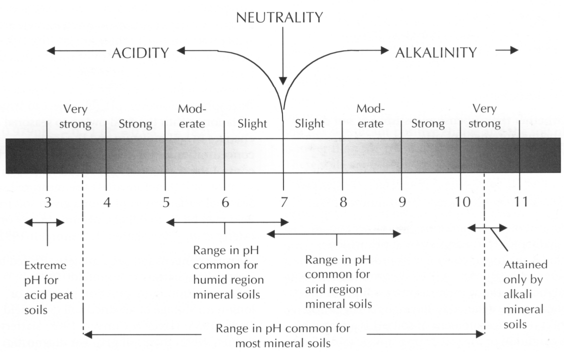
Light grey/pale/bleached

Soil Chemistry

- pH, fertility, salinity, sodicity

Soil pH

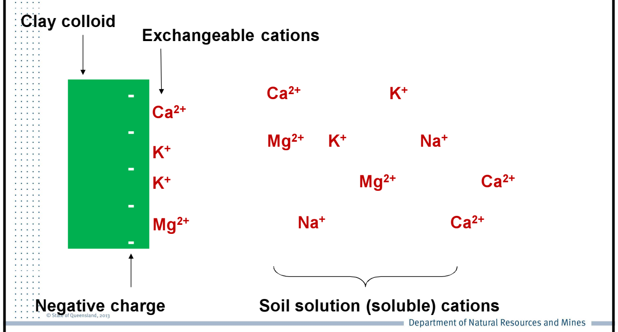
- Soil pH is a measure of the acidity or alkalinity of the soil
- Soil pH determines the availability of different nutrients to plants, and therefore is an important influence on plant growth



Soil Fertility

- Soil fertility refers to the amount and availability of nutrients necessary for plant growth
- Macronutrients = essential plant nutrients required in the largest proportions by plants – N, P, K, S, Ca, Mg
- Micronutrients = nutrients that plants need in only small or trace amounts – B, Cl, Cu, Fe, Mn, Mo, Zn

- Nutrients are held in the soil as electronically charged ions (cations and anions)
- Soil surfaces are charged



Soil Fertility

- Cation exchange capacity (CEC) is the total amount of exchangeable cations a soil can hold (i.e. the soil's negative charge)
- The CEC depends on the amounts and kinds of clay and organic matter that are present
- High clay content and high organic matter content = high CEC

Soil Fertility

- The amount of nutrients in soils depends on interactions between:
  - Soil properties (pH, texture, clay minerals)
  - Soil biology (organisms break down animal and plant matter)
  - Soil organic matter
  - Fertilisers
- The availability of nutrients is strongly influenced by pH

Soil Salinity

- Presence of soluble salts at levels high enough to cause problems
  - Natural feature in this region (primary salinity)
  - Induced due to human activity (secondary salinity)
- Measured using field tests ($EC_{1:5}$) and laboratory tests

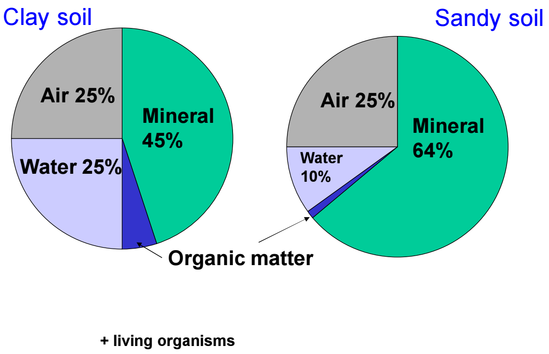
Soil Sodicity

- Presence of a high proportion of sodium ions relative to other cations (like calcium, magnesium, potassium)
- Measured using field test (Emersons) and laboratory tests (Exchangeable Sodium Percentage ESP)

Effects of Sodicity

- Waterlogging
- Surface crusting
- Hardsetting surface
- Poor infiltration rate
- Reduced plant available water
- Poor seedling emergence
- Poor aeration
- Gully and tunnel erosion

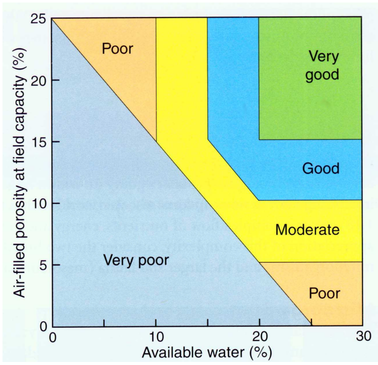
Soil Water and Air



Soil Water and Air

- Water is held in pores
- The amount of water held in soil varies
- Soils with higher clay content hold more water
- Not all soil water is available to plants – this is influenced by:
  - The depth of soil the roots can explore
  - Texture, structure and organic matter

The proportion of soil air and water is important

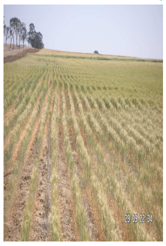


- Understanding your soil means you can manage it appropriately
- So get your hands dirty!

Soil Constraints Management

On-farm identification: Paddock Assessment

Do parts of the paddock or whole paddock display poor crop growth and yield despite good starting moisture and adequate in crop rainfall?

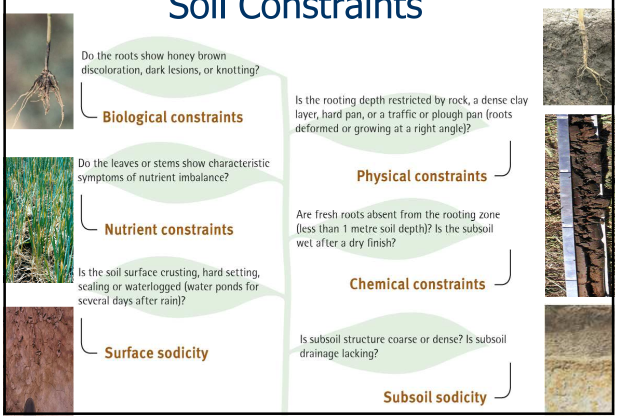


Look for:

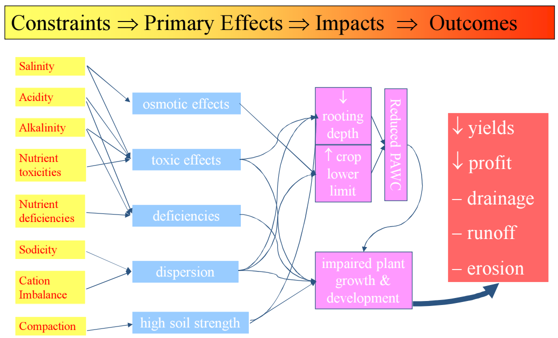
✓Nutrition
✓Disease
✓Insect
✓Nematode
✓Herbicide damage
✓Frost

✓Soil constraints (Biological, Physical, Chemical)
➢Surface
➢Subsoil

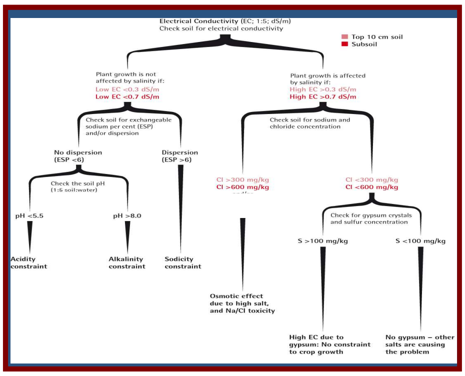
Soil Constraints



Soil Constraints Impacts



Interpretation of soil tests



Management Approaches

- First step is to Id the problem, then determine management options
- 2 options or approaches:

1. Reduce or eliminate the constraint
   - "Amelioration"
2. Optimise production in the presence of the constraint
   - "Live with it"

Amelioration of Salinity

- If high EC, need to determine what salt is causing high levels
  - If high chloride, one option is to flush out – BUT be aware of consequences!
  - If high gypsum, no problem!
  - Other options: bio-sequestration
    - Eg 5000 kgDM/ha/Yr x 3% Cl = 150kg Cl/ha/yr
      - Reduce 247 kg NaCl/ha/yr (salt) from soil profile

Amelioration of Sodicity

- Replace Na^{+} with Ca^{++}
- Need to remove displaced Na^{+}
- Options:
  - Gypsum ($CaSO_4 .2H_2O$) – Alkaline soils
  - Lime ($CaCO_3$) – Acid soils
  - Combination – Acid to neutral soils
  - OM
- Placement?

How much gypsum do you need?

Gypsum requirement (t/Ha)

$$= \frac{\Delta ESP(\%) \times CEC(meq/100g) \times BD\ (g/cm^3) \times depth\ (cm) \times 0.86}{1000}$$

….assuming 100% solubility & 100% replacement

Gypsum requirement – an example

- To reduce ESP from 12% to 6% in top 10 cm depth of a soil with a CEC of 40 meq/100g and a bulk density of 1.2 g/cm^3

$$GR = \frac{\Delta ESP(\%) \times CEC(meq/100g) \times BD\ (g/cm^3) \times depth\ (cm) \times 0.86}{1000}$$

$$= \frac{6 \times 40 \times 1.2 \times 10 \times 0.86}{1000}$$

= 2.48 t/Ha

Surface applied gypsum

2. Optimising production

1. Land use
   - Crop
     - Crop selection
     - Variety selection
   - Pasture
   - Agro-forestry?

2. Crop management
   - Tillage systems
   - Fallow management
   - Water availability
   - Agronomic management

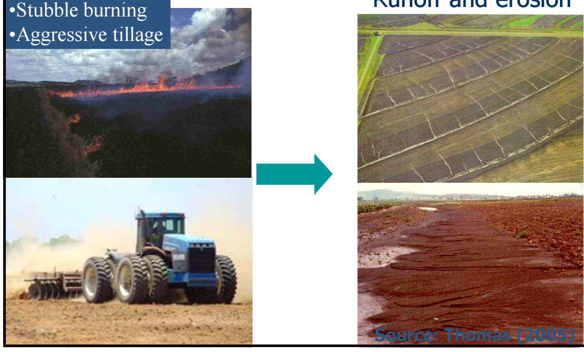
Good agronomic management!

Good agronomic management helps minimise the water and other physiological stresses imposed by subsoil constraints. In paddocks with soil constraints, successful cropping can be achieved by:

- maximising fallow efficiency with short fallows;
- effective weed control;
- suitable rotations for disease minimisation;
- matching nutrients to realistic yield expectations;
- appropriate species and cultivar selection; and
- timely crop sowing

Conventional Farming Systems

Where we have come from …



Conservation Agriculture

50 Years of R,D & E….

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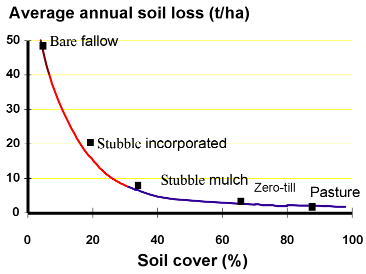

Conservation Agriculture

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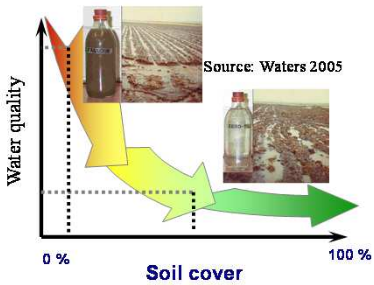

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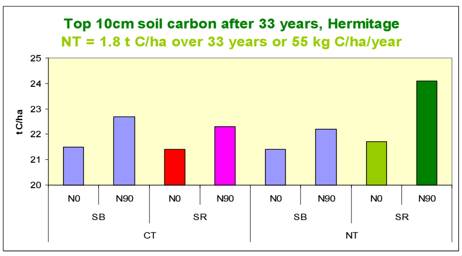

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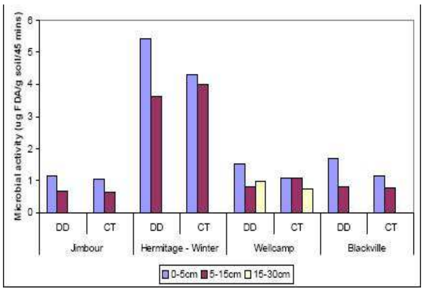

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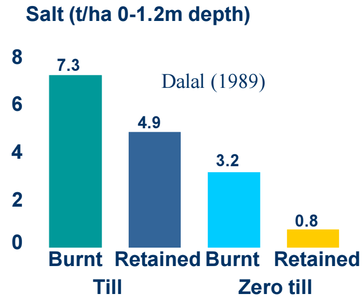

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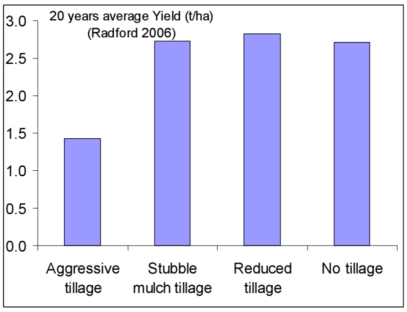


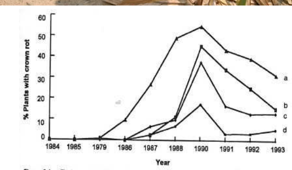
No-till: challenges and possible solutions

- Build-up of hard-to-kill weeds
- Herbicide resistance
- Environmental & health concerns
- IWM promotes use of tillage to manage hard-to-kill weeds

No-till: challenges and possible solutions

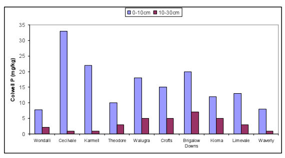
- Increase incidence of soil- and stubble-borne diseases

- Tillage: one of the effective management strategies



No-till: challenges and possible solutions

- Nutrient stratification



- Deep placement of nutrients

No-till: Does 'No' mean 'Never'?

Is strategic occasional tillage the way to go forward?

Many growers emphasized 'we can't zero-till any more' or 'we'll have to go back to ploughing' in order to address specific issues of no-till

Growers who practise no-till: a single tillage may be enough to revert soil conditions back to the start of conservation farming systems

Effectiveness of tillage to manage NT constraints vs Impacts on soil health and environment

Strategic Tillage

Opportunistic use of occasional tillage operation/s (right tillage implement for desired outcome at right soil moisture contents) in an otherwise no-till system to address specific biotic or abiotic challenges

Other options

Match inputs with outputs
Learn to live with these
Fence and Forget!

Matching Inputs to Realistic Yield Potential

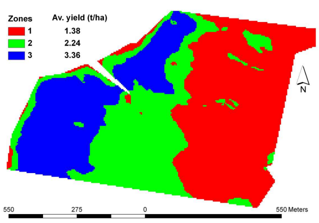
- Determine realistic yield potential in presence of subsoil constraints

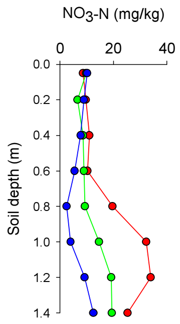
Y_{max} = (Starting Soil Water + In Crop Rain) * Water Use Efficiency

Realistic Yield Potential = Y_{max} ± Soil constraints ± Soil Nutrition

N requirement

N required (kg/ha) = (RYP x protein goal x 1.75 x 2) - Average NO_3-N to 0.9 m





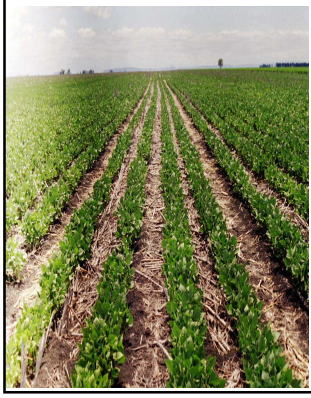
Matching Nitrogen Fertiliser: Economics

	Zone 1 (20 ha) Low	Zone 2 (28 ha) Medium	Zone 3 (16 ha) High	Field average (64 ha)
Realistic yield potential (t/ha)	1.29	2.22	3.36	2.21
Nitrogen requirement (kg N/ha)	59	100	150	101
Average available N in the soil (kg N/ha)	119	55	36	70
Farmer's rate (kg N/ha)	46	46	46	46
Actual N required (kg N/ha)	0	45	114	31
Consequence of uniform N application	2.0 t urea waste	0.06 t urea wasted	3.9 t urea required	2.0 t urea waste

Soil compaction

- Tillage can be an effective method to alleviate surface and subsoil compaction
- controlled traffic has been suggested as an effective method to avoid widespread field compaction due to farm machinery

What is Controlled Traffic Farming (CTF)



- System of <u>permanent</u> traffic lanes in a paddock that separates planted areas and wheeled areas
- All tyres are restricted to tracks (ideally)
- Whole farm system
  - machinery
  - agronomy
  - paddock layout

Benefits

- Management efficiencies
  - Reduced overlaps
  - Spray when conditions are right
  - Better harvest efficiencies (header front full)
  - Greater cropping frequency
- Natural resource management
  - improved soil structure
  - greater water infiltration
  - better plant extraction of water
  - improved soil biology

Nutrient Management

Essential Plant Nutrients

Plants require 17 nutrient elements for growth.

The elements that are required or necessary for plants to complete their life cycle are called essential plant nutrients.

Each has a critical function in plants and are required in varying amounts in plant tissue.

The nutrient elements differ in the form they are absorbed by the plant, by their functions in the plant, by their mobility in the plant and by the plant deficiency or toxicity symptoms characteristic of the nutrient.

Essential Plant Nutrients

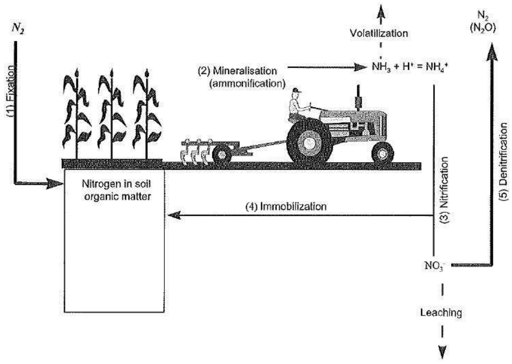
Element	Chemical symbol	Atomic weight	Ionic forms Absorbed by plants	Approximate dry concentration
Macronutrients				
Nitrogen	N	14.01	NO_3^-, NH_4^+	4.0 %
Phosphorus	P	30.98	PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$	0.5 %
Potassium	K	39.10	K^+	4.0 %
Magnesium	Mg	24.32	Mg^{2+}	0.5 %
Sulfur	S	32.07	SO_4^{2-}	0.5 %
Calcium	Ca	40.08	Ca^{2+}	1.0 %
Micronutrients				
Iron	Fe	55.85	Fe^{2+}, Fe^{3+}	200 ppm
Manganese	Mn	54.94	Mn^{2+}	200 ppm
Zinc	Zn	65.38	Zn^{2+}	30 ppm
Copper	Cu	63.54	Cu_2^+	10 ppm
Boron	B	10.82	BO_3^{2-}, $B_4O_7^{2-}$	60 ppm
Molybdenum	Mo	95.95	MoO_4^{2-}	2 ppm
Chlorine	Cl	35.46	Cl^-	3000 ppm
Essential But Not Applied				
Carbon	C	12.01	CO_2	40 %
Hydrogen	H	1.01	H_2O	6 %
Oxygen	O	16.00	O_2, H_2O	40 %

Plant tissues also contain other elements (Na, Se, Co, Si, Rb, Sr, F, I) which are not needed for the normal growth and development.

Nitrogen

- ❖Nitrogen makes up about 78% of our atmosphere.
- ❖Nitrogen in the atmosphere it is mostly in the form of N_2, which is a compound that plants and animals cannot use.
- ❖The process of converting nitrogen into compounds that can be used by plants and animals is called the Nitrogen cycle.

Nitrogen cycle in soil



Nitrogen Fixation

-**Transformation of atmospheric N to nitrogen forms available to plants**

❖Main process: Bacteria convert the nitrogen gas (N_2) to ammonia (NH_3), which only some plants can use (peas, beans).

Rhizobium (symbiotic) found in legumes (bean, soybean)
Azotobacter (non-symbiotic bacteria)

❖Lightening strikes convert N_2 to N_2O or NO_3.

❖Industrial production. Chemical manipulation turns N_2 into NH_3 (fertiliser)

Nitrogen Mineralization

Ammonification:

Decomposition of organic matter into ammonium and nitrate

Nitrification:

Mediated by ammonifying and nitrifying bacteria

	Ammonifying bacteria (*Actinomycetes*)		Nitrifying bacteria (*Nitrosomonas*)		(*Nitrobacter*)	
Plant residue	→	**NH_4^+**	→	**NO_2**	→	**NO_3^-**
(Protein, aa, etc)		Ammonium		Nitrite		Nitrate

Losses of N

Denitrification

Process in which nitrogen compounds converts back into atmospheric nitrogen (N_2 or N_2O).

The main process is performed by bacteria or chemical in the soil.

Anaerobic process

It can also happen by burning fossil fuels

Volatization

Gaseous loss of ammonia

Leaching

Loss of nitrate-N

Nitrogen

- Function
  - Promotes growth of leaves and stems.
  - Gives dark green color and improves quality of foliage.
  - Necessary to develop cell proteins and chlorophyll

Optimum range (e.g. for wheat)

- Soil (0-10 cm) 20-25 mg NO_3-N/kg
- Plant 3.5-5.0 % N

Nitrogen requirement

N required (kg/ha) = (Realistic Yield Potential x protein goal x 1.75 x 2) - NO_3-N to 0.9 m

Available Soil NO_3-N = Soil test value (mg/kg) * soil bulk density (assume average bulk density for clay soil 1.1 g/cm3) * number of 10 cm increment

For example:
Soil test value = 8 mg/kg in 0-10 cm, 5 mg in 10-30 cm and 3 mg/kg in 30-90 cm soil depths

Total Soil N supply = (8 * 1.1 * 1) + (5 * 1.1 * 2) + (3 * 1.1 * 6)
= 8.8 + 11.0 + 19.8
= 39.6 kg N/ha

Nitrogen

- Deficiency Symptoms
  - Sick, yellow-green color.
  - Short stems, small leaves, pale colored leaves and flowers.
  - Slow and dwarfed plant growth.

Nitrogenous fertilisers

More than 80 per cent of the fertilisers used in this country are made up of nitrogenous fertilisers, particularly urea.

Ammoniacal	Nitrate	Ammoniacal and Nitrate	Amide fertiliser
Ammoniumm Sulphate	Sodium Nitrate	Ammonium Nitrate	Urea
Ammonium chloride	Calcium Nitrate	Calcium Ammonium Nitrate	Calcium Cynamide
Anhydrous ammonia	Potassium Nitrate	Ammonium Sulphate Nitrate	

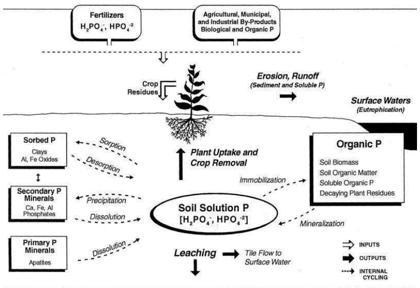
Most plants prefer 50:50 NH_4^+ : NO_3^-

NH_4^+-form of N → lowers soil pH
NO_3^--form of N → raises soil pH
- Organic fertilisers (manure, plant residue) – slow acting
- N can be applied foliarly

Phosphorus (P)

Soil Relations

- Mineral apatite [$Ca_5F(PO_4)_3$]
- Relatively stable in soil
- Has a low mobility
(top dressing not effective)



Phosphorus

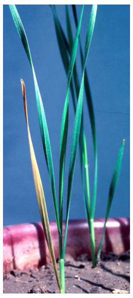
- Functions
  - Stimulates early formation & growth of plants.
  - Provides for fast & vigorous growth and speeds maturity.
  - Stimulates flowering & seed development.
  - Necessary for the enzyme action of many plant processes.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 10-15 mg P/kg
- Plant 0.3-0.5 % P

Phosphorus

- Deficiency Symptoms
  - Decrease in growth.
  - Slow maturity.
  - Older leaves are purplish color.



Phosphorus (P)

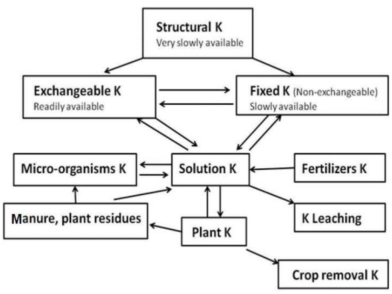
fertilisers

- Superphosphates (may contain F)
  - Single superphosphate (8.6% P): $CaH_4(PO_4)_2$
  - Triple superphosphate (20% P): $CaH_4(PO_4)_2$
- Ammonium phosphate: $(NH_4)_2PO_4$, NH_4HPO_4
- Bonemeal
- Available forms: PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$
  P absorption influenced by pH

Potassium (K)

Soil Relations

- Present in large amounts in mineral soil
- Low in organic soils



Potassium

- Functions
  - Used to form carbohydrates & proteins.
  - Formation and transfer of starches, sugars, & oils.
  - Increases disease resistance, vigor, & hardiness.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 100-125 mg K/kg (0.4 meq/100 g)
- Plant 2.5-4.0 % K

Potassium

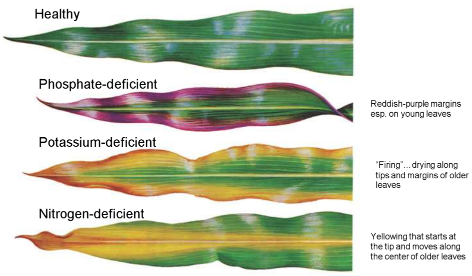
- Deficiency Symptoms
  - Mottled, spotted, streaked or curled leaves.
  - Scorches, burned, dead leaf tips & margins.

Potassium (K)

fertilisers

- **Potassium chloride (KCl)- murate of potash**
- **Potassium sulfate (K_2SO_4)**
- **Potassium nitrate (KNO_3)**

- The most common deficiencies
  - nitrogen, potassium, and phosphorus



Calcium

- Functions
  - Improves plant vigor.
  - Influences intake & synthesis of other plant nutrients.
  - Important part of cell walls.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 400 mg Ca/kg (2 meq/100 g)
- Plant 0.2-0.4 % Ca

Calcium

- Deficiency Symptoms
  - Small developing leaves, wrinkled older leaves.
  - Dead stem tips.

Magnesium

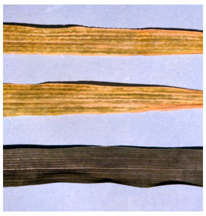
- Functions
  - Influence the intake of other essential nutrients.
  - Helps make fats.
  - Assists in translocation of phosphorus & fats.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 40-50 mg Mg/kg (0.4 meq/100g)
- Plant 0.13-0.3 % Mg

Magnesium

- Deficiency Symptoms
  - Interveinal chlorosis.
    - (Yellowing of leaves between green veins)
  - Leaf tips curl or cup upward.
  - Slender, weak stems.



Sulfur

- Functions
  - Promotes root growth and vigorous vegetative growth.
  - Essential to protein formation.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 8-10 mg S/kg
- Plant 0.15-0.3 % S

Sulfur

- Deficiency Symptoms
  - Young leaves are light green with lighter color veins.
  - Yellow leaves and stunted growth.

Secondary major-nutrient fertilisers

Mg- Magnesium Sulphate (MgSO4)

Ca- Calcium sulphate (CaSO4)

S- Elemental sulphur

Zinc

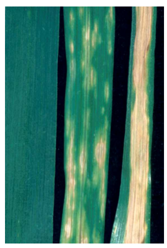
- Functions
  - Plant metabolism.
  - Helps form growth hormones.
  - Reproduction.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 0.3 mg Zn/kg
- Plant 15-20 mg Zn/kg

Zinc

- Deficiency Symptoms
  - Retarded growth between nodes (rosetted)
  - New leaves are thick & small.
  - Spotted between veins, discolored veins.



Iron

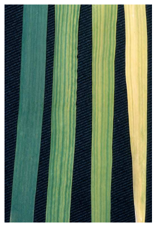
- Functions
  - Essential for chlorophyll production.
  - Helps carry electrons to mix oxygen with other elements.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 2-3 mg Fe/kg
- Plant 25-100 mg Fe/kg

Iron

- Deficiency Symptoms
  - Mottled & interveinal chlorosis in young leaves.
  - Stunted growth & slender, short leaves.



Manganese

- Functions
  - Plant metabolism.
  - Nitrogen transformation.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 2-3 mg Mn/kg
- Plant 25-50 mg Mn/kg

Manganese

- Deficiency Symptoms
  - Interveinal chlorosis.
  - Young leaves die.

Copper

- Functions
  - Helps in the use of iron.
  - Helps respiration.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 0.3 mg Cu/kg
- Plant 1.5-2.0 mg Cu/kg

Copper

- Deficiency Symptoms
  - Young leaves are small and permanently wilt.
  - Multiple buds at stem tips.

Molybdenum

- Functions
  - Plant development.
  - Reproduction.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 2 mg Mo/kg
- Plant 0.1-0.2 mg Mo/kg

Molybdenum

- Deficiency Symptoms
  - Stunted growth.
  - Yellow leaves, upward curling leaves,& leaf margins burn.

Boron

- Functions
  - Affects water absorption by roots.
  - Translocation of sugars.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 1-2 mg B/kg
- Plant 5-10 mg B/kg

Boron

- Deficiency Symptoms
  - Short, thick stems tips.
  - Young leaves of terminal buds are light green at base.
  - Leaves become twisted & die.

Chloride

- Functions
  - Essential to some plant processes.
  - Acts in enzyme systems.

Optimum range (e.g. for wheat)

- Soil (0-10cm) 3 mg Cl/kg
- Plant 2.0 mg Cl/kg

Chloride

- Toxicity Symptoms
  - Usually more problems with too much chloride or toxicity than with deficiency.

D. Micronutrient fertilisers

Zn- Zinc sulphate, zinc oxide

Mn- Managense sulphate

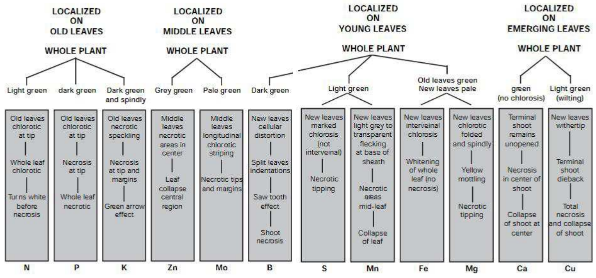
Cu- Copper sulphate

Fe- Ferrous sulphate, Fe-chelates

B- Borax, Boric acid

Mo- Sodium molybdate, ammonium molybdate

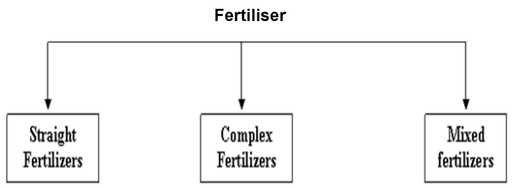
Nutrient deficiency symptoms identification



Fertilisers

Fertiliser is any material of natural or synthetic origin added to the soil to supply one or more plant nutrients.

CLASSIFICATION OF FERTILISERS



Organic vs. Inorganic

- Organic fertilisers
  - from plant or animal matter & contain carbon compounds.

Disadvantages

- Hard to get.
- Expensive.
- Not sterile.
- Low nutrient content.

Advantages

- Slow release of nutrients.
- Not easily leached from soil.
- Add organic components to growing media.

Organic vs. Inorganic

- Inorganic fertilisers
  - Come from sources other than animals or plants….
    - Chemical products.

Disadvantages

- No organic material.
- Possible chemical building up in growing media.

Advantages

- Can make desired ratio of nutrients
- Lower cost
- Easy to get

To Sum up

Fertilisers are available in both organic as well as inorganic forms.

They are classified as straight, complex and mixed fertilisers.

They can also be classified into solid and liquid fertilisers.

Fertilisers are applied to supply nutrients required by the crop that are taken up from the soil.

Sampling and Analysis of Soils: three reasons

- Predictive
- Monitoring
- Diagnostic or Trouble-shooting

Soil sampling

- Sampling Tools;
- Depth of Sampling;
- Where to sample;
- Where not to sample;
- Sample storage;
- Sample Transit, etc

Sampling Tools

Sample Hygiene

- Sampling equipment
- Storage vessels
- Hands
- Most common problems:- OC %, Zn

Sample Storage

- in field - esky with cooler bricks
- short term (24 - 48 hours) - cool to about 4oC
- long term (48 hours - months) - dry
  - freeze

Sample Transport

- by reliable courier or mail sample delivery to lab in 48 hours
- time dispatch so samples are not in mail over weekend

When To Sample Soil?

Need to consider in relation to:

- time recommended in calibration data set
- land prep. / crop management stage
- fertilizer application options
  - labour
  - equipment
  - weather
  - fertilizer pricing ("early deals")

General Guidelines Of Where To Sample

- dependent on purpose for sampling
- different soil types separately
- same production system/ rotation
- sub-soil for new field
- with plant sample for trouble shooting

Where Not To Sample

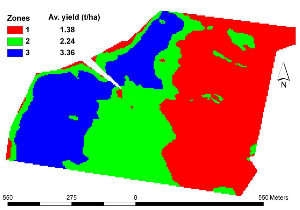
- unusual areas eg. *stock camps, fence lines, headlands, table drains, poorly drained areas.*
- areas limed within 3 months or fertilized within 2 months
- unusual soil conditions eg. *waterlogged*

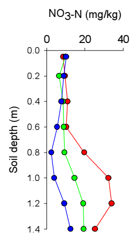
Depth Of Sampling

- based on depth in selected soil test calibration
- sub-soil samples for sub-soil constraints (0-150 cm),
- N-requirements (0-90 cm in increments),
- Immobile nutrients (0-10 cm, 10-30 cm)

Soil Sampling Variability

There is more variability introduced into results at sampling than any other step.





How many samples?

- More cores put into the sample the more likely you are to be near the actual mean
- Homogenise it
- Get representative subsample (Approximately 500 g soil)

Sample labelling

- Date and time of collection
- Place of collection
- Sample type
- Sample identification code
- Identity of sampler

Sample storage

- Pesticides – samples should be cooled to 4°C or less as soon as possible for transport, then frozen until analysis
- Ute, esky, portable fridge/freezer

What to describe

- Use a standard recording sheet
- Site
- Soil

Site

- Landform (hills, rises, plains)
- Vegetation (species, density)
- Geology (type)
- Landscape position (upper, mid, lower)
- Ground surface (dry, wet, cracked, cover)

Soil

- Colour
- Texture
- Structure
- Coarse fragments
- Depth
- Moisture content
- Field test results
- Horizons

What do we test for, and how often should we test?

Typical Analyses For Grain Crops And Their Use

Analyte	Application
pH	Acidity, Sodicity, metal availability
EC,	Salinity, soil dispersion
Chloride	Subsoil constraint
NO3-N	Crop N supply
P (Colwell),	Crop P supply, Potential P fixation
S (MCP or KCl-40)	Crop S supply
Exchangeable Cations	Sodicity, dispersion, K supply
Trace Elements	Availability

How often should we measure?

Most dryland systems: 5 to 7 to 10 years

- pH, EC
- Organic C
- Ca, K, Mg, Na, Al including slaking and dispersion index
- Colwell-P & PBI
- Zn, Cu, B

What… so infrequently?

Most of those analytes will change in either at a slow rate, or will have a "predictable" behaviour

What about Nitrogen?

Depends on how good your accounting is?

N behaves (generally) in a mass balance approach:

- **How much was applied?**
- **How much did the soil mineralise?**
- **How much was removed?**
- **How much are you likely to have lost?**

Good Sampling Protocols

- We could sample less frequently and still make predictions on fertiliser required;
- Make better assessments of changes in soil as we've got better records and are sampling at spatially defined locations, so we have less background variability we're trying to assess against.

What's changed?

Changes to farming systems since most fertiliser responses where studied:

- Zero tillage
- Controlled traffic
- Sowing on wider rows
- Stratification
- Precision Placement
- Low disturbance tines and disk openers
- Environmental buffer zones and filter strips

Soil Testing: good, not perfect

Some soil tests have “robust” relationships to crop response and fertiliser input:

• N and P;

Others require some further development:

• K, S, Micro-nutrients.

Plant Tissue Analysis

- Tissue concentration levels for diagnosis of sufficiency are pretty constant worldwide.
- If the soil test suggests a marginal level, measure the plant.
- Plant Tissues are much more robust for micro-nutrients than soils are.

Laboratory Selection

Select laboratory on:-

- Recognised quality standards e.g. NATA
- Standard published procedures (Rayment and Higginson)
- Involvement in recognised proficiency programs e.g. ASPAC Proficiency Testing Program
- Local result/interpretation calibration
- Value for money

Edited by Ben Harms and Justin Claridge (2000)
Department of Natural Resources, Indooroopilly, Queensland

1.0 UNDERSTANDING THE SOIL PROFILE

1.1 Why describe a soil profile?

Plant roots are not confined to the surface 10 cm, and frequently extend below one metre. Because the subsoil is just as important as the surface, soils should be examined to a metre depth wherever possible. A soil profile is a vertical cross section of soil extending from the surface to a depth of about 2 m or to where the parent material is encountered. Describing a soil profile gives provides an opportunity to observe the different 'parts' of the soil and understand it better. The description can be used in association with the laboratory analysis to better understand how the soil may react to various uses.

Knowledge of a soil's attributes or features can be very useful, even essential, in choosing suitable pastures, crops and management strategies. The productive and sustainable use of land depends on a good basic understanding of soil.

Most soil profiles consist of layers commonly referred to as *horizons* (Figure 1). Differences in appearance usually mean differences in properties, so each horizon must be described. Soils are best described using soil pits, however samples carefully extracted with a soil auger are more commonly used.

Sampling for soil profile analysis

When samples are to be sent in for laboratory analysis, it is important to sample each horizon and the top 20 cm of the B horizon. Where horizons are not obvious, samples should be taken every 10 to 20 cm in the upper part of the profile and every 30 to 40 cm in the lower part of the profile.

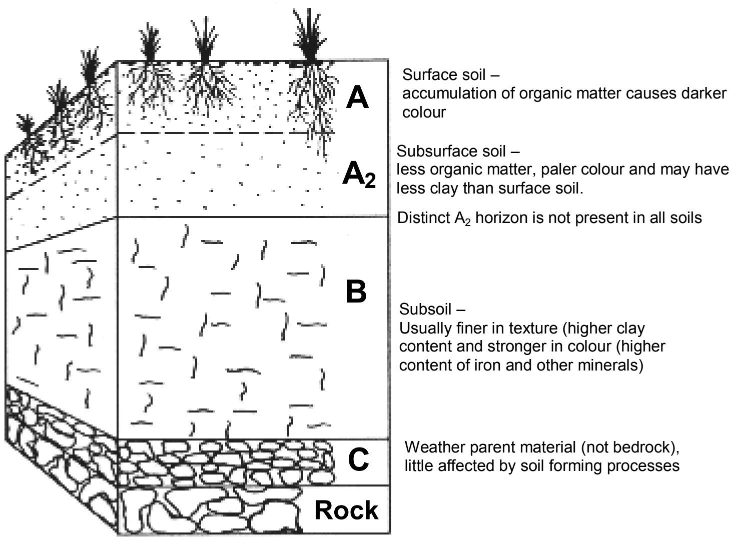


Figure 1. Idealised soil profile showing horizons

For each horizon in the profile, the following items should be described: surface condition, horizon layer depth and thickness; texture; structure; slaking and dispersion; colour; pH; roots and other biological activity; presence of gravels; stone or other characteristic materials such as calcium carbonate (lime) or ironstone.

1.2 Soil texture

Texture is a soil feature that can be assessed simply, and provides a wealth of information about the soil. Texture influences the amount of water that can be stored in the soil, the rate of movement of water and air through the soil, the soil's nutrient supply, ease of root growth, workability and resistance to erosion.

Texture refers to the proportion of sand, silt and clay sized particles, which make up the mineral fraction of the soil. The size ranges of these particles are:

Sand *2.0 – 0.02 mm*
Silt *0.02 – 0.002 mm*
Clay *less than 0.002 mm*

Soil texture is easily assessed in the field by observing the behaviour and 'feel' of a small handful of moist soil, kneaded into a ball and pressed into a ribbon. The feel of the soil ball and the length of the ribbon indicate the texture grade (Table 1).

Table 1. Classifying Soil Texture

Texture grade	Behaviour of moist soil		Approx. Clay %
Sands	FEEL BALL RIBBON	Very sandy, no stickiness Very fragile, falls apart easily Will not ribbon	0-5
Loamy sands	FEEL BALL RIBBON	Sandy, no stickiness Fragile, just holds together About 5 mm	about 5
Sandy loams	FEEL BALL RIBBON	Sandy, slight stickiness Can be handled 15 to 25 mm	10-20
Loams	FEEL BALL RIBBON	Slightly sandy, a bit spongy and 'greasy' Smooth or spongy, holds together About 25 mm	about 25
Sandy clay loams	FEEL BALL RIBBON	Sandy Holds together strongly 25 to 40 mm	20-30
Clay loams	FEEL BALL RIBBON	Almost no sand, distinctly sticky Smooth, plastic, holds together strongly 40 to 50 mm	30-35
Light clays	FEEL BALL RIBBON	Little evidence of sand*, very sticky Smooth, very plastic, holds together strongly 50 to 75 mm	35-40
Medium to heavy clays	FEEL BALL RIBBON	No sandy feel*, extremely sticky Smooth, extremely plastic, like plasticine More than 75 mm	>40

plastic - can be moulded and shaped
* Occasionally coarse sand may be evident in soils of clay or clay loam texture. If so, they may be described as 'sandy', for example clay loam *sandy*, *sandy* light clay or *sandy* medium clay

The actual quantities of sand, silt and clay can be determined by particle size analysis in a laboratory (see the site sheets at the start of this document). The 'texture triangle' (Figure

2) is a way of illustrating the proportions of sand, silt and clay that correspond to the different texture grades.

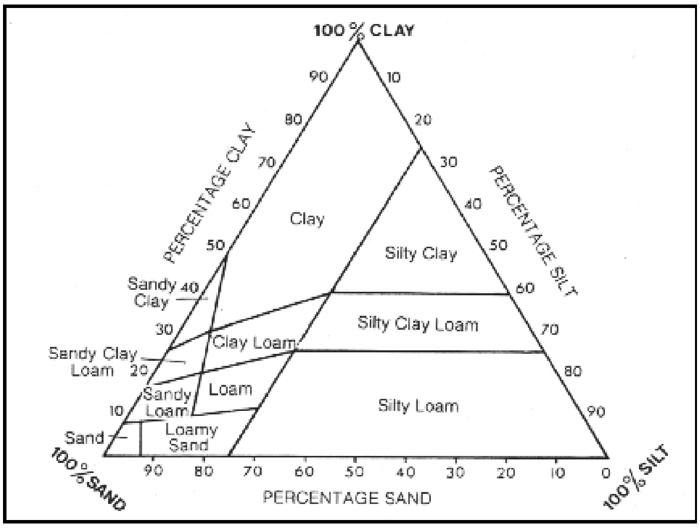


Figure 2. Soil texture triangle (from Charman and Murphy, 1991)

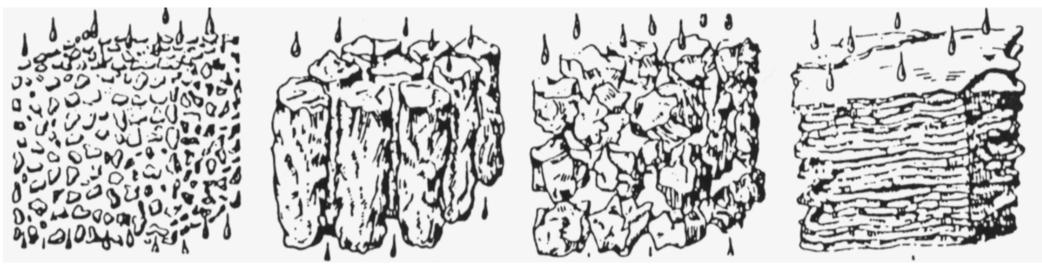
1.3 Soil structure

Soil particles (sand, silt and clay) are usually arranged into larger units. Soil structure refers to the size and arrangement of these larger units (or aggregates) and the pore spaces between them. The larger units are often referred to as ***peds****.*

Where there are no peds present, the soil is described as *structureless* and may be either loose (single grained) or hard (massive). Soil structure is described in terms of the *shape* of the peds, their *size* (coarse or fine) and their *distinctness* (strong, moderate or weak). These terms are defined under soil structure in the glossary. Four common types of soil structure are illustrated in Figure 3.

Some soil peds can be broken easily in the hand, while others can only be crushed under foot. This soil property is called *consistence* (or hardness) refers to the strength of bonding between the soil particles. However, consistence varies according to how wet (or dry) the soil is.

Both structure and consistence have an important bearing on the permeability of the soil to water and air, the ability of roots to penetrate and of seedlings to emerge, the resistance of the soil to the erosive forces of water and wind, and the workability of the soil.



CRUMB **PRISMATIC** **BLOCKY** **PLATEY**

Figure 3. Four common types of soil structure (from Hunt and Gilkes, 1992)

1.4 Slaking and dispersion

Testing for slaking and dispersion helps assess the structural stability of the soil aggregates. The degree to which soils slake and/or disperse can give an indication of the types of problems that might be encountered with particular soils.

Slaking is the breakdown of dry soil aggregates into smaller aggregates when placed in water. Sometimes this can be a rapid collapse with bubbles of air seen escaping to the surface. Slaking is caused by the rapid entry of water into the dry aggregate and the subsequent swelling of the clay component. *Dispersion* occurs when the soil aggregate breaks down completely into individual particles. These individual particles are far too small to be seen individually, but cause the water to go 'milky' or 'cloudy'. Dispersion is almost always accompanied by slaking. Slaking usually occurs in a few minutes. Dispersion may be observed in as little as 10 minutes, but may take 24 hours to be evident. Dispersion is due to the soil being sodic (see *Soil Sodicity* in the next section).

Testing for slaking and dispersion is done by dropping pea sized soil aggregates into a glass jar half filled with distilled water (rainwater is the best substitute) and observing the results. Take care not to shake the jar. The soil may then be classified into one of the stability classes outlined in the following figure.

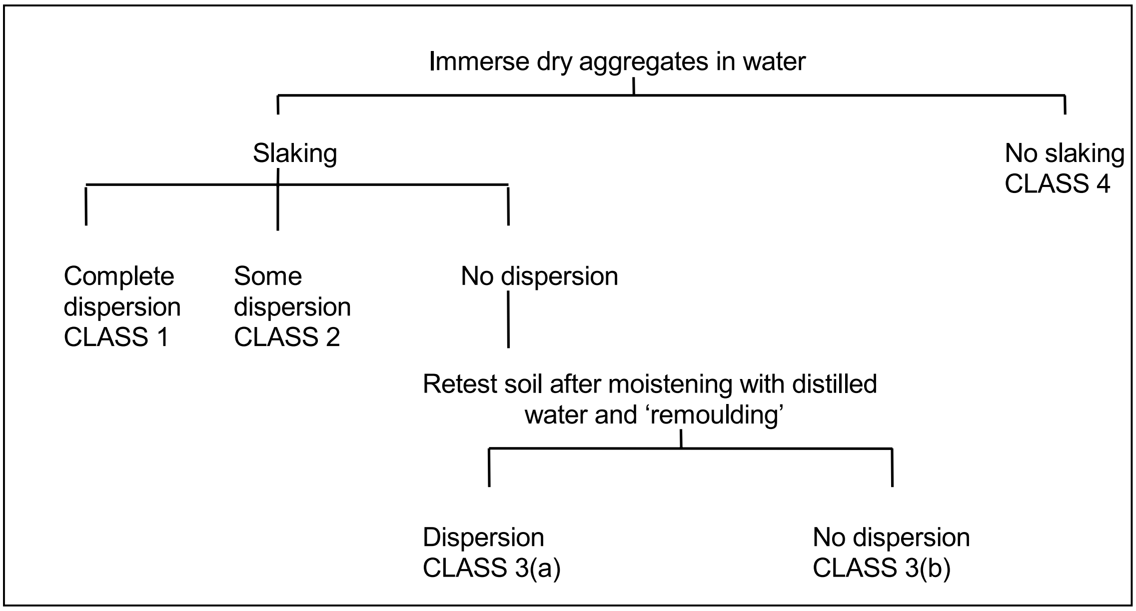


Figure 4. Flow chart for testing dispersion

Interpreting the results:

CLASS 1: A thin cloud covers the bottom of the jar and the aggregate appears as a small heap of sand. This soil may suffer from severe crusting, erosion and poor drainage.

CLASS 2: A cloud of dispersed clay surrounds the aggregate and usually spreads in thin streaks on the bottom of the jar. These soils may have problems similar to CLASS 1 soils but not as bad.

CLASS 3(a): Dispersion occurs only after the aggregates have been remoulded. The remoulding simulates management practices such as cultivating or compacting the soil when wet. If these practices are avoided, dispersion is also avoided.

CLASS 3(b) Slaking (but no dispersion) has occurred. This is a favourable result, although slaking alone could still lead to problems.

CLASS 4: If the aggregates remain intact they are stable and the soil is in good condition.

1.5 Soil Colour

Colour is a very distinctive feature and may be diagnostic of other soil properties. Colour is mainly due to the presence of iron oxides and organic matter. Organic matter consists of darkly coloured compounds, which if present in any quantity, tend to mask the colours of iron oxides. The presence of manganese oxides also darkens the soil. In a few soils the colour is derived directly form the parent material.

Colour provides a useful indication of soil drainage, the degree of leaching and the organic matter content.

Red and yellow colours are both caused by iron oxides. Red indicates good drainage and aeration, while yellow usually indicate a more moist and less well aerated soil. Grey often indicates impeded drainage. Bleached (near white or white) horizons as in bleached A2 horizons are indicative of seasonal saturation and intense leaching of organic matter.

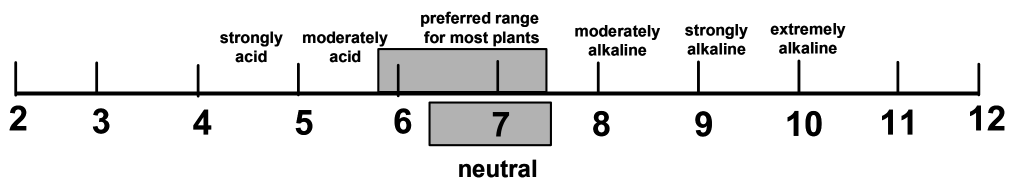
Colour is objectively assessed by comparing the colour of a freshly broken surface of moist soil with standard Munsell Soil Colour Charts.

1.6 Soil pH

Soil pH is a measure of the acidity or alkalinity of the soil. The soil pH determines the availability to plants of different nutrients (see figure 5).

Soil pH is easily estimated in the field, using commercially available field pH kits. Half a teaspoonful of soil is placed on a plate with enough liquid dye to just saturate the sample. Sprinkle on the white powder (barium sulphate) and let the colour develop. The colour is compared with the test card to estimate pH to 0.5 of a unit.

The pH scale and ratings are shown in the following diagram:



It is important to realise that for each unit change in pH there is a ten-fold change in either the acidity or alkalinity. For example, a soil with a pH of 5.0 is 10 times more acid than a soil of pH 6.0.

Importance of pH

A low pH often leads to an oversupply of some nutrients, which can actually be present in toxic amounts (eg. manganese and aluminium). Calcium, magnesium and phosphorus deficiencies may be present in strongly acid soils. A high pH is often associated with a deficiency of nutrients such as zinc, copper, boron and manganese. The correct balance of nutrient availability occurs when the pH is between about 6.0 and 7.5. A very high pH (greater than 9) usually indicates high levels of sodium (hence a sodic soil).

The relationship between soil pH and the relative availability of individual nutrients is shown in Figure 5. This figure should not be used to compare amounts of *different* nutrients; use only to compare the relative availability of *individual* nutrients.

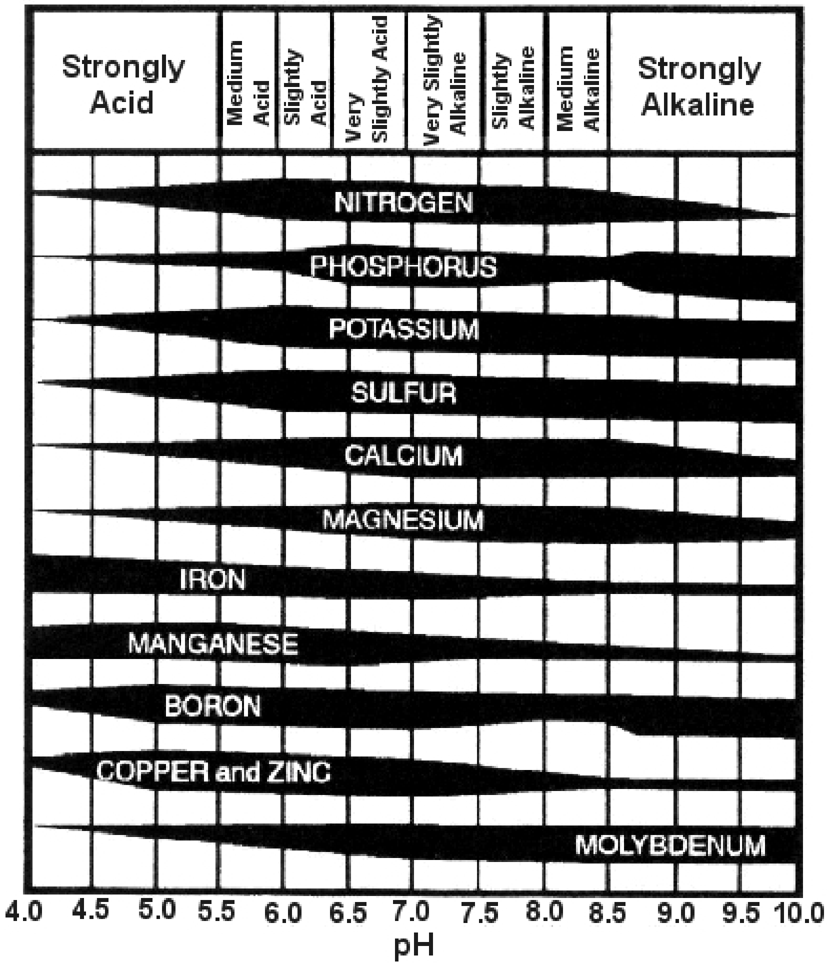


Figure 5. Soil pH in relation to the availability of plant nutrients (from McLaren and Cameron, 1996).

1.7 The soil surface

The surface condition of the soil is important for such things as water infiltration, seed germination and runoff. Soil surface condition may also be indicative of particular kinds of soil. Every effort should be made to observe the surface condition in the *dry* state. Many Australian soils are hard setting in their natural state, but this becomes more common because of management practices such as grazing and cultivation.

The soil surface may be described as:

loose	surface easily disturbed by pressure of forefinger.
firm	surface disturbed or indented by moderate pressure of forefinger
hard setting	hard, not disturbed or indented by pressure of forefinger
crusted	having a distinct surface layer of about 10mm which is hard and brittle and not readily separated or lifted off the underlying soil material.
cracking	racks at least 5 mm wide occur at least during some part of the year
self-mulching	strongly structured, loose surface mulch forms on wetting and drying; aggregates tend to be fine and granular.

2.0 UNDERSTANDING SOIL PROPERTIES FOR MANAGEMENT

After a soil profile has been described and soil tests carried out, the task is to interpret the information and consider management options.

2.1 Water storage and drainage

One of the main functions of soil is to store moisture and supply it to plants between rainfall or irrigation. Evaporation from the soil surface, transpiration by plants and deep percolation combine to reduce soil moisture status between water applications. Typically, cultivated soils lose 60-80% of rainfall as runoff and evaporation, leaving only 20-40% in the soil for crop growth (Dalgleish and Foale, 1998). If the soil water content becomes too low, plants become stressed. The ability of a soil to store plant available moisture helps determine a plant's capacity to withstand dry spells.

Factors Affecting the Water Holding Capacity of Soil
The amount of soil water available to plants is governed by the depth of soil that roots can explore (the root zone), and the nature of the soil material. Because the total and available moisture storage capacities are linked to the soil's porosity (amount of pore space), the soils texture and structure are critical factors. Figure 6 shows the factors affecting the plant available water capacity of soils.

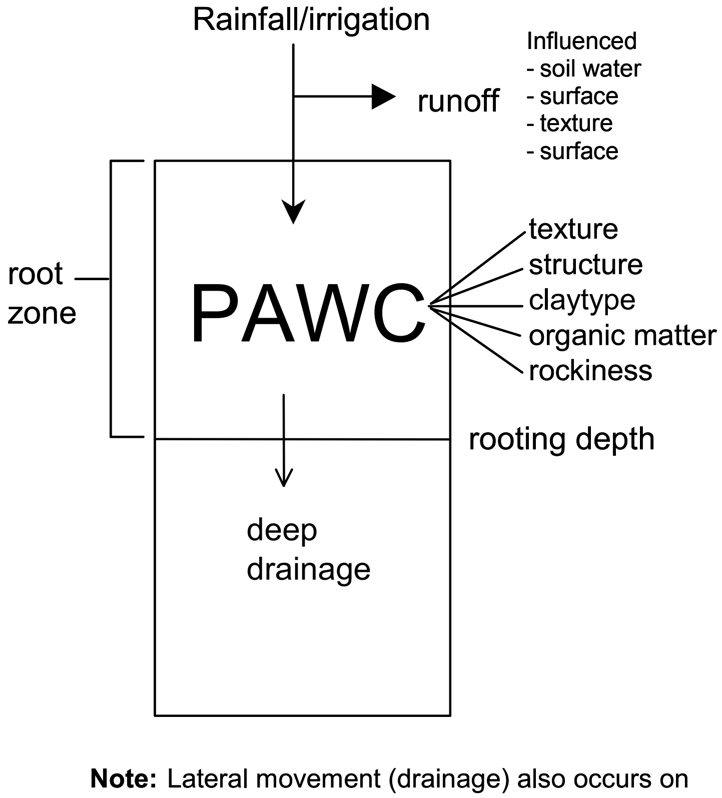


Figure 6. Factors affecting plant available water capacity (PAWC) of soils

Rainfall is measured in units of depth, either inches or millimetres. Likewise, plant available water is usually quoted as a measure of ***equivalent depth of water*** *in the soil in millimetres.*

A plant available water capacity of 100 mm is considered desirable for a cropping soil in southern Queensland, and 150 mm is preferred. The water holding characteristics of the main texture groups are illustrated in Figure 7. In general, the higher the percentage of clay the greater the moisture holding capacity of a soil. However, in clay soils a greater proportion of this water is unavailable to plants. Soils with an intermediate texture tend to have a higher plant available water capacity (given a similar rooting depth). The importance of structure is indicated by the fact that a poorly structured loam will hold only half as much water as a well structured loam.

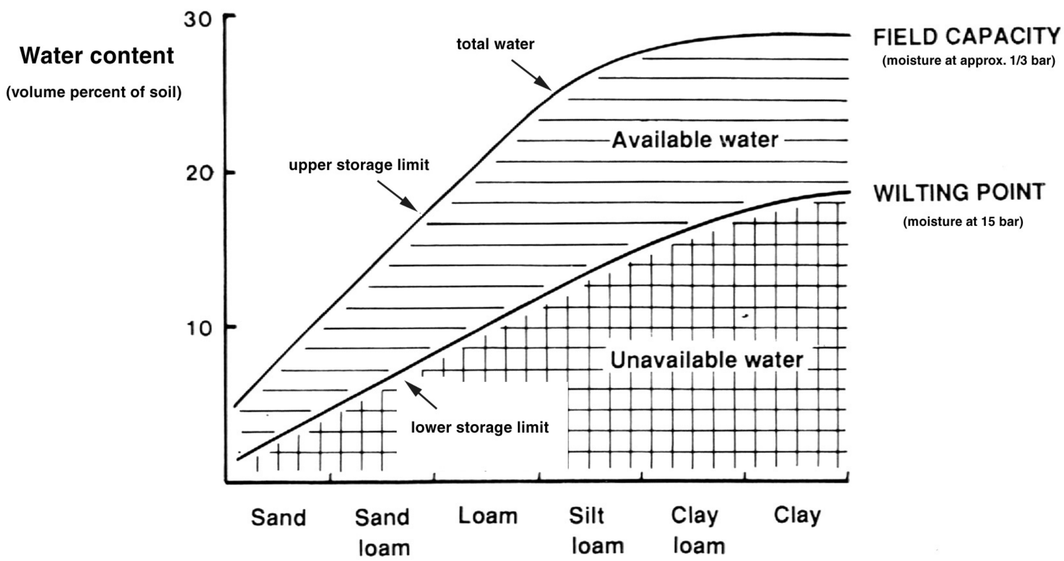


Figure 7. The relative amounts of water available and unavailable for plant growth in soils with textures from sand to clay (McLaren and Cameron, 1996).

Effective rooting depth

It is not possible to make definitive conclusions about plant available water in a particular soil without performing costly and time-consuming on-site measurements (in conjunction with laboratory analysis). However there are guidelines for estimating the existing moisture status and the potential water storage capacity of a soil (see Dalgliesh and Foale, 1998). A critical factor in the process is the estimation of *effective rooting depth*, ie. the depth to which plant roots can grow and function efficiently. The depth at which 'exploring roots' can be observed does not necessarily correspond to effective rooting depth. Root functioning can be retarded by factors such as low pH (<5.5), low levels of calcium (Ca < 2%), salinity (Cl% >0.1%) or dense intractable clay (ESP >20%). The depth at which salt accumulates in the soil profile is often a good guide to effective rooting depth. This is because water recharge and drainage following plant (crop) water use flushes salts from the active root zone and accumulates it just below the root zone.

Waterlogging

In waterlogged soil, all the soil pores are filled with water and no oxygen is available to plant roots or for soil microbial activity. If waterlogging continues for a long period, plant roots and eventually the whole plant may die. Under waterlogged conditions, nitrate, the most available form of nitrogen, breaks down and is lost as a gas.

2.2 Managing Soil Structure

The importance of soil structure in influencing soil productivity cannot be over emphasised. The suitability of a soil for plant growth and its response to management depends as much on its structure as on its chemical fertility.

Good soil structure is important for:

- permeability of the soil to water and air;
- ease of plant establishment
- workability of the soil; and
- resistance of soil to erosion.

The way in which soil particles bond together is primarily affected by the amount and type of clay in the soil. For surface soils, the amount of organic matter is crucial, while other bonding agents such as calcium carbonate and compounds of iron, silicon and aluminium are important in some soils. A model for soil structure is shown in Figure 8.

Farm practices such as excessive cultivation, working the soil when too wet or too dry, stubble burning, and stock trampling and pulverising cause a loss of organic matter and the destruction of the small aggregates. Undesirable characteristics arising from these practices include hard setting surface soils, crusting, surface sealing and compaction.

2.21 Soil Structure Decline

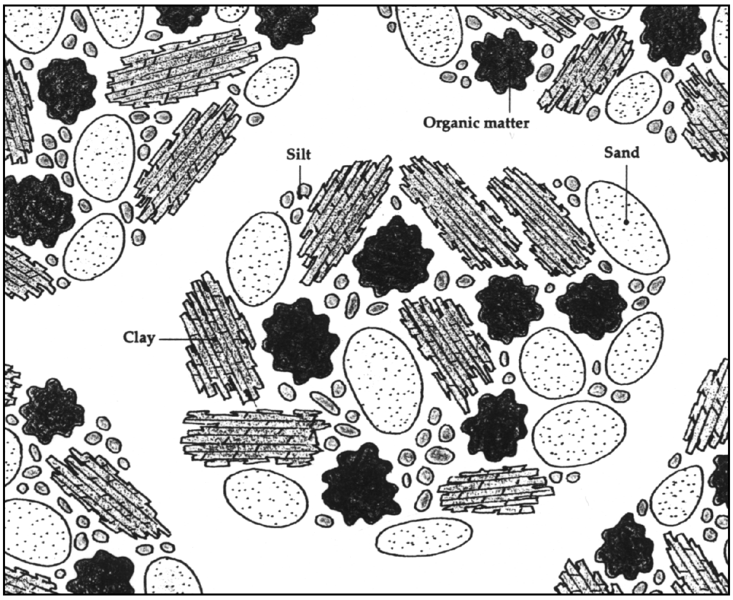


Figure 8. Peds consist of sand, silt, clay and organic matter (from Jacobsen et al., 1992).

Good soil structure is typified by many interconnected air spaces, which are the prime regulator of water and nutrient supply to plants. It is the loss of this pore space, especially the interconnected pore spaces that best defines soil structure degradation.

Soil structure degradation can take many forms. In considering soil structure decline and remediation strategies to correct it, it is important to consider the type of land use (cropping, grazing etc.) and to separate surface degradation from subsoil degradation.

Surface structure

Poorly structured surface soils usually seal over after rain and set hard when dry, causing:

- reduced infiltration
- ponding of water on the surface

- problems with seedling emergence
- increased susceptibility to erosion
- limited opportunities for efficient and non destructive cultivation.

Hard setting soils usually have high fine sand and silt contents with low levels of clay and organic matter in the surface soil. In such soils the bonds between particles are weak when wet. Wetted soil aggregates may slake to very small aggregates or even disperse into individual particles. These small particles then pack between the larger particles to form a densely packed soil with very small pore sizes. When these soils are wet the surface soil is soft but as they dry out they become very hard.

Many Australian soils have a natural tendency to set hard, but this tendency is made worse by management practices, which destroy the surface aggregates and reduce organic matter. It is often difficult to establish plants on a bare, hard-set soil. Any implement that will create a rough surface will trap rain in hollows and assist infiltration. The chisel plough is often used for this purpose.

Surface crusting is also due to an unstable soil structure. It is caused by slaking or physical breakdown from raindrop impact. It can also be caused by too much tillage. All soils seal under raindrop impact to some extent. On some soils, the seal is very weak or it cracks on drying so that a crust does not form. In other soils, peds slake and/or disperse on wetting. This prevents infiltration, increases runoff and makes it more difficult for seed germination. A soil with a dispersive surface is more likely to be *surface sealing*.

Subsoil structure

Poor subsoil structure restricts root development by providing a mechanical barrier to the proliferation of fine roots. Roots are usually confined to the surfaces of the aggregates, reducing their ability to explore the bulk of the soil. Waterlogging is associated with poorly structured subsoils, because water lies on top of the clay, drowning roots coming down from the soil surface. Poor structure also reduces the capacity of the soil to store moisture.

Subsoils that are loose or friable or with a strong granular to medium blocky type of structure do not impose any limitation to root growth. Compacted layers in the soil can occur naturally or be caused by heavy traffic and cultivation on soils above their *plastic limit*. These compacted layers may restrict root growth and reduce infiltration. In pasture soils, this layer begins close to the surface and may extend to a depth of 100-150 mm. In cropping soils, most compaction occurs in the top 200 mm, but it will extend deeper particularly under wheel tracks.

2.22 Repairing compacted soils

Soil compaction is reversible. Repair can be either mechanical or biological or a combination of both. Where possible biological methods are preferable as they not only remove the risk of further damage caused by mechanical treatments and are also generally cheaper and more sustainable (McGarry, Sharp and Bray, 1999). Soils that naturally shrink and swell will tend to 'crack out' compaction.

Improving surface structure

The addition of organic matter is the best way to improve surface structure. In a cropping situation, one of the best ways to increase organic matter is to introduce a pasture rotation. Green manure crops may also be incorporated. If crusting is due to sodicity (causing dispersion) then the addition of gypsum may improve soil structure and allow better water and air entry.

Improving subsoil structure

The biological methods mentioned above (especially the establishment of deep rooted pastures) will have an effect on subsoil structure. In some situations, mechanical methods may be useful.

Mechanical options of ripping and cultivation must only be done after ensuring the soil (to a depth below the intended cultivation zone) is below the plastic limit. This will tend to 'bust' the soil up and avoid further smearing and compaction. With heavy soil types the plastic limit is often drier than the permanent wilting point of plants. So that even directly after a crop has been harvested it may still be too wet to cultivate/rip without smearing and compaction.

The **deep ripping** required to shatter the hardpans in cropping areas will probably be different to the **deep tillage** required to renovate a compacted pasture soil. Deep tillage should aim to completely loosen the compacted layer while leaving the surface 20-30mm relatively undisturbed. This may require successively deeper tillage operations over a number of years. Good success has been reported using modified chisel ploughs. Deep ripping for plough pans is generally done with more widely spaced tynes that break through the compacted layer at intervals, often leaving the soil surface rough and cloddy.

Before conducting mechanical repair methods, the soil must be carefully examined to determine the extent and nature of any compaction and the pattern of root distribution in the soil profile. This can be done with soil pits or test holes. Any patterns of occurrence related to landscape position or soil type are noted. If roots are restricted to the top 100mm or less, then there is a possibility of a positive response to deep tillage.

If there is no visible consolidated layer and root growth is good, there is unlikely to be a response to deep tillage. Before embarking on major deep ripping or deep tillage, it is advisable try it in a small area and evaluate the results. The associated costs can be quite high, particularly where the operation is done in hard, abrasive soils. A decision to proceed further should be based on a benefit cost analysis.

With any mechanical repair method, it is important not to disturb soil layers that are sodic. The clay (or B) horizons of soil types with a strong texture contrast are often sodic. Any shattering of a such a layer is likely to have a short term affect because the chemical nature of the soil has remained unchanged and poor physical properties will redevelop. Also, there is also the possibility that disturbance will bring sodic materials closer to the surface, which is undesirable.

2.3 Chemical Fertility

The chemical fertility of a soil refers to its ability to supply the various mineral nutrients required for healthy plant growth.

Laboratory Analyses

Soil tests or laboratory analyses should be an integral part of all soil management strategies. They are useful in providing a guide as to the chemical status of soils and for monitoring trends. A range of soil analyses is available. These can be used to assess soil chemical condition as a guide to fertiliser management, and to monitor trends in the chemical constituents of the soil. A summary guide for interpreting analysis results is included in the 'Interpretation of Chemical Analysis' Section.

2.31 Cation Exchange Capacity

Mineral nutrients are held in the soil by electrostatic forces. Soil particles have a negative charge and therefore attract positively charged ions (cations). Many important nutrients such as K, Mg, Ca, Na, Zn, Cu, Fe, Ni, Mn, and Co are cations.

The amount of negative charge carried by a soil (that is, its ability to hold nutrients) is called the cation exchange capacity or CEC. In general, soils with high CEC are more fertile. The proportion of clay and the amount of organic matter in a soil have a significant effect on CEC.

Clay has a very high specific surface area and a high CEC per unit weight. This is due to the small size of clay particles (less than 0.002 mm), and their plate like structure. Cations are held *within the crystalline framework* of the clay minerals. Soil organic matter also has a high surface area to absorb nutrients, and so makes a significant contribution to the soils total CEC.

2.32 Clay type

Clays are important for their contribution to the nutrient and moisture holding capacity of a soil. However, not all clays have the same properties.

The most important property of clays is their crystalline, sheet like structure. Each clay particle is made up of a series of layers much like the pages of a book. It is the exact chemical composition and the internal arrangement of atoms in these layers, which determines the physical and chemical properties of the clay. For example, some clays are very sticky and plastic while others are only mildly so.

Each individual clay layer is structured around aluminium (Al) or silicon (Si) atoms. In other words, it can be a 'silicon layer' or an 'aluminium layer'. Clays can be classified into two main groups depending the ratio of silicon to aluminium layers present.

1:1 - type clays

The sheets in this clay are made up of silicon and aluminium layers in a 1:1 ratio. The sheets are held together by strong *hydrogen bonding* resulting in a fixed structure with no capacity for swelling when the clay is wetted. Cations and water do not enter between the structural layers of a 1:1-type clay particle (Brady, 1990). 1:1-type clays have a very low surface area and therefore a low capacity to absorb cations (Figure 9)

2:1 - type clays

The sheets in this clay are made up of silicon and aluminium layers in a 2:1 ratio. These clays generally have the capacity to expand. When they are wetted, the water entering the interlayer space forces the layers apart (Brady, 1990). Exchangeable cations and associated water molecules are attracted between layers, the *internal surface*, then exposed, greatly exceeds the external surface area of these clays (Figure 9).

These clays commonly have a high cation exchange capacity (up to 40 times more than 1:1-type clays) and are marked by swelling when wet and shrinking on drying which often produces large cracks.

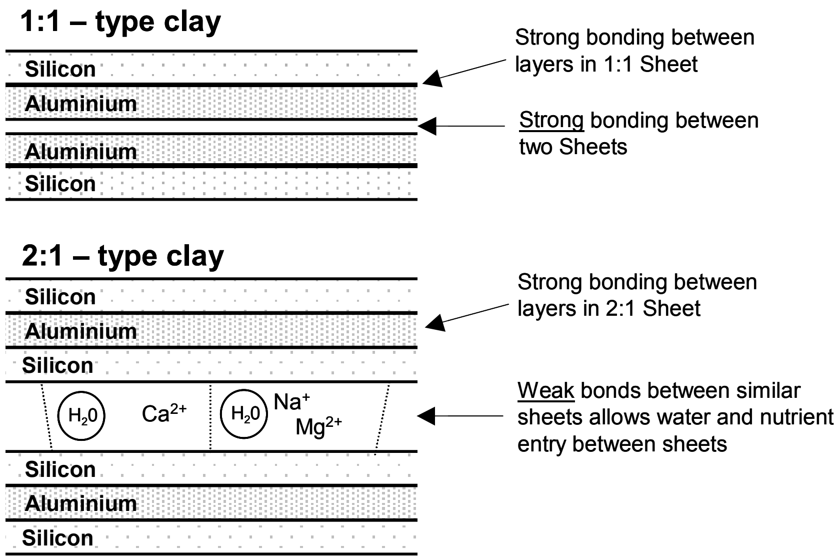
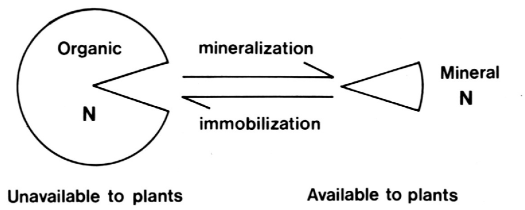


Figure 9. Illustration of clay type

2.33 Organic matter, nitrogen and sulfur

In addition to its critical role in stabilising the soil and promoting good soil structure, soil organic matter has many vital roles in soil, plant, water and chemical interactions. It is a major source of N, P and S. Organic matter is not measured directly in the laboratory, but relates directly to the amount of organic carbon.

Most of the nitrogen in the soil is present in organic matter. However, it can only be taken up by plants when it is in the mineral (inorganic) form of nitrate (or ammonium). Mineral nitrogen is released when the soil is cultivated or otherwise disturbed (this process is called mineralisation). Organic nitrogen remains tied up in leaves, litter and old roots where it awaits decomposition or mineralisation. In other words, nitrogen is recycled in a natural vegetation (or pasture) situation.



Nitrate (NO_3^-) is a negatively charged ion ('particle') and cannot be 'fixed' to the clay structure like a positively charged ion (cation). Consequently it can be quickly lost from the root zone of plants by leaching (removal with water).

Most of the sulfur in soil is also present in the soil organic matter and is not available to the plant until released by bacterial action, converting it to the sulphate ion (SO_4).

2.34 Fertilisers

For normal growth, plants need adequate levels of nutrients in the soil. However, most soils are deficient in one or more nutrient either naturally, through the removal of agricultural products or via erosion. Nutrients that are deficient can be added as either inorganic (chemicals) or organic (plant or animal wastes) fertilisers.

Inorganic (chemical) fertilisers

Inorganic or chemical fertilisers can be bought as a straight fertiliser (containing only one element) or as a mixture. Urea is an example of a 'straight' fertiliser containing only nitrogen and superphosphate is a mixed fertiliser containing phosphorus, sulfur and calcium.

Fertilisers must be used judiciously as they are expensive and overuse may adversely affect plant growth. Long-term use of fertilisers can also acidify the soil, thereby affecting plant growth and nutrient availability.

Organic Fertilisers

Organic fertilisers such as animal manures and mulches can be very effective in supplying nutrients. However, because they are bulky and large amounts are required, they are expensive to apply. A major benefit of organic fertilisers is their ability to increase soil organic matter content. Chemical fertilisers do not influence organic matter content.

Artificial soil conditioners

Artificial soil conditioners, such as synthetic polymers, have been developed but most of these are expensive and often ineffective.

2.35 Fertility decline

Cultivation and cropping generally cause a decline in the chemical fertility and a reduction in the biological activity of a soil. Cultivation of a soil previously supporting native vegetation or pasture generally leads to reduced organic matter and consequently lower mineral nitrogen and sulfur. Reduced organic matter leads to reduced yields and a lower protein level in wheat and barley. Exchangeable calcium, magnesium and potassium, and cation exchange capacity (CEC) may also be reduced.

Research on a range of Queensland soils shows that with increasing age of continuous cereal cropping, all soils reach a stage where they cannot provide the nitrogen requirements of a crop.

Restoration of Soil Fertility

The profitability of grain production enterprises is dependent on the adoption of sustainable farming systems that provide enough nitrogen for optimal yield and grain protein levels. There are two main options or strategies to achieve this:

- ***Nitrogen fertiliser***
  The nitrogen requirement for a particular paddock will depend on soil variation in the paddock and cropping history. It is recommended to try a number of different rates over a 2 to 3 year period and monitor both yield and protein levels. Specific guidelines for calculating nitrogen requirement are available from you local extension officer.
- ***Rotations***
  The nitrogen status of a particular soil can be significantly enhanced by rotating paddocks to grain legumes or pasture leys. Ley pasture can be either a straight legume, for example a lucerne or a medic, or it can be a grass/legume mixture. Research has shown that for a fertility depleted soil, a longer term pasture ley has significant benefits (eg. four years or more)

In most cases, a combination of nitrogen fertilisers and rotations is the best bet.

Fertility tie-up in pasture

The removal of timber (particularly brigalow) and the development of country for pasture, often results in a flush of growth due to the extra nutrients (including phosphorus) available. This enhanced fertility is largely due to higher levels of organic matter present in the virgin soil. The more fertile a soil to begin with, the longer the flush will last.

A similar effect can be seen in a sown pasture such as buffel grass. Over time, nutrients are ‘tied up’ and the pasture reaches a growth equilibrium, which is largely based on nitrogen availability and water supply. For example, buffel grass pasture might be highly productive when first established, but then gradually declines as the pasture ages. The ‘rundown’ pasture may be only half as productive within 5-7 years because the available nitrogen gets removed from the soil and ‘tied up’ in organic matter. Visible symptoms are reduced vigour and seed production, while new foliage may be yellow-green in colour. Pasture rundown may also be due to over grazing, soil erosion and weed infestation.

Pasture renovation

Pasture renovation options include:

- ***cultivation***. This incorporates organic matter and promotes mineralisation of nitrogen. It is best done prior to summer pasture growth. Chisel, offset disc or blade ploughs are recommended.
- ***crop-pasture rotations***. Plough the pasture, crop for a couple of years and return to pasture.
- ***nitrogen fertiliser***. The costs can only be justified if the extra feed greatly improved animal production.
- ***oversowing with a pasture legume.*** Legume plants release additional mineral nitrogen into the soil which improves feed quality. The appropriate legume depends on the local climate and soil type. Winter growing medics will grow on most soils suitable for buffel where there is normally winter rainfall.

Legumes can be established by broadcasting seed, bandseeding, using a crocodile seeder, or doing a one-pass cultivation of the existing pasture with a chisel, offset disc or blade plough or by sod seeding. However, the most reliable method to establish both grass and legume is using a fully prepared seedbed.

Improved pastures should be fenced off separately from native pastures. They are more sensitive to heavy grazing pressure, so their grazing should be more carefully controlled.

2.4 Soil Salinity

Soil salinity is a measure of the concentration of *soluble salts* present in a soil. That is, salts that are free to move down the profile or into plant roots. Salt is naturally present in a soil from rock weathering or additions from the atmosphere. Rising of salty groundwater may also cause soil salinity. Total soluble salt content is estimated from the electrical conductivity (EC) of the soil solution. Percentage chloride (%Cl) is measured to determine how much of that salt is chloride.

For a soil, it is important to consider the trend down the profile, as well as individual values. Brigalow soils for example, commonly have a salt bulge at a depth of between 50-150 cm. The depth at which this occurs is related to rainfall, drainage and clay content.

Saline soils are those, which have sufficient levels of salt in the root zone to adversely affect plant growth. High salinity affects plant growth in two ways. Firstly it reduces the ability of plants to take up water (an osmotic effect). It also causes ion toxicities (usually chloride and sodium ions) and nutrient imbalances.

2.5 Soil Acidity

Acid soils occur naturally in humid areas and the acidification of soils, by which the pH slowly decreases over time, is a continuing, natural process. Paired site studies in Queensland have clearly demonstrated that agricultural practices can accelerate the acidification process.

The development of strongly acidic soils (pH in water < 5.5), results in poor plant growth as a consequence of one or all of the following problems:

- aluminium toxicity
- manganese toxicity
- deficiencies of calcium, magnesium, phosphorus and molybdenum
- reduced microbial activity leading to a reduction in the cycling of nutrients such as nitrogen

Both surface and subsoil acidity occur both naturally and as a result of agricultural management practices. Strongly acidic subsoils are likely to limit or entirely prevent root growth which limits the use of subsoil water and nutrients. Lime is only weakly soluble and does not move far from its point of application. Therefore, subsoil acidity cannot be corrected by typical application rates of lime either at the surface or by mixing into the plough layer. It is therefore important that management practices are designed to minimise or remove the potential for subsoil acidification.

Farming practices recommended for minimising acidification include:

- more closely matching nitrogen fertiliser inputs to crop demand;
- using alternative (nitrate) forms of nitrogen fertiliser;
- efficient irrigation management to minimise leaching;
- early sowing after fallow to minimise nitrate leaching;
- growing deep-rooting perennial species to minimise nitrate leaching; and
- regular applications of lime to counter the acidification inherent in the agricultural system.

2.51 Liming acid soils

In strongly acidic soils (pH <5.5), plant growth can be limited by toxicities of aluminium and/or manganese, or a deficiency of calcium. Lime and dolomite are commonly used to raise soil pH and correct these problems. Attaining a pH of 6 to 6.5 will usually overcome any problems due to low pH.

The rate of lime application will vary from soil to soil because the buffering capacity of the soil (its resistance to pH change) is affected by organic matter content, clay content, sesquioxide content, etc. It is therefore necessary to have the soil tested to determine the liming rate with a particular depth interval and target pH in mind.

In assessing different liming materials a number of factors should be considered; the cost per tonne, the chemical guarantees, fineness and moisture content. These factors determine the effectiveness of each dollar spent on lime. Limes with finer particles and a higher neutralising value will act more quickly and bring about a greater shift in pH than other liming materials applied at the same rate. Coarse particles of lime take longer to react with the soil than finer materials.

2.6 Soil Sodicity

Sodium in the form of Na^+ cations (charged particles) may be present in either of two forms:

- dissolved in the soil solution with other ions such as Cl^- (in salty soils) and free to move, or
- attached to crystalline framework of the clay structure (not normally free to move)

Other ions such as calcium, magnesium and potassium are also held on the clay (see cation exchange capacity in the *glossary*). Where there is too much sodium present on the clay, compared to the other ions, it may cause undesirable properties and the soil is said to be **sodic**.

A scale for assessing the sodicity of Australian soils is as follows:

non-sodic	sodic	strongly sodic
ESP <6%	ESP 6-15%	ESP >15%

[ESP = exchangeable sodium percentage = Na/CEC expressed as a %]
ie. Sodium as a percentage of the soils total cation exchange capacity.

Sodicity has both chemical effects on crops and physical effects on the soil structure. The sodium weakens the bonds between the clay particles when wetted. The clay particles may become detached and spread out or disperse making the soil water cloudy. This process is called **dispersion**. The fine clay particles, in suspension, clog up the small pores in the soil, restricting root growth and water movement.

Sodicity can occur at any depth in the soil. In the rooting zone of plants, the symptoms of sodicity include poor infiltration and drainage resulting in waterlogging. These soils are usually difficult to manage and have low productivity. Soils that are sodic below the rooting zone of plants often go unnoticed, as there is little obvious impact on farm management. At the surface, sodicity causes surface crusting or sealing which increases runoff and reduces infiltration.
Some soils may be both sodic and saline. These soils will often not show symptoms of sodicity as the salt prevents the clay from dispersing.

Dispersion ratio

The dispersion ratio (R1) reported in laboratory analysis tables can be used to predict whether dispersion is likely to occur. The following ratings apply to values of R1:

low dispersion	moderate dispersion	high dispersion
R1 = 0.6	0.6-0.8	< 0.8

Treating sodic soils

To increase productivity of dispersive sodic soils, gypsum can be added. Gypsum is sparingly soluble, but dissolves in sufficient quantities to reduce dispersion in the short term. In the long term, the calcium from the gypsum displaces the sodium or magnesium in the clay which consequently reduces the sodicity (exchangeable sodium percentage). Lime is not has soluble as gypsum, so it does not have the same short term effect. However, in the long term lime is also a source of calcium ions to replace sodium, thereby reducing sodicity.

It is important to realise that gypsum will have little effect as a general soil conditioner unless the soil is shown to be dispersive.

2.7 Soil Erosion

The major effect of erosion is the loss of fertility and productive potential of a soil. Erosion removes nutrients and organic matter and reduces the capacity of the soil to store water.

2.71 Types of soil erosion

Sheet erosion

Sheet erosion refers to the removal of surface soil from the surface. Soil particles are dislodged when raindrops fall on bare soil. Sheet erosion may not be obvious or easy to detect because only a thin, uniform layer of soil is removed.

Rill and gully erosion

Rill and gully erosion occur when runoff water begins to concentrate in definite channels. As the water flows down the slope, the channels become deeper, wider and longer. Rills are channels up to 30 cm deep, while gullies are deeper. The potential for gully erosion is increased when water moves over long slopes, gathering speed and volume.

Strategies for reducing the incidence of rill and gully erosion include:

- maintaining adequate groundcover all year around; and
- diverting runoff water from unstable, fragile areas or areas which already show signs of eroding.

Where a gully has already formed and is advancing up the slope, some things that can be done are:

- simple vegetative control. This protects the bare soil and reduces the erosive impact of water. A concept sometimes referred to as *'fence, fertilise and watch'* involves fencing the area, fertilising it and seeding it. It may also involve mulching and holding down the mulch with pegs and netting.
- diversion banks to take away the water from the gully head
- measures to silt up gully floors such as building pervious netting weirs and haybale weirs.
- gully filling if practical and economically viable

Tunnel erosion

Tunnel erosion is a subsurface form of erosion which occurs when water scours underground channels through highly dispersible subsoils. Water may enter through such things as an old tree root, a fence post hole or animal burrows. Tunnels eventually cave in to form gullies (see Figure 10).

The rehabilitation of tunnel eroded areas can be difficult and expensive. For these reasons, prevention is better than cure.

The best method of prevention is to retain as much surface cover as possible and avoid exposure of the subsoil. Where tunnel erosion exists, the following suggestions can be used to alleviate the problem:

- divert top water from the eroded area. It is vital to find a safe disposal area, otherwise the problem is being shifted from one place to another. The disposal site must be well grassed and on a soil not susceptible to tunnel erosion. It may need to be constructed from the lower side so that the subsoil is not exposed in the bank channel;

- if the tunnels are deeper than 60 cm, the tunnels can be filled with soil. This should be done when the soil moisture conditions are fairly high and it is vital the area is well compacted. The soil used as fill should be sourced from an area not susceptible to tunnel erosion;
- water entry areas should be determined and if necessary property layout altered to alleviate concentration of water entry. This may involve the relocation of fences, tracks and stock pads;
- the treated area should be fenced to exclude all stock, fertilised and sown to grasses suitable for the area; and
- ongoing regular monitoring is vital. Once rehabilitated, the area must be grazed carefully to avoid repeat tunnelling.

Permanent tunnel erosion control can only be achieved with vegetation and this must be maintained by management practices that build fertility and encourage even infiltration of water.

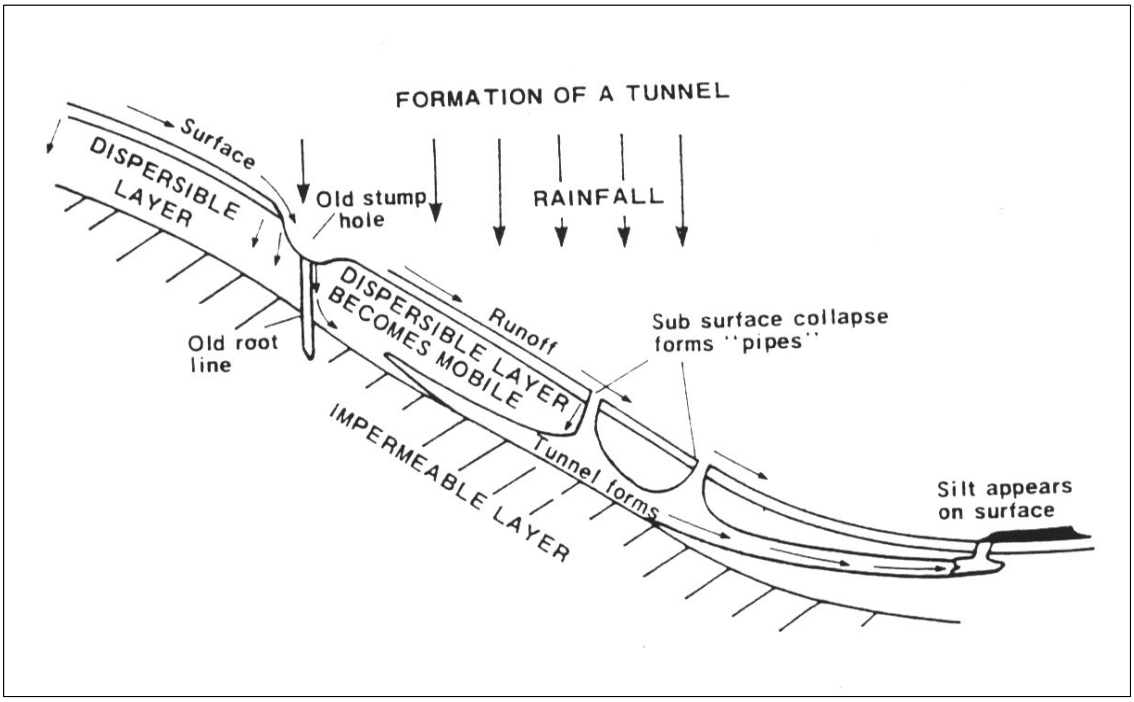


Figure 10. Formation of tunnel erosion (from Houghton, 1984)

Scalding
Most scalds are the result of loss of topsoil, by the action of wind and water, after the vegetation is removed. This usually results through drought or overgrazing. The remaining surface of the scald is generally the B horizon (or subsoil). In some texture contrast soils this surface will be saline or sodic.

High soil surface temperatures, sand blasting by wind, and lack of moisture penetration, make it difficult for plants to survive. The potential for scalding can be reduced by using conservative grazing strategies to retain as much surface cover as possible.

Shallow water ponding is an effective method of reclaiming scalds. This involves construction of a series of ponds to trap and store runoff to a maximum depth of 10cm. Eventually, the ponded runoff will soak into the soil producing two main benefits:
- stored soil moisture; and
- leaching of salts from the surface to deeper in the soil profile.

Ponded areas require fencing for grazing management to ensure repeat scalding does not occur.

Wind Erosion
Potential is highest where soil particles are light enough to be moved by the wind. The wind speed at the soil surface determines the capability of the wind to remove soil particles. Ways of reducing the wind erosion potential of a soil include:

- retaining as much surface cover as possible - this reduces wind speed at the soil surface and also keeps the soil moister and therefore less likely to blow away; and
- locating timber shelter belts at right angles to the prevailing winds.

2.72 Controlling soil erosion
All cultivated land is susceptible to some degree of erosion by water. In the Western Downs and Maranoa, slopes of over 4% should not be farmed because erosion rates are unacceptable regardless of the conservation techniques used.

Ways to reduce erosion in cropping lands are many and varied. On sloping land, the installation of a contour layout incorporating banks and waterways is an important first step. Diversion banks and waterways may also need to be incorporated. On slopes less than 5%, a strip cropping pattern at right angles to the flow of water can be used to reduce the velocity of overland flow. Management strategies such as zero or reduced till should be considered in all cases to reduce erosion and promote water infiltration.

The principle soil erosion control in pasture country is the maintenance of adequate groundcover. Adequate groundcover ensures that soil infiltration rates are maintained, overland flow velocities are reduced when runoff does occur, and the risk of erosion is minimised. It has been shown that a pasture cover above 40% reduces runoff (hence soil loss) in grazed land. The adoption of safe, flexible stocking rates is the key to maintaining a good pasture cover.

Regardless of the enterprise or the erosion control system employed, the secret to success is to retain as much soil surface cover as possible to minimise detachment of soil particles and hence erosion.

INTERPRETATION OF CHEMICAL ANALYSIS

pH
Preferred level: 6.0 - 7.5

The pH of soil is a measure of its acidity or alkalinity and is important in determining the degree and likelihood of acidification, in estimating possible nutrient deficiencies and assessing suitability for certain crops.

Soils which are neither acid nor alkaline are neutral and have a pH of 7. Acid soils have lower pH values and alkaline soils have higher values. Because the pH scale is logarithmic, going down the scale from pH 7 (neutral), each unit decrease is 10 times more acid than the one before it. For example, soil with a pH of 6 is 10 times more acid than a neutral soil (pH 7); soil with a pH of 5 is 100 times more acid than the neutral soil.

Most plants grow best when soil pH is between 6.0 and 7.5. Soils which are excessively acid may suffer from aluminium or manganese toxicity. On the other hand, soils which are excessively alkaline may suffer from trace element deficiencies.

$EC_{1:5}$ (Electrical Conductivity)
Preferred level: <0.9 dS/m

If >0.9 dS/m pasture yields are lower. Excess salt causes marginal scorching in oldest leaves. If a salt bulge is present down the profile it will affect root growth.

Cl (Chloride)
Preferred level: <0.06%

Usually associated with high $EC_{1:5}$; if >0.06%, can cause growth reductions in sensitive plants.

Total N (Nitrogen)
Preferred level: >0.15%

If <0.1%, need fertiliser or legumes. Plants deficient in nitrogen are stunted with premature death of oldest leaves and pale green or yellow leaves often with reddish tints. N supply may be inadequate if:

- Age of cultivation greater than 30 years.
- High yield potential crop.
- Poor mineralisation of N during the preceding fallow.

Organic Carbon
Preferred level: >1%

The organic carbon test is a useful indicator of organic matter status and therefore of overall fertility and structural stability of the surface soil. Soil organic matter acts as a soil aggregate stabiliser thereby improving porosity. It also supplies plant macro-nutrients and chelates micro-nutrients (Fe, Zn, Cu) making them more available to plants, and plays a key role in stabilising the soil surface.

Sulfate Sulfur Preferred level: >5 mg/kg	Compared to phosphorus, research on sulphur deficiency is sparse. As a result, sulfur 'adequacy' levels are not easily determined and probably depend on pasture species involved, the climate and the adequacy of other minerals in the soil.
P (Phosphorus) Preferred level: Bicarb. P cropping: >20-30 mg/kg improved pasture: >10 mg/kg	Phosphorus deficiency is common on many types of soils. It is also susceptible to loss by erosion due to its concentration in the surface. Plants deficient in phosphorus are stunted, dark green with short erect leaves and stout stems which often develop orange, red or purple colours. Tiller production, root development and yield are reduced. The presence of mycorrhizae can greatly increase the uptake of P.
CEC (Cation Exchange Capacity) Preferred level: >5 meq/100g	CEC measures the amount of nutrients held in a soil. If it is low means possible fertility problems.
Ca (Calcium) Preferred level: >2 meq/100g	If too low, tiphooking in youngest leaves. In soils with very high levels such as calcareous soils there may be an induced Mg deficiency. High Ca is needed for soil physical stability.
Mg (Magnesium) Preferred level: >2meq/100g	Patchy yellowing of older leaves and brilliant colours around the edge is an indication of deficiency. If Mg>Ca can cause Ca deficiency and also lead to unstable soils.
Na (sodium)	If the soil is sodic then it tends to disperse and often has problems with surface crusting and poor aeration.
K (Potassium) Preferred level: >0.3 meq/100g	If <4% of CEC growth reduction and deficiency symptoms occur. If <1% of CEC scorched margins of oldest leaves and spots surrounded by pale zones. If >10% of CEC may cause Mg deficiency.
Total S (Sulfur) Preferred level: >0.02%, 200 ppm	Sulfur occurs in both organic matter and as sulfate in the soil. Sulfur deficiency is not common and is most likely in acid sandy soils and in soils low in organic matter. If S accumulates in alkaline clay subsoil it may crystallise out as gypsum. Gypsum at the rate of 200 to 400 kg/ha every 3 years is the cheapest source of sulfur.
Total P (Phosphorus) Preferred level: >0.02%	Measures the reservoir in the soil. To determine fertiliser levels need to take into account the fixation ability of the soil. Excess P can cause deficiency of Zn, Cu and worsen a Fe deficiency.

Total K (Potassium) Preferred level: >0.5%	Measures the total reservoir of K in the soil both in soluble and insoluble forms. Values give some indication of long term status of K in soils. Found in the clay mineral illite and total K can be helpful in estimating clay mineralogy.
Zn (Zinc) Preferred level: >0.8 mg/kg	If pH <5, critical levels drop to 0.2-0.5 mg/Kg. Zinc plays a vital role in a plant's ability to use nitrogen and transform it into yield and protein. The availability of zinc to many crops is increased by the presence of mycorrhizae in the soil.
Cu (Copper) Preferred level: >0.4 mg/kg	If pH <5, critical levels drop to <0.01 mg/Kg. Copper deficient soils are generally brigalow belah, grey or grey-brown clays adjacent to rocky outcrops of quartz and sandstone where the natural vegetation is silver-leaf ironbark, narrow-leaf ironbark and wattle. Copper deficiency can be corrected with foliar sprays of copper sulfate (bluestone).
B (Boron) Preferred Level: >1-4 mg/kg	Maybe deficient at high pH, especially if high Ca. Can be toxic especially when, low Ca + low pH + high K.
Mo (Molybdenum) Preferred level: >5 mg/kg	If the pH is less than 5 it may cause deficiency. P enhances Mo uptake. Disorders can result from excessive Cu, Mn, SO_4^- in soil.
Fe (Iron)	Can be temporarily deficient, especially at pH >7 when P levels are high. Deficiency symptoms show interveinal yellowing in the youngest leaves.
Mn (Manganese)	At high levels, can be toxic if pH <5.2 and at high temperatures and extremes of wetting.
Al (Aluminium)	If pH <5.2, then Al toxicity may occur, seen as stunted roots with many short laterals, root tips commonly brown.

For more information refer to *Interpreting soil analyses - for agricultural land use in Queensland* by Baker and Eldershaw (1993)

GLOSSARY OF SOIL TERMS

A horizon — See Soil horizon.

A2 horizon — See *Subsurface soil; Bleach.*

Acid soil — A soil giving an acid reaction throughout most or all of the soil profile (precisely, below a pH of 7.0; practically, below a pH of 6.5). Generally speaking, when the pH drops below 5.5 the following specific problems may occur - aluminium toxicity, manganese toxicity, calcium deficiency and/or molybdenum deficiency.

Alkaline soil — A soil giving an alkaline reaction throughout most or all of the soil profile (precisely, above a pH of 7.0; practically, above a pH of 8.0

B horizon — See *Soil horizon.*

Bleach — Subsurface soil (A2 horizon) that is white, near white or much paler than adjacent soil layers.

C horizon — Layer(s) below the B horizon which may be weathered parent material, not bedrock, little affected by soil-forming processes.

CEC (Cation Exchange Capacity) — The measure of the capacity of a soil to hold the major cations: calcium, magnesium, sodium and potassium (including hydrogen, aluminium and manganese in acid soils). It is a measure of the potential nutrient reserve in the soil and is therefore an indicator of inherent soil fertility. An imbalance in the ratio of cations can result in soil structural problems. High levels of individual cations (e.g. aluminium and manganese) can also be toxic to plants.

Clays — Soils with a uniform clay texture throughout the surface soil and subsoil.
- *cracking:* Clay soils that develop vertical cracks when dry
- *non-cracking:* Clay soils that do not develop vertical cracks when dry.

Colluvium *(pl. colluvia)* — Slope deposits of soil and rock material.

Compaction — The process whereby soil density is increased as a result of tillage, stock trampling and/or vehicular trafficking. Compaction can lead to lower soil permeability, poor soil aeration resulting in increased erosion hazard and poorer plant productivity. Deep ripping and conservation tillage can alleviate the condition.

Concretion (in soil) — See *Segregation.*

Consistence *(of soil)* — Refers to the degree of resistance to breaking or deformation when a force is applied.

Deep weathering — The process by which earthy or rocky materials are slowly broken down into finer particles and soil by chemical processes over a long period of time. The chemical alteration of the rocks involved:

- leaching of the calcium-rich cement which previously bound the constituent particles together to form the rocks;
- a progressive transformation of feldspar minerals, clay minerals and labile fragments to form a new matrix of kaolinite white clay;
- the alteration of iron-rich minerals to form iron oxides (red colour); and mobilising and recrystallising of silica produced from the breakdown of minerals; more resistant quartz grains were relatively unaffected. See *Laterite*.

Dispersion — The process whereby soils break down and separate into their constituent particles (clay, silt, sand) in water. Dispersible soils tend to be highly erodible and present problems for earth works. Dispersion is associated with sodicity levels. See *Sodicity.*

Drainage*(soil profile)*

The rate of downward movement of water through the soil, governed by both soil and site characteristics. Categories are as follows:

- Very poorly drained: free water remains at or near the surface for most of the year.
- Poorly drained: all soil horizons remain wet for several months each year.
- Imperfectly drained: some soil horizons remain wet for periods of several weeks.
- Moderately well drained: some soil horizons remain wet for a week after water addition.
- Well drained: no horizon remains wet for more than a few hours after water addition.
- Rapidly drained: no horizon remains wet except shortly after water addition.

Duplex soil See *Texture contrast soil*.

Duricrust A cemented layer at or near the surface resulting from the concentration of breakdown products from rock weathering (see induration).

Earths Soils with a sandy to loamy (including clay loam) surface soil, gradually increasing to a loamy to light clay subsoil.

Effective rooting depth (ERD) Depth to which most plant feeder roots will penetrate. This is taken here to be the depth either to which salts have been leached and have therefore accumulated, or to an impeding layer. This represents the long-term depth of wetting.

Electrical conductivity (EC) A measure of the conduction of electricity through water,or a water extract of soil. The value can reflect the amount of soluble salts in an extract and therefore provide an indication of soil salinity.

Erodibility *(soil)* The susceptibility of a soil to the detachment and transportation of soil particles by erosive agents. It is a function of the mechanical, chemical and physical characteristics of the soil, and is independent of the other factors influencing soil erosion such as topography, land use, rainfall intensity and plant cover. It may be changed by management.

Erosion hazard The susceptibility of a parcel of land to the prevailing agents of erosion. It is dependent on a combination of climate, landform, soil, land use and land management factors.

ESP Exchangeable sodium percentage. See *Sodicity*.

Gradational The term describes a soil with a gradual increase in texture (i.e. becomes more clayey) as the profile deepens.

Granite/granitic rocks A coarse-grained, *igneous* rock formed beneath the earth's surface and consisting essentially of 20-40% quartz, alkali feldspars (which are a source of sodium and potassium) and very commonly a mica.

Gypsum A naturally occurring soft crystalline material which is a hydrated form of calcium sulphate. Gypsum contains approximately 23% calcium and 18% sulfur. It is used to improve soil structure and reduce crusting in hard setting clayey soils.

Hard setting Surface soil that becomes hard and apparently structureless on the periodic drying of the soil.

Igneous rocks	Rock crystallised from molten rock material (magma). It may be extruded to the Earth's surface (*volcanic*) or cool at depths below the surface (intrusive).
Induration	Process of forming indurated horizons or hard pans (sometimes known as 'billy'). Indurated layers are often associated with *laterite* where they are usually dominated by iron oxides (ferricrete) but may include forms of silica (silcrete) or aluminium oxides (alcrete or bauxite).
Infiltration	The movement of water through the soil surface. Soils with a high infiltration capacity allow more rain to enter the soil than soils with a low capacity. Runoff will occur when the rate of rainfall exceeds the soil's infiltration capacity. Surface soil structure and texture are important determinants of the infiltration capacity of a soil.
Jumpups	Local term used to describe stony, lateritised ridges and scarps.
Laterite	A profile formed by intense weathering. Many deeply weathered profiles termed 'lateritic' exhibit a distinct series of layers including a surface *duricrust*, ironstone and mottled and pallid (kaolinised) zones. The word laterite is used for any profile in which ironstone is a major feature. See *Duricrust*.
Lateritised rocks	Rocks which have been partially or completely weathered to laterite.
Leaching	The removal in solution of soluble minerals and salts as water moves through the soil profile.
Metamorphic rocks	Rocks that were originally igneous or sedimentary that have been physically and/or chemically altered by high temperatures and/or pressures beneath the Earth's surface.
Mineralisation	The breakdown of soil organic matter and crop and animal residues by micro-organisms to inorganic (available) forms.
Mottle	Spots, blotches or streaks of subdominant colours different from the main soil colour.
Nodules *(in soil)*	See Segregation.
Parent material	The rock from which a soil profile develops.
Permeability	The capacity for transmission under gravity of water through soil or sediments.
pH	A measure of the acidity or alkalinity of a soil. A pH of 7.0 indicates neutrality, higher values indicate alkalinity and lower values indicate acidity. Each unit change in pH represents a 10-fold change in either the acidity or alkalinity of the soil. For example, a pH of 5.0 is 10 times more acid than a pH of 6.0. Soil pH affects the amount of different nutrients that are soluble in water and therefore the amount of nutrient available to plants.
Plant available water capacity (PAWC)	The quantity of water held in a soil that can be extracted by plant roots. It is expressed as millimetres of plant available water within the root zone.
Plastic limit (PL)	The moisture content of a soil above which it can be remoulded (is plastic) and below which it cannot be remoulded (is brittle).
Porosity *(of soil)*	The degree of pore space in a soil (i.e. the percentage of the total space between solid particles). The extent and type of soil porosity indicates

	the ease with which water, air and roots can move through the soil. Without sufficient pores of the right size, soil is unproductive because plant roots cannot move through the soil easily, air and water movement are poor, and there is insufficient water for plant growth.
Sedimentary rocks	Rocks formed from the accumulation of material which has been weathered and eroded from pre-existing rocks, then transported and deposited as sediment by wind (aeolian) or water (fluvial, marine). Sedimentary rocks have been classified according to grain size and constituent minerals: Clay-sized grains **Mudstone** Silt-sized grains **Siltstone** Sand-sized grains **Sandstone** Gravel-sized grains **Conglomerate** Sandstone is further subdivided on the basis of the dominant minerals making up the clasts (solid inclusions) or the matrix which cements the clasts together: 90% or more of grains are quartz: **Quartzose sandstone** less than 75% of grains are quartz: **Labile sandstone**
Segregations	Discrete accumulations of minerals in the soil because of the concentration of some constituent, usually by chemical or biological action. Segregations are described by their nature, abundance and form.
1) nature	for example, calcareous (carbonate), gypseous (gypsum), manganiferous (manganese) and ferromanganiferous (iron-manganese).
2) form	Concretions: spheroidal formations (concentric in nature). Nodules: irregular rounded formations (not concentric or symmetric). Can have a hollow interior. Fragments: broken pieces of segregations. Crystals: single or complex clusters of visible crystals. soft segregations: finely divided soft segregations accumulated in the soil through chemical action with water. They contrast with surrounding soil in colour and composition but are not easily separated from the soil as separate bodies.
Self-mulching	A condition of well-structured surface soil, notably of clays, in which the aggregates fall apart naturally as the soil dries to form a loose mulch of soil aggregates. In cultivated soils, ploughing when wet may appear to destroy the surface mulch which, however, will re-form upon drying.
Slickensides	Subsoil structural features which develop as a result of two masses moving past each other, polishing and smoothing the surfaces. These are common in black cracking clays.
Sodicity	A characteristic of soils (usually subsoils) containing exchangeable sodium to the extent of adversely affecting soil stability, plant growth and/or land use. It is measured as a percentage of the cation exchange capacity of the soil.
Soil colour	The colour of soil material is determined by comparison with a standard Munsell soil colour chart. The colours are described for moist soils unless otherwise stated.

Soil horizon	A layer of soil material within the *soil profile* with distinct characteristics and properties produced by soil-forming processes, and which are different from those of the layers above and/or below. The three main horizons are: A (topsoil); B (subsoil); C (see C horizon). Boundaries between horizons take many forms. From sharp - less than 5 mm wide to diffuse - more than 100 mm wide.
Soil profile	A vertical cross-sectional exposure of a soil, from the surface to the parent material or *Substrate*.
Soil reaction trend	The general direction of the change in pH with depth.
Soil structure	The arrangement of natural soil aggregates that occur in soil; structure includes the distinctness, size and shape of these aggregates.
1) distinctness	
- strong	The natural soil aggregates are quite distinct in undisplaced soil; when displaced more than two-thirds of the soil material consists of aggregates (i.e. well structured).
- moderate	Natural soil aggregates are well formed and evident but not distinct in undisplaced soil; when displaced more than one-third of the soil material consists of aggregates (i.e. moderately structured).
- weak	The natural soil aggregates are indistinct and barely observable in undisplaced soil; when displaced up to one-third of the soil material consists of soil aggregates (poorly structured).
2) shape	
- apedal	There are no observable natural soil aggregates (structureless); the soil may be either a coherent mass (massive) or a loose, incoherent mass of individual particles such as sand grains (single grain).
- blocky	The natural soil aggregates have the approximate shape of cubes with flat and slightly rounded sides.
- prismatic	The natural soil aggregates have the approximate shape of elongated blocks.
- columnar	The natural soil aggregates are like those of *prismatic* but have domed tops.
- polyhedral	The natural soil aggregates are irregular, many sided and multi-angled.
- lenticular	The natural soil aggregates are like large vertical lens shapes with curved cracks between the aggregates.
- platy	The soil particles are arranged around a horizontal plane and bounded by relatively flat horizontal faces.
- granular	The natural soil aggregates are rounded, porous, stable and less than 12 mm in diameter. They usually occur in the surface horizons.
Soil texture	The coarseness or fineness of soil material as it affects the behaviour of a moist ball of soil when pressed between the thumb and forefinger. It is generally related to the proportion of clay, silt and sand within a soil
Subsoil	Soil layers below the surface with one of the following attributes: - a larger content of clay, iron, aluminium, organic material (or several of these) than the surface and subsurface soil; - stronger colours than those of the surface and subsurface soil above, or

the *substrate* below. The B horizon.

Substrate — The material below the soil profile which may be the parent material or may be unlike the material from which the soil has formed; substrate which is not parent material for the soil above may be layers of older alluvium, rock strata unrelated to the soil or the buried surface of a former landscape.

Subsurface soil — Soil layers immediately under the surface soil which usually have less organic matter, paler colours and may have less clay than the surface soil. The A2 horizon.

Surface crust — Distinct surface layer, often laminated, ranging in thickness from a few millimetres to a few tens of millimetres, which is hard and brittle when dry and cannot be readily separated from and lifted off the underlying soil material.

Surface soil — The soil layer extending from the soil surface down. It is usually distinguished by organic matter accumulation and is darker in colour than the underlying soil layers. It may also be separated from the underlying subsoil by a difference in structure (finer or massive compared to the B horizon).

Texture contrast soil — A soil in which there is a sharp change in soil texture between the A and B horizons (surface and subsoil) over a distance of 10 cm or less. Also known as a duplex soil.

Volcanic rocks — Igneous rocks which have cooled from magma extruded to the Earth's surface. The size of the rock crystals depends on its duration of cooling - rapid cooling forms very fine crystals or even volcanic glass.

Waterlogging — A situation in which all the pores in the soil have filled with water. Excess water may lie on the surface of the soil. All the air in the pores has been displaced by water, so no oxygen is available to plant roots or for soil microbial activity. If waterlogging continues for a long period, plants die. Under waterlogged conditions, nitrate, the most available form of nitrogen, breaks down and is lost as a gas.

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Dalby State High School

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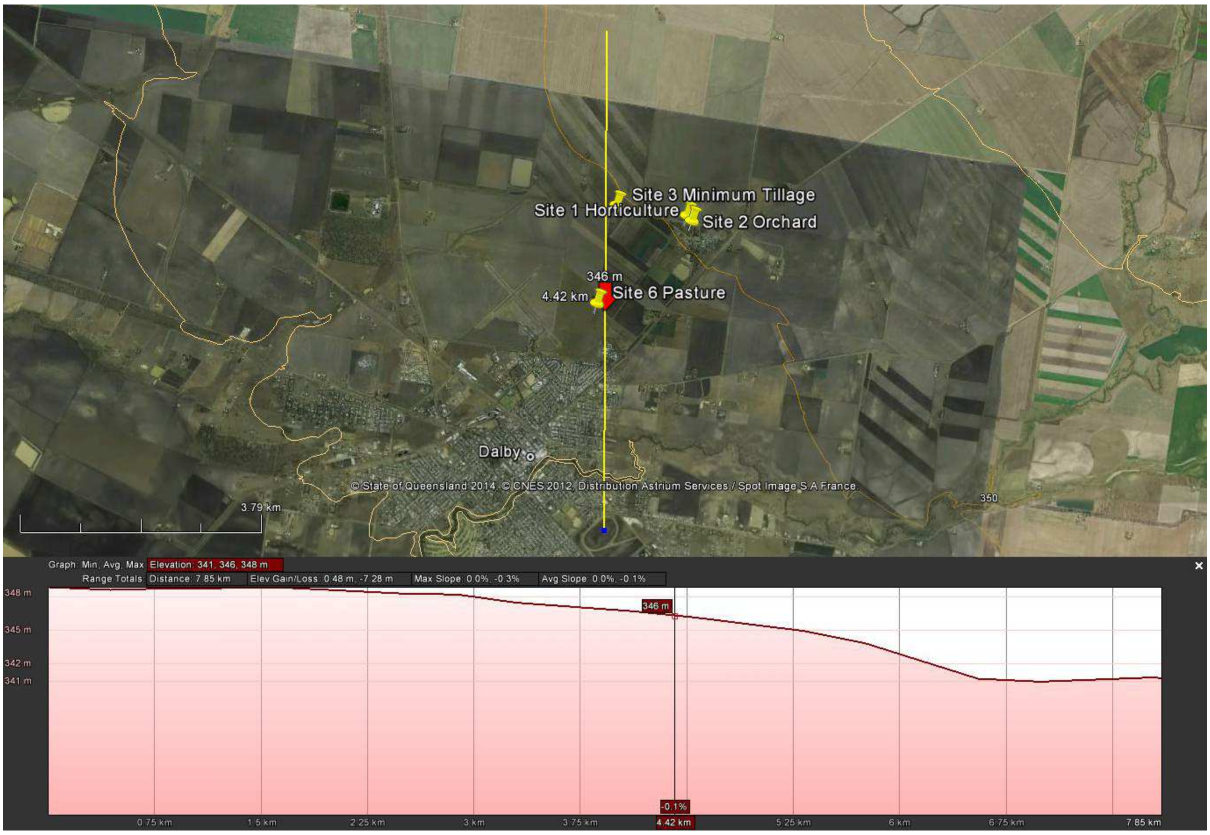

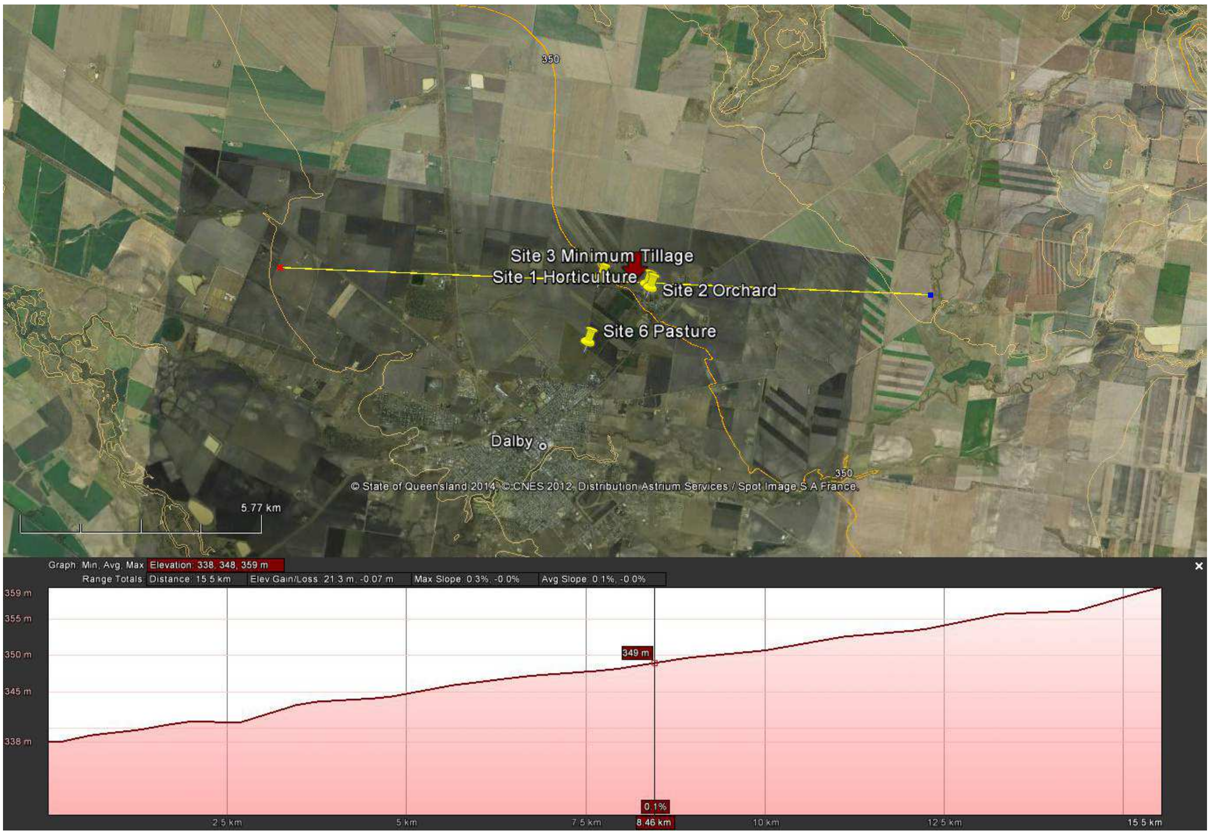

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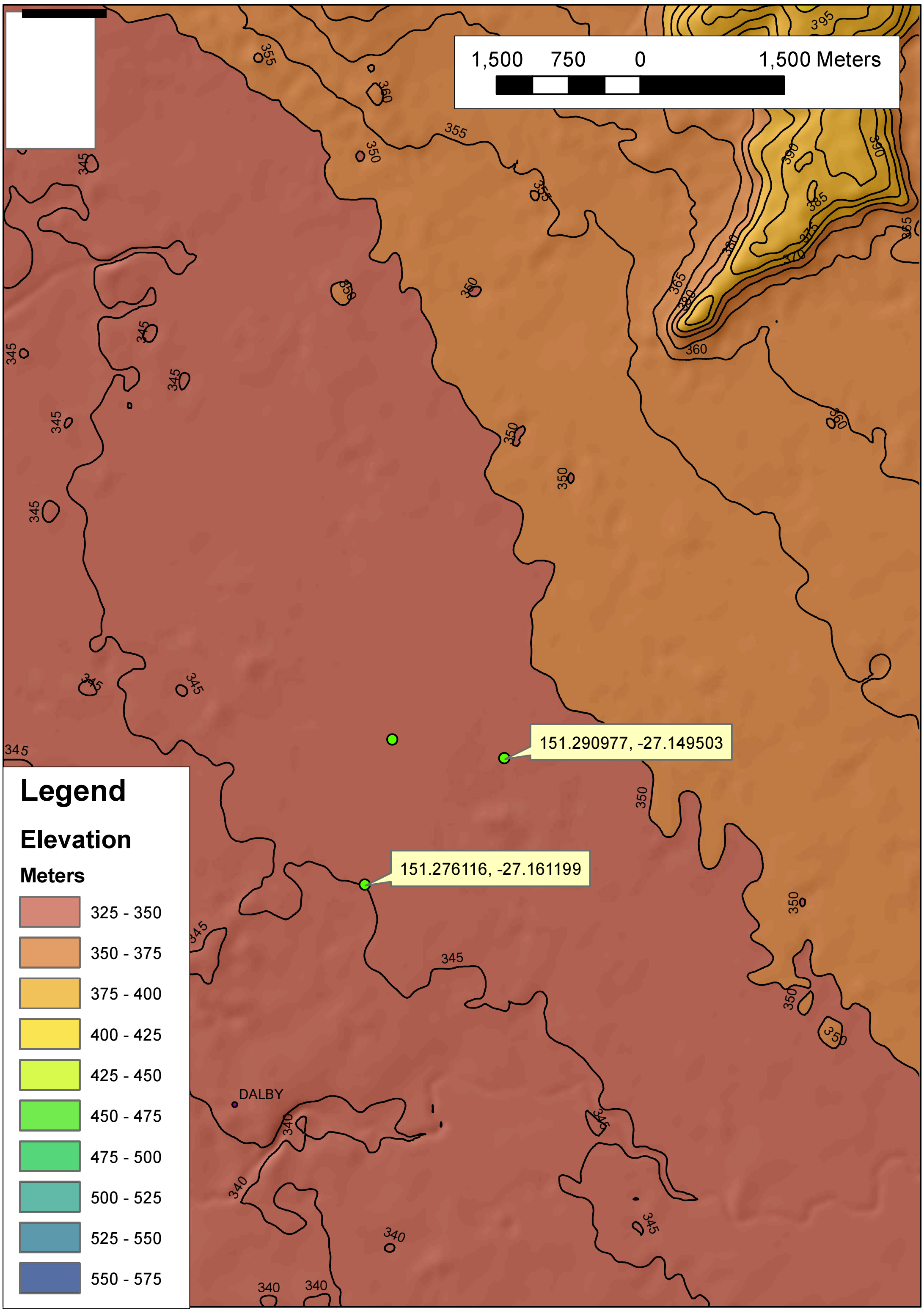

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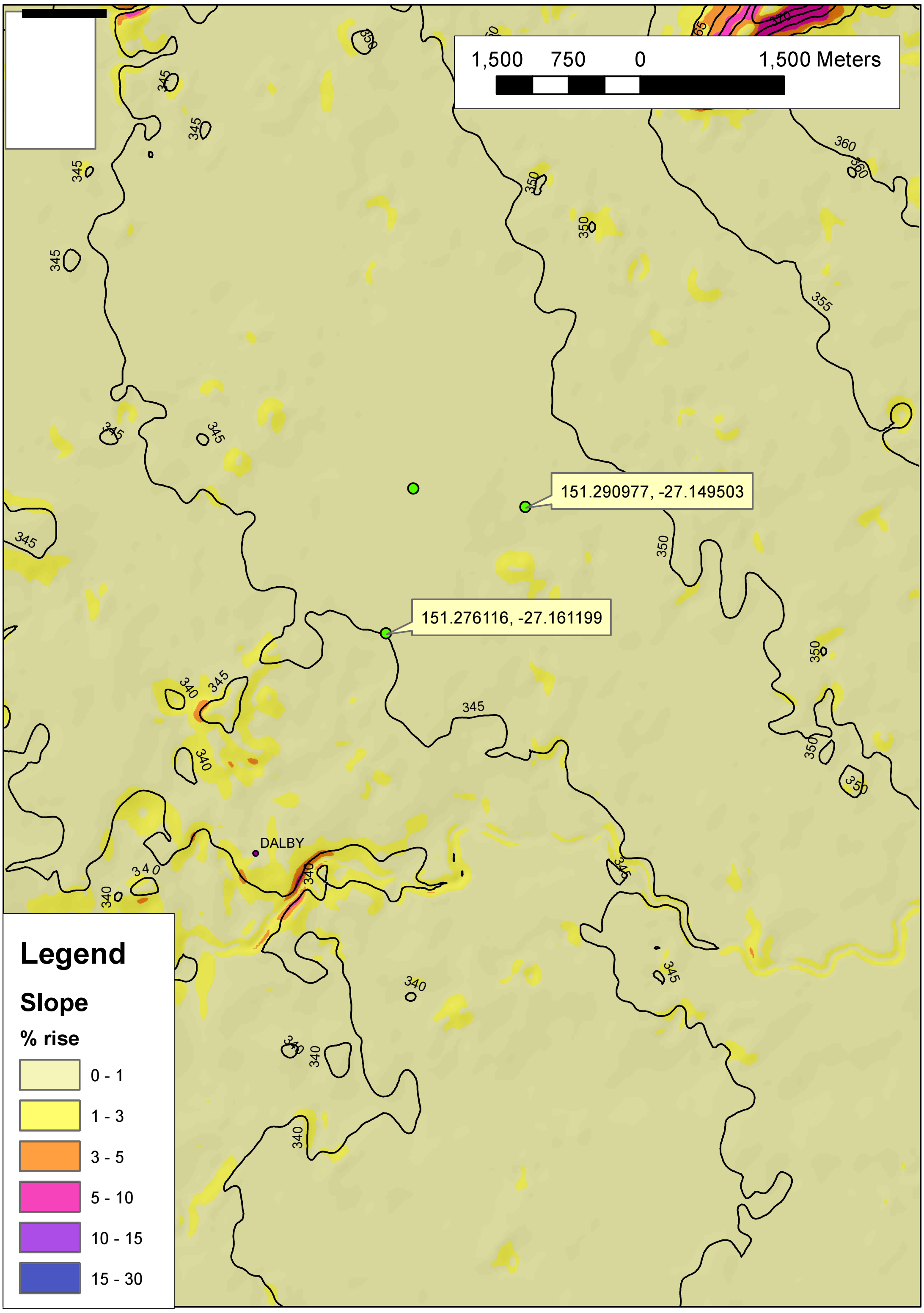

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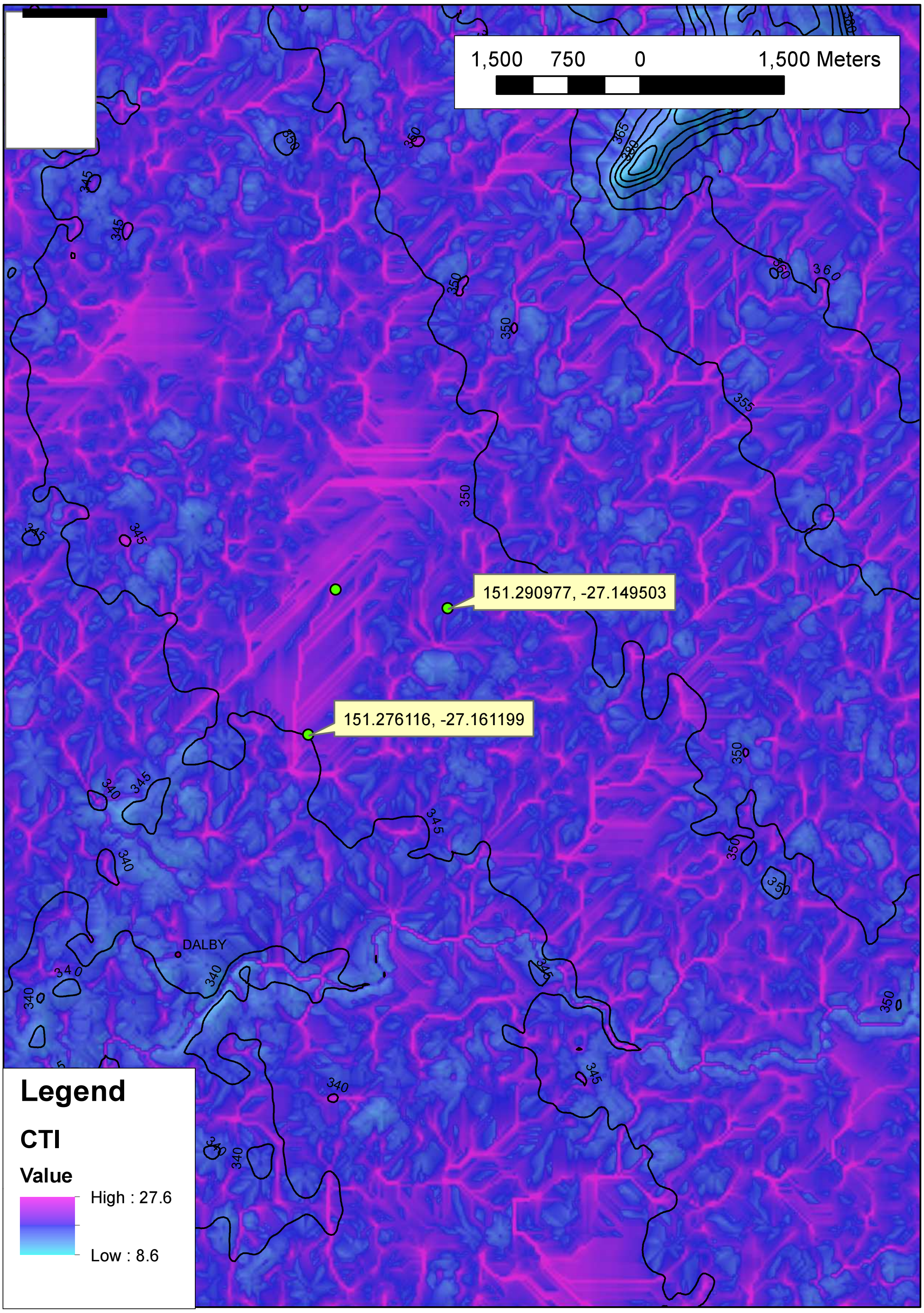

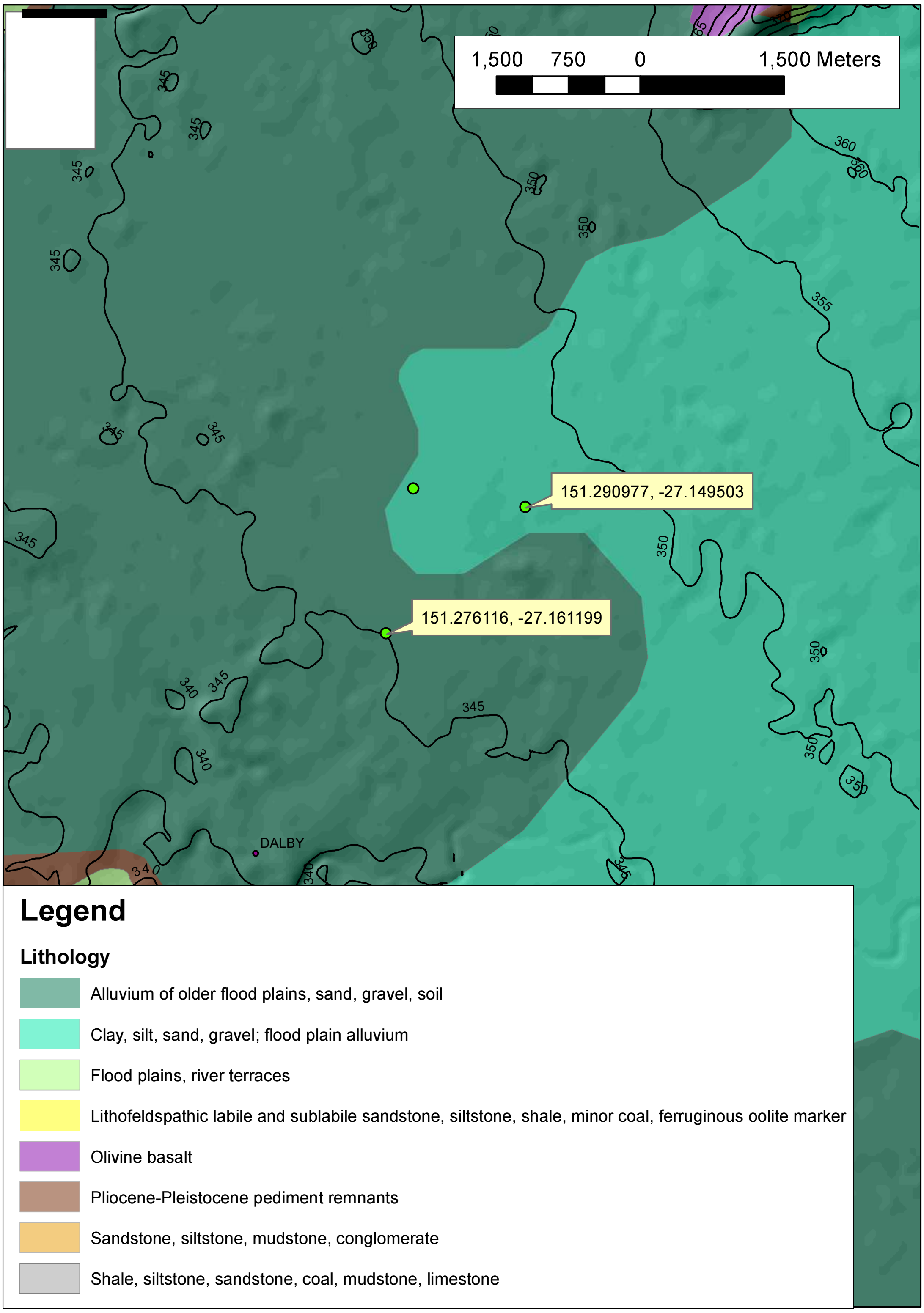
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355
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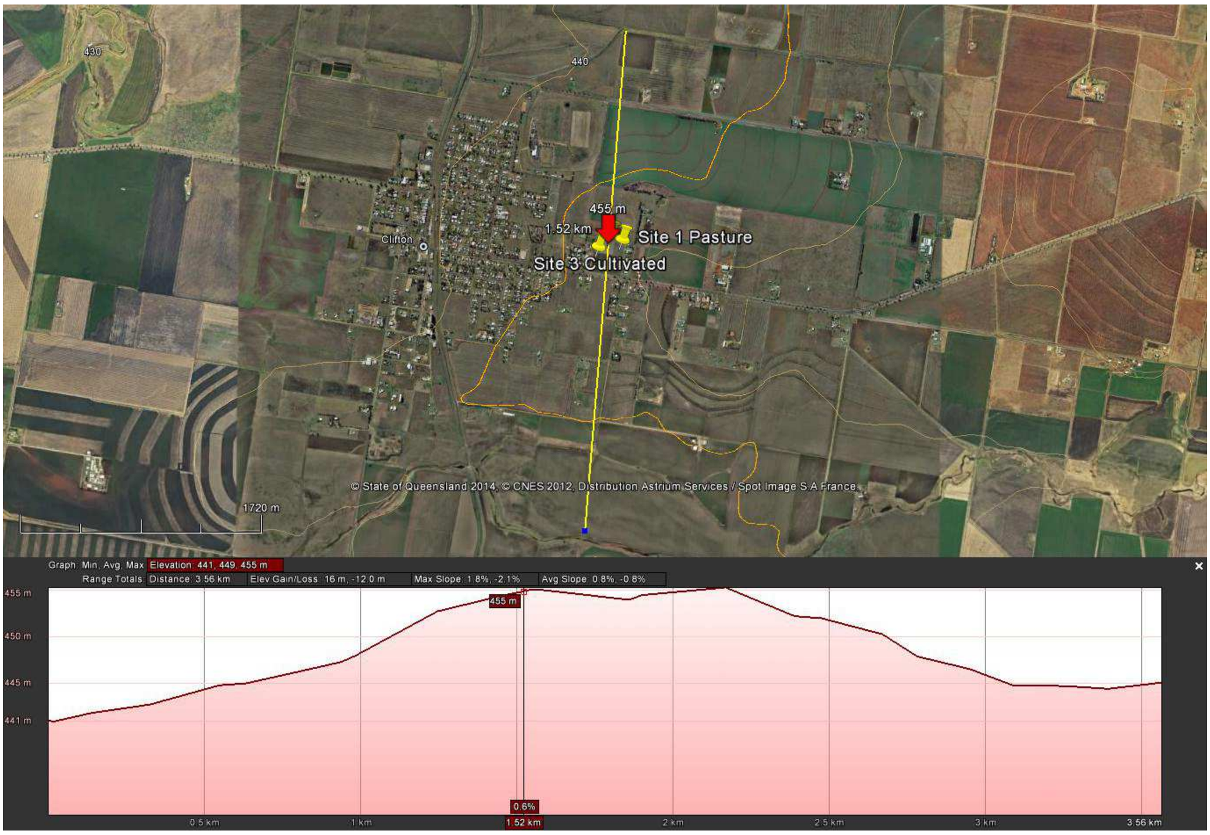
340
Legend
Lithology
Alluvium of older flood plains, sand, gravel, soil
Clay, silt, sand, gravel; flood plain alluvium
Flood plains, river terraces
Lithofeldspathic labile and sublabile sandstone, siltstone, shale, minor coal, ferruginous oolite marker
Olivine basalt
Pliocene-Pleistocene pediment remnants
Sandstone, siltstone, mudstone, conglomerate
Shale, siltstone, sandstone, coal, mudstone, limestone

Clifton State High School

Clifton State High School



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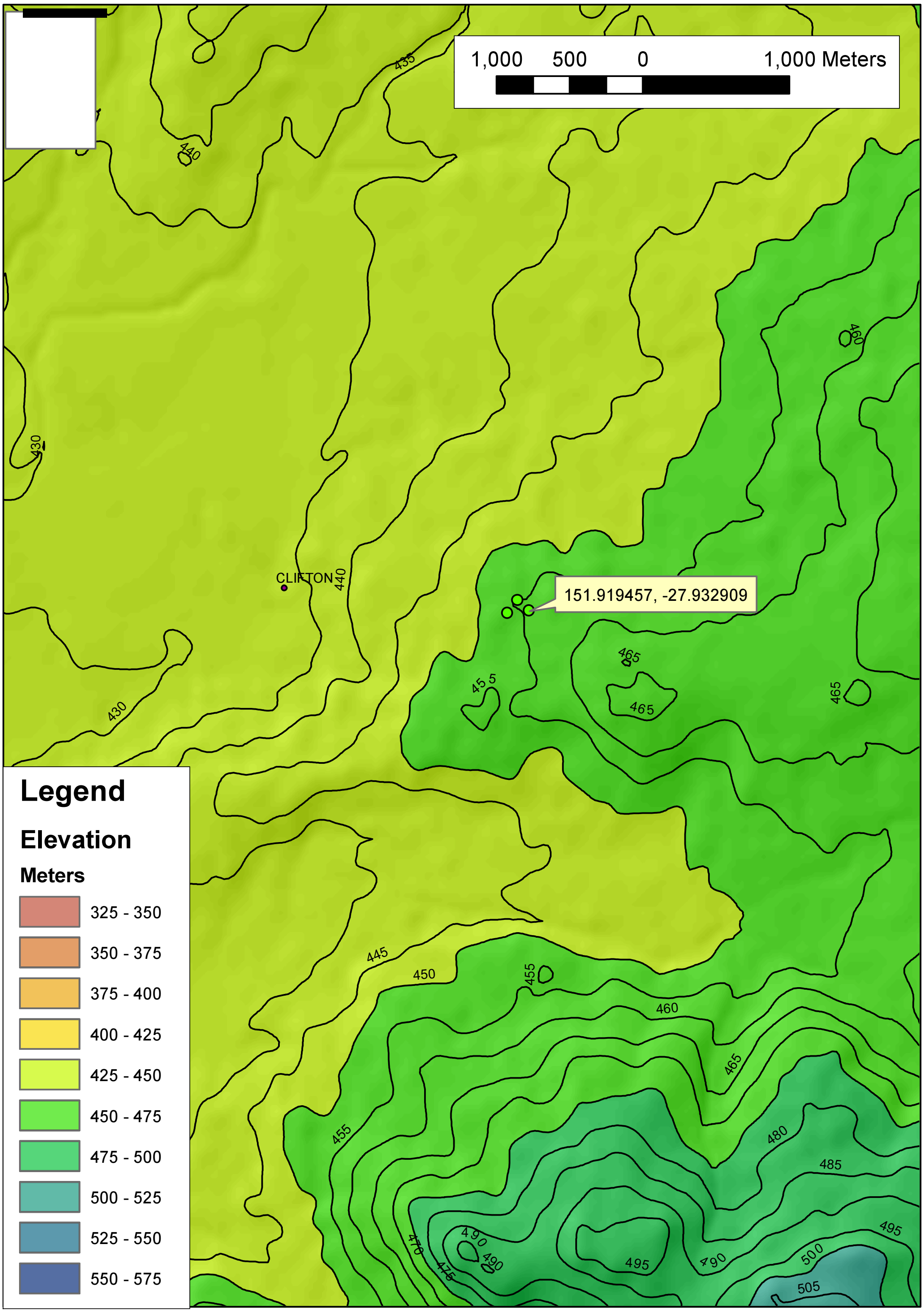

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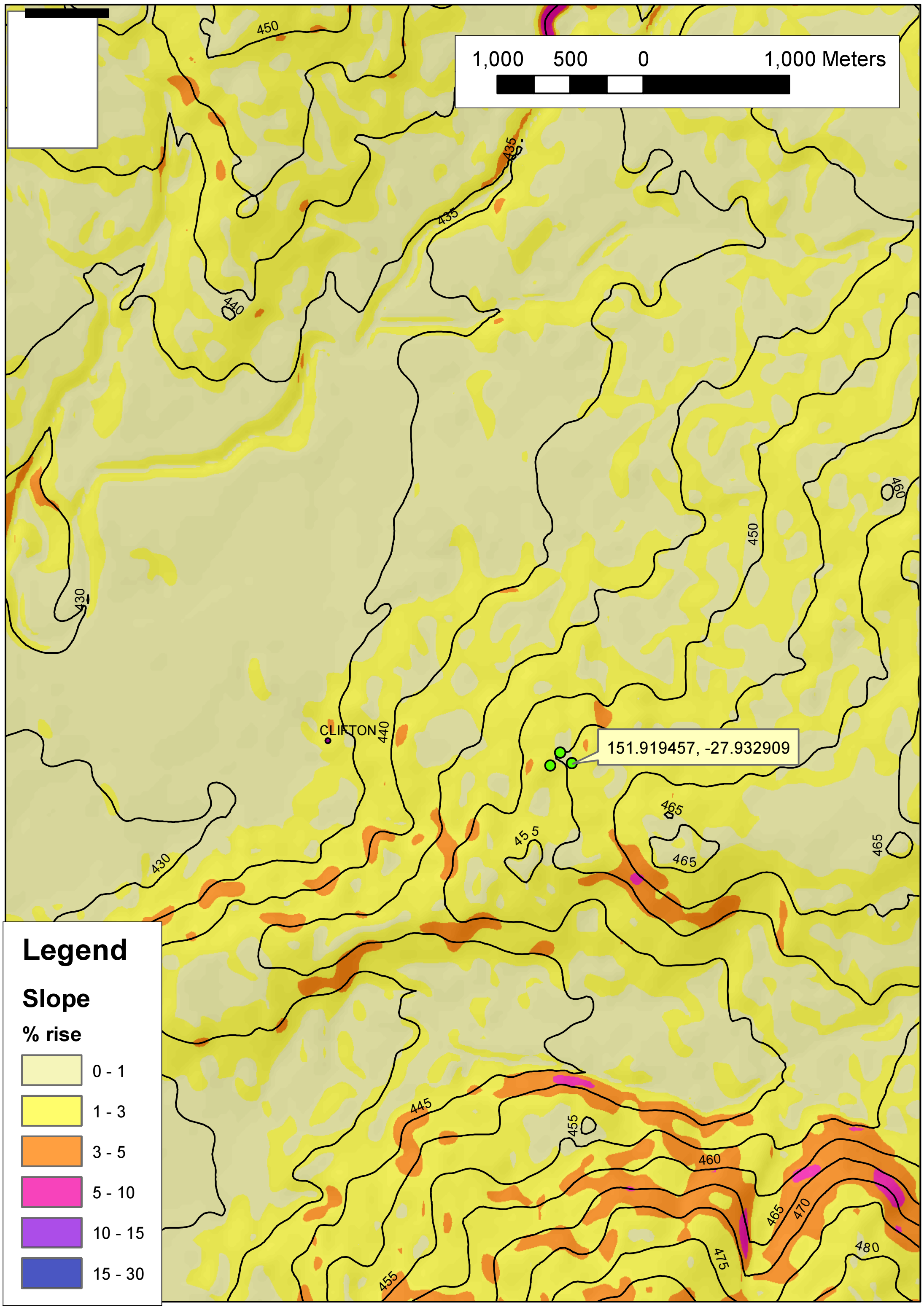

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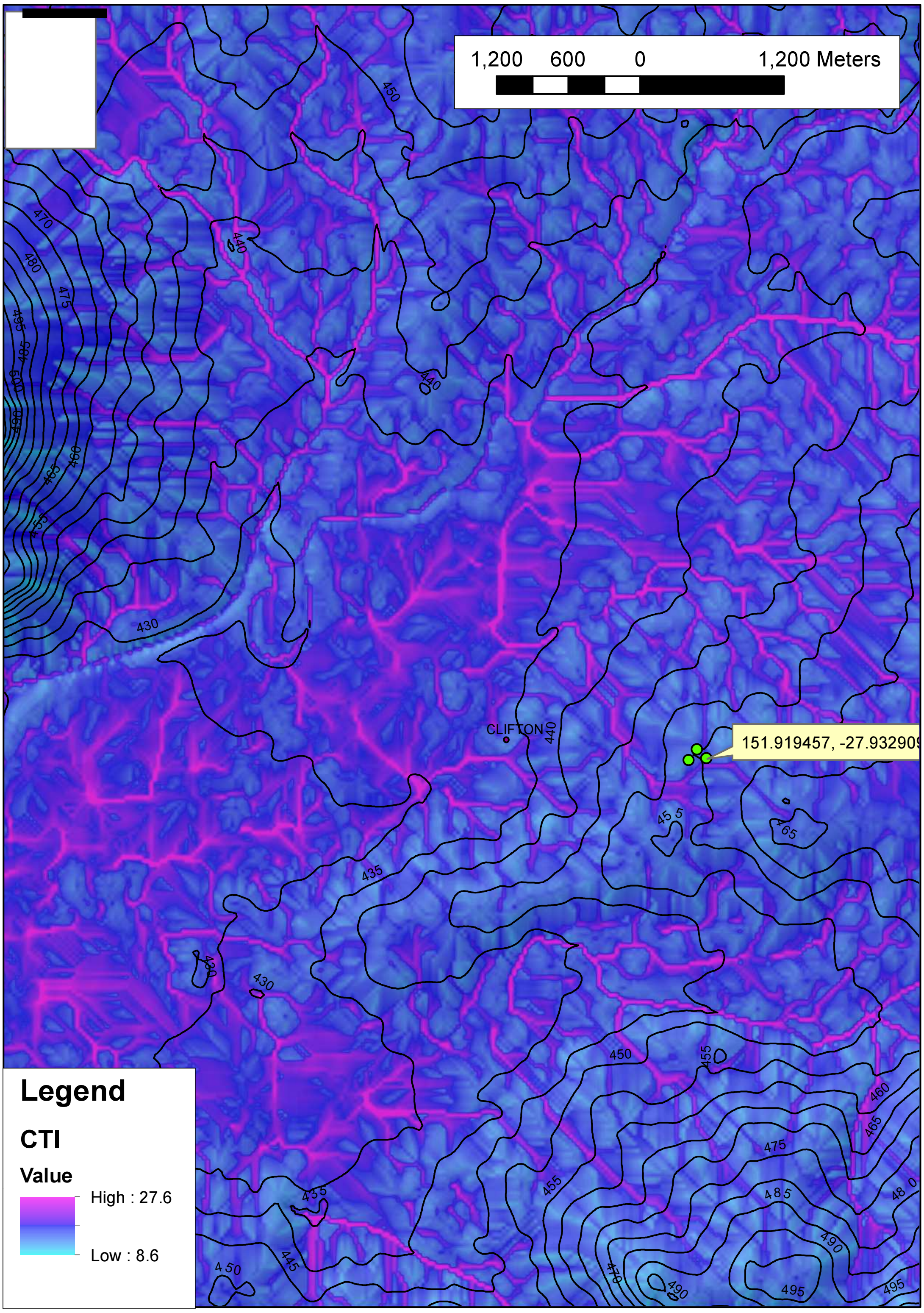

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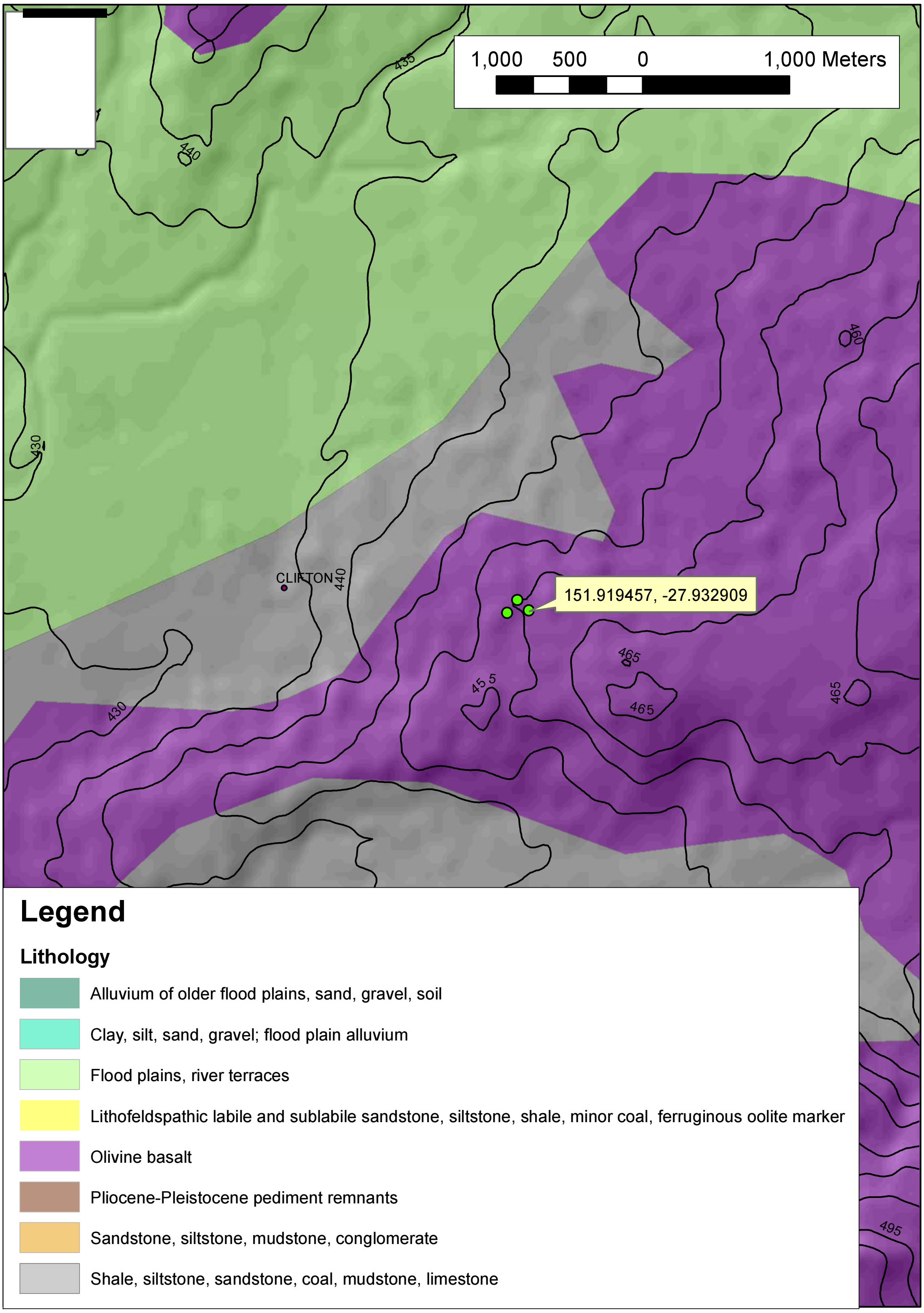


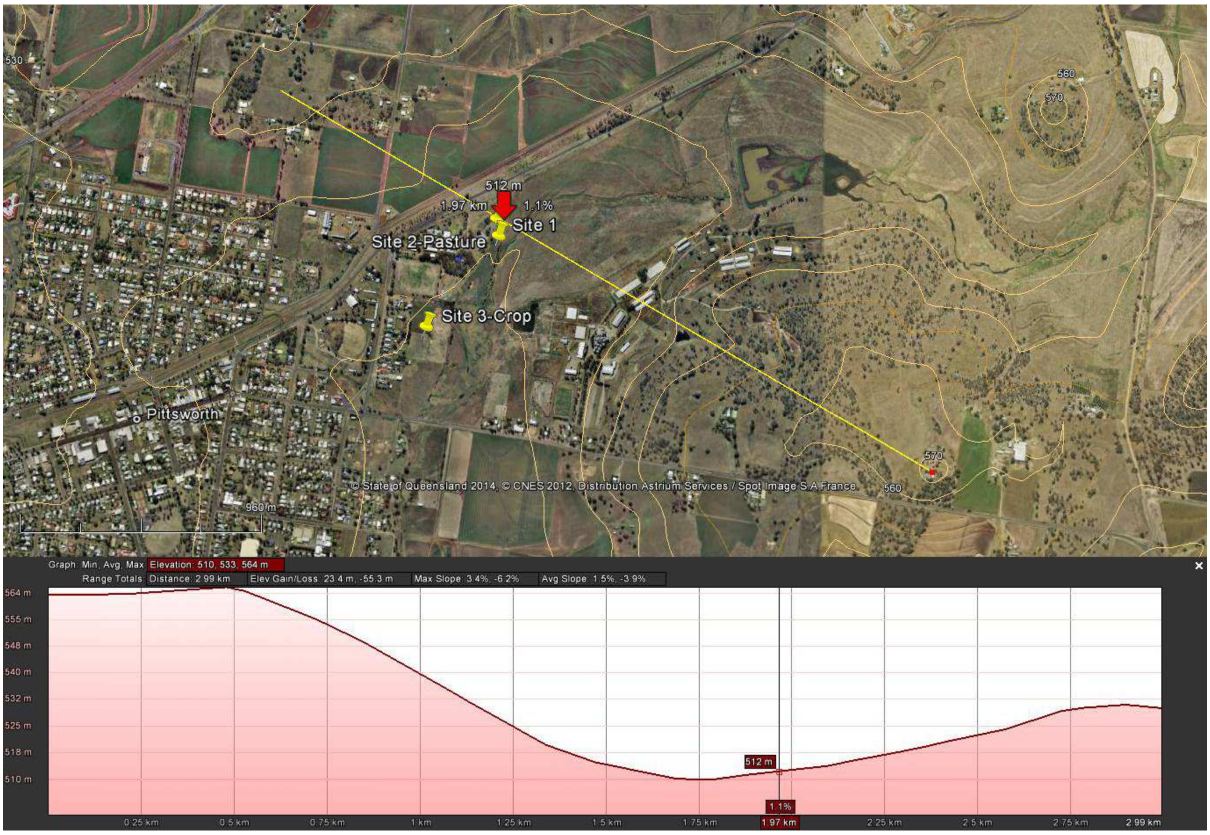
Legend

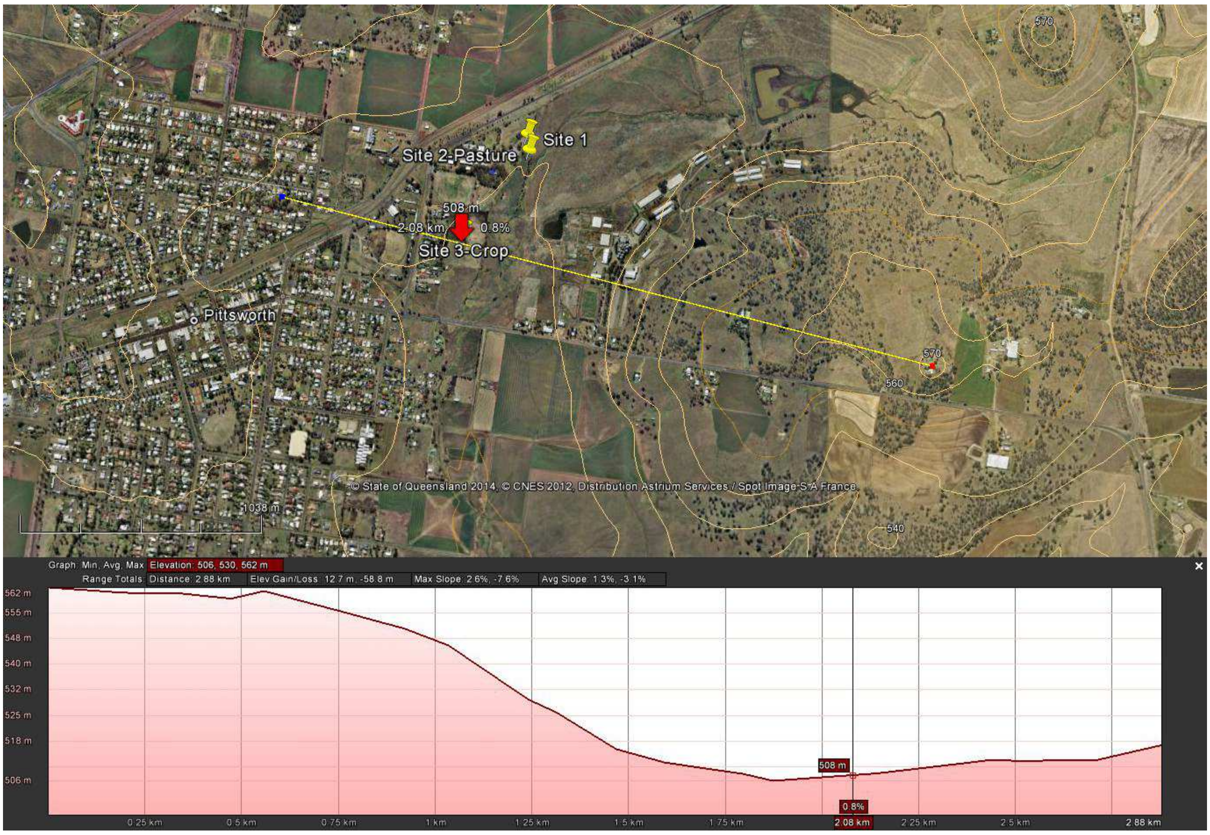
Lithology

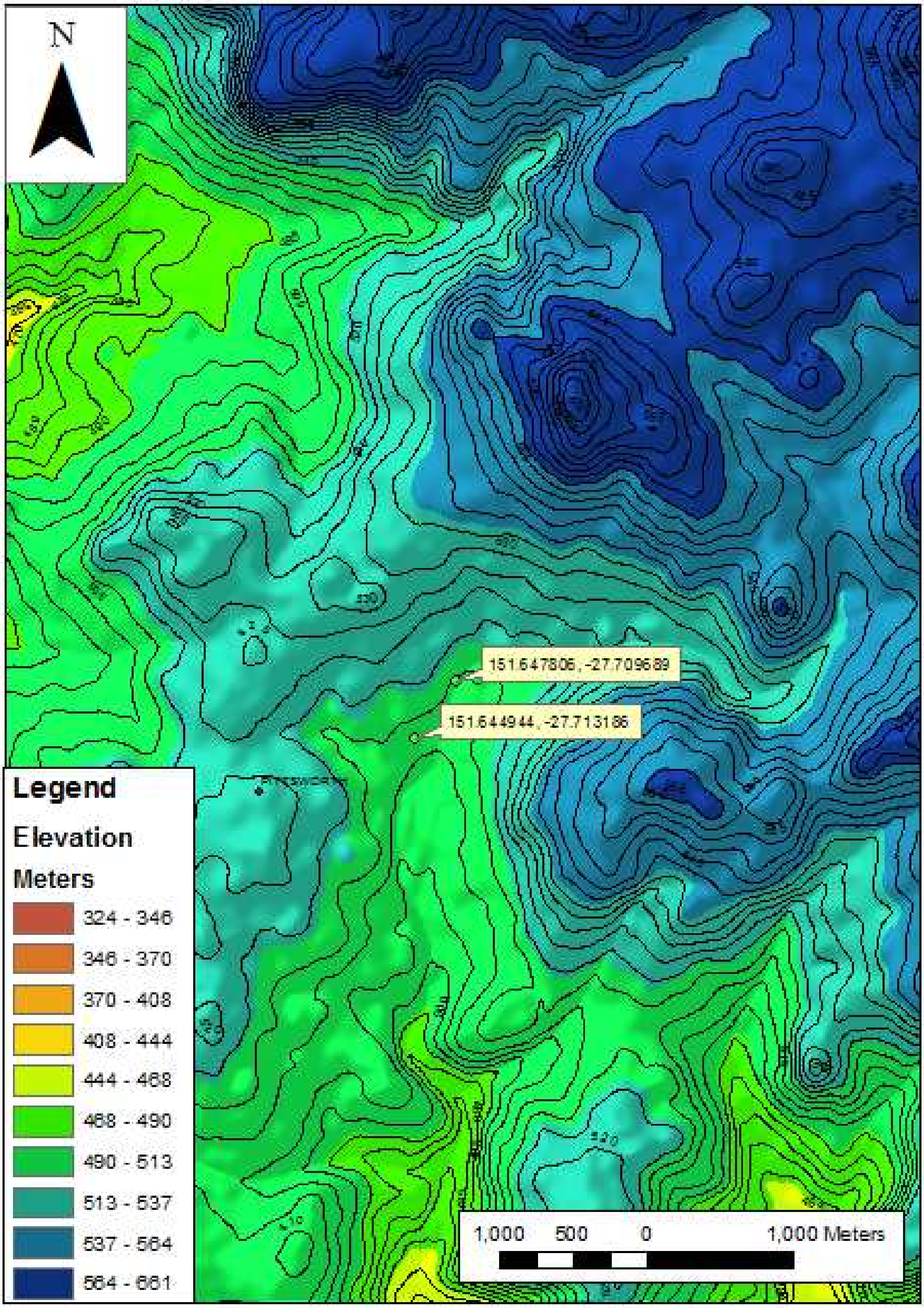
- Alluvium of older flood plains, sand, gravel, soil
- Clay, silt, sand, gravel; flood plain alluvium
- Flood plains, river terraces
- Lithofeldspathic labile and sublabile sandstone, siltstone, shale, minor coal, ferruginous oolite marker
- Olivine basalt
- Pliocene-Pleistocene pediment remnants
- Sandstone, siltstone, mudstone, conglomerate
- Shale, siltstone, sandstone, coal, mudstone, limestone

Pittsworth State High School

Pittsworth State High School



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Legend
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Meters
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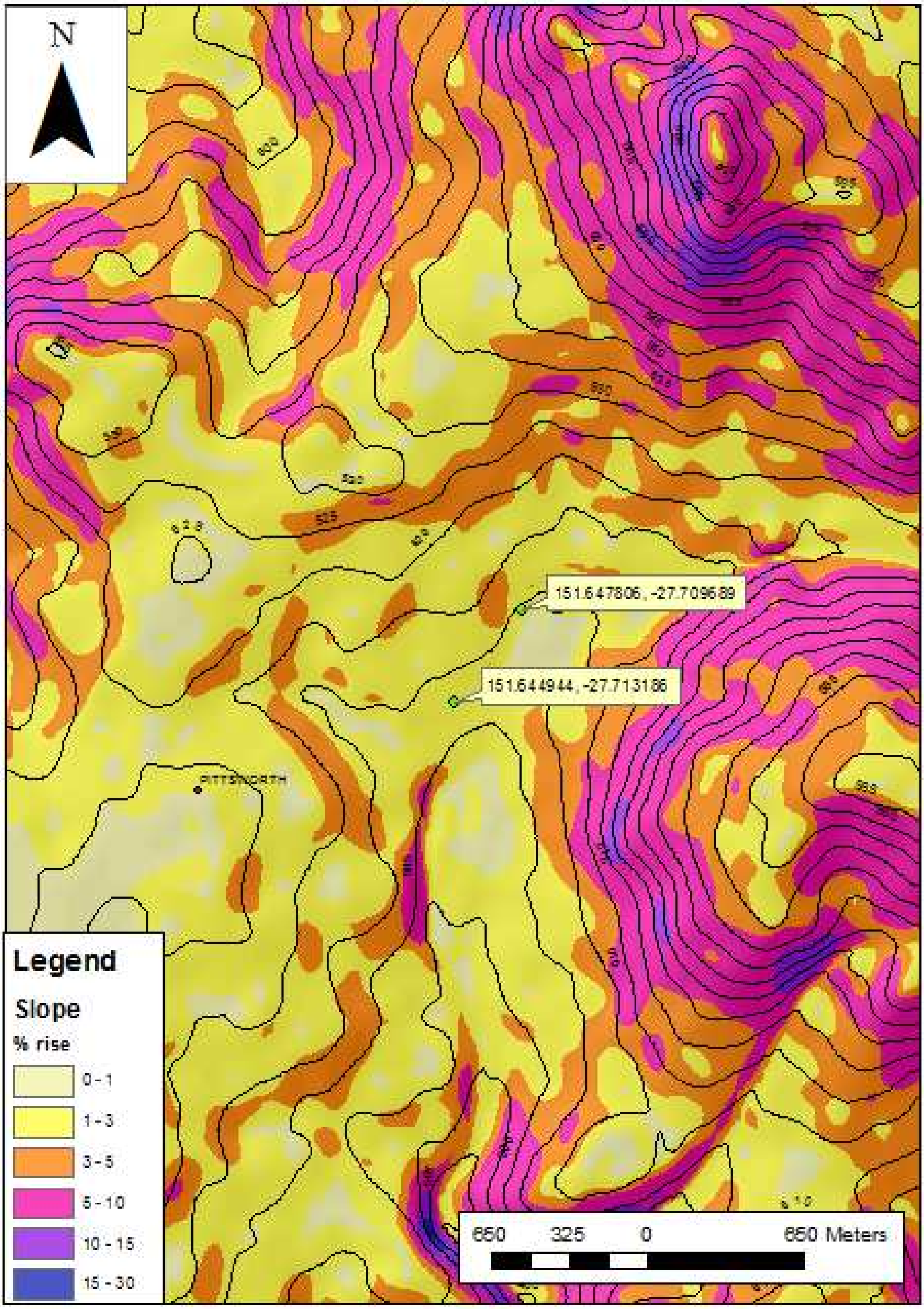
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PITTSWORTH
Legend
Slope
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3 - 5
5 - 10
10 - 15
15 - 30
650
325
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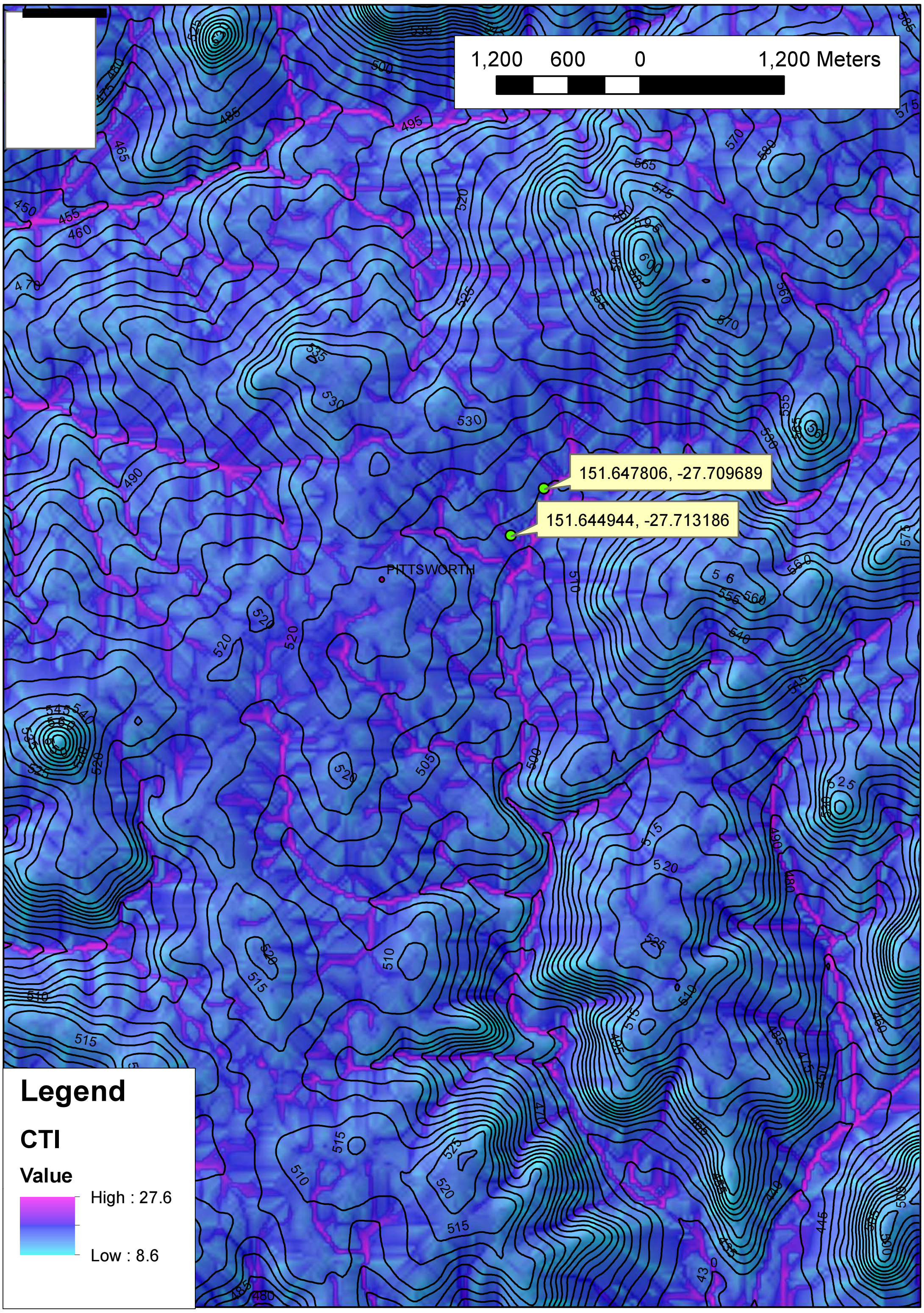
650 Meters
525

Pittsworth State High School



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