MURRAY DAIRY

ACCELERATING CHANGE SOILS PROGRAM.

"SETTING THE SCENE"

Physical and Chemical Parameters Which Influence Soil Productivity on Selected Irrigated & Dryland Sites Under Dairy Production in the Goulburn Valley.

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Accelerating Change

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GLOSSARY OF TERMS

A Horizons:	Topsoil horizons, or surface horizons.
Aggregates:	Individual units of soil forming blocks which are surrounded by air, water, plant roots and other aggregates.
Ag. Vic:	Agriculture Victoria.
AWC:	Available Water Content (mm).
B Horizons:	Subsoil horizons.
Catena:	A sequence of soil profiles on a slope.
Calcium Carbonate:	Natural CaCO3 or lime found in the soil, usually as nodules.
DAW:	Deficit Available Water, where soil suction is 200 kPa or greater.
ERZ:	Effective Root Zone Depth (cm).
Gypsum:	Natural Calcium Sulphate (CaSO4) found in the soil at depth, usually as crystals.
Lime:	Calcium carbonate (as above).
Root Score:	A score of plant roots out of 10. 0 = No roots. 10 = prolific mass of plant roots.
Topsoiling:	Process of removing topsoil prior to landforming, then landforming subsoil to achieve the desired level or slope, then uniform placement of topsoil over land-formed subsoil (not ‘cut and fill’).
VRT:	Variable Rate Technology, generally applied to fertilizers or irrigation water based on soil characteristics.

1. INTRODUCTION.

1.1. Report Outline.

Soils are a fundamental component of dairy production systems in the Murray Dairy region. In a climate where the viability of dairy farm production is threatened by rising costs of production, all aspects of soil and agronomy come under regular scrutiny to identify opportunities for change and improving practice and soil performance.

Murray Dairy's "Accelerating Change" program for 2016 and 2017 involves three soils based workshops which investigate the soil issues that confront landowners on typical soil types in the region. The program aims to increase the efficiency of dairy production systems through improved management of soils, irrigation and feed base. Fundamental to changing management is the recognition of the key soil physical and chemical properties, their recognition at a farm level and understanding on how they impact production. Murray Dairy engaged South East Soil & Water to facilitate investigation and presentation at each of the inspected sites and compile this review.

This report summarises the findings from Workshop 1, titled "Setting the Scene". Observations from five sites used for dairy production in the Goulburn Valley are contrasted with the key points impacting on soil physical and chemical conditions and management options being the focus of discussion.

Establishing priorities for soil amelioration and management were a primary outcome of the workshop. Wet conditions dominated the irrigated sites, with waterlogging and drainage aspects covered in detail. In addition, anthropogenic disturbance to the landscape from land forming, channel banks and drains provided further discussion around aspects of soil water, infiltration, drainage, waterlogging and soil water holding capacity. Further recognition of the soil catena and the soil sequences that exist were also covered, to put historic soil mapping and published literature into perspective.

Details of the key observations from Workshop 1 follow.

Figure 1. Photograph of attendees surrounding a soil pit on the Emmett property during Workshop 1.

1.2. Soil Management Issues & Observations from Workshop 1.

Eight key soil properties that influence production were identified during Workshop 1. These are listed below with further explanation included in the report. They include:

1. Depth and structure of A horizon topsoil.

2. Effective Root Zone Depth (ERZ) measured in millimetres (mm) and Available Water Content (mm/cm).

3. Waterlogging, surface and profile drainage.

4. Consolidated, compacted or bleached subsurface horizons, including the "A_2" horizon.

5. Medium and heavy clay subsoils with low permeability and poor drainage.

6. Dispersive or sodic topsoils and subsoils.

7. Hostile subsoil layers evincing minimal plant roots.

8. Acidic topsoil layers with poor nutrient availability.

The listed soil management issues were not limited to the abovementioned points. The list above is a best attempt to delineate key issues influencing production of pastures and crops. Many interact and these interactions were the focus of discussion.

1.3. Personnel Conducting this Review.

<u>Field presentation and report drafting:</u>

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Personnel undertaking this assessment collectively hold over 45 years of practical experience with site investigation and land capability assessment for agricultural production, environmental impact, geotechnical structures, wastewater management, contaminated site investigation and soil management for irrigated and dryland agriculture, horticulture, viticulture. Experience is derived from continual engagement in projects of this kind with commercial agencies, the government sector and private enterprise.

2. INSPECTED SITES FOR WORKSHOP 1.

2.1. Site Locations.

The sites inspected are listed below as follows:

- Sites 1 and 2: Lang property, Dhurringile road, Tatura.
- Sites 3 and 4: Emmett property, Johnson road, Stanhope.
- Sites 5 and 6: McDonald property, Wigg road, Girgarre.

Figure 2 shows the location of sites inspected during Workshop 1. Soil test results from the A and B_1 horizon of each site were collected in advance of the field day. These are included in Appendix A and named in accordance with the points delineated in Figure 2.

2.2. Summary of Site Details.

This section describes key soil issues which were identified after field inspection and soil testing. This process was undertaken approximately 4 weeks prior to the event.

2.2.1. Sites 1 & 2. Lang. Dhurringile Road.

Site History: The two inspected sites have been devoted to perennial and annual pasture production using channel, bore and recycled water. The selected sites are close to the dairy and are used for intensive grazing.

Key Issues:

- Waterlogging, patchy growth, slow or impeded drainage from flat grades on bays
- Dispersive and sodic A and B horizons
- Generally alkaline soil conditions
- Soil types include Lemnos Loam and Goulburn Loam (Skene & Poutsma, 1962).

2.2.2. Sites 3 & 4. Emmett. Johnson Road.

Site History: The two inspected sites have been used for dryland farming for approximately 20 years. The sites were previously used for irrigated pasture production using a traditional cut and fill layout. The sites have been deep ripped in early 2016 and remain subject to potential development for centre pivot irrigation.

Key Issues:

- Deep ripping was carried out to improve the structure of consolidated or compacted layers
- Dense soil was manifest as a bleached A_2 horizon
- There may be impacts on growth from traditional cut and fill land-forming
- Site remains cloddy from ripping
- A horizon topsoil is moderately acidic
- Dispersive and sodic subsoil conditions exist
- Site sown to wheat with optimal germination
- Soil types include Lemnos Loam and Shepparton Fine Sandy Loam (Skene & Poutsma, 1962).

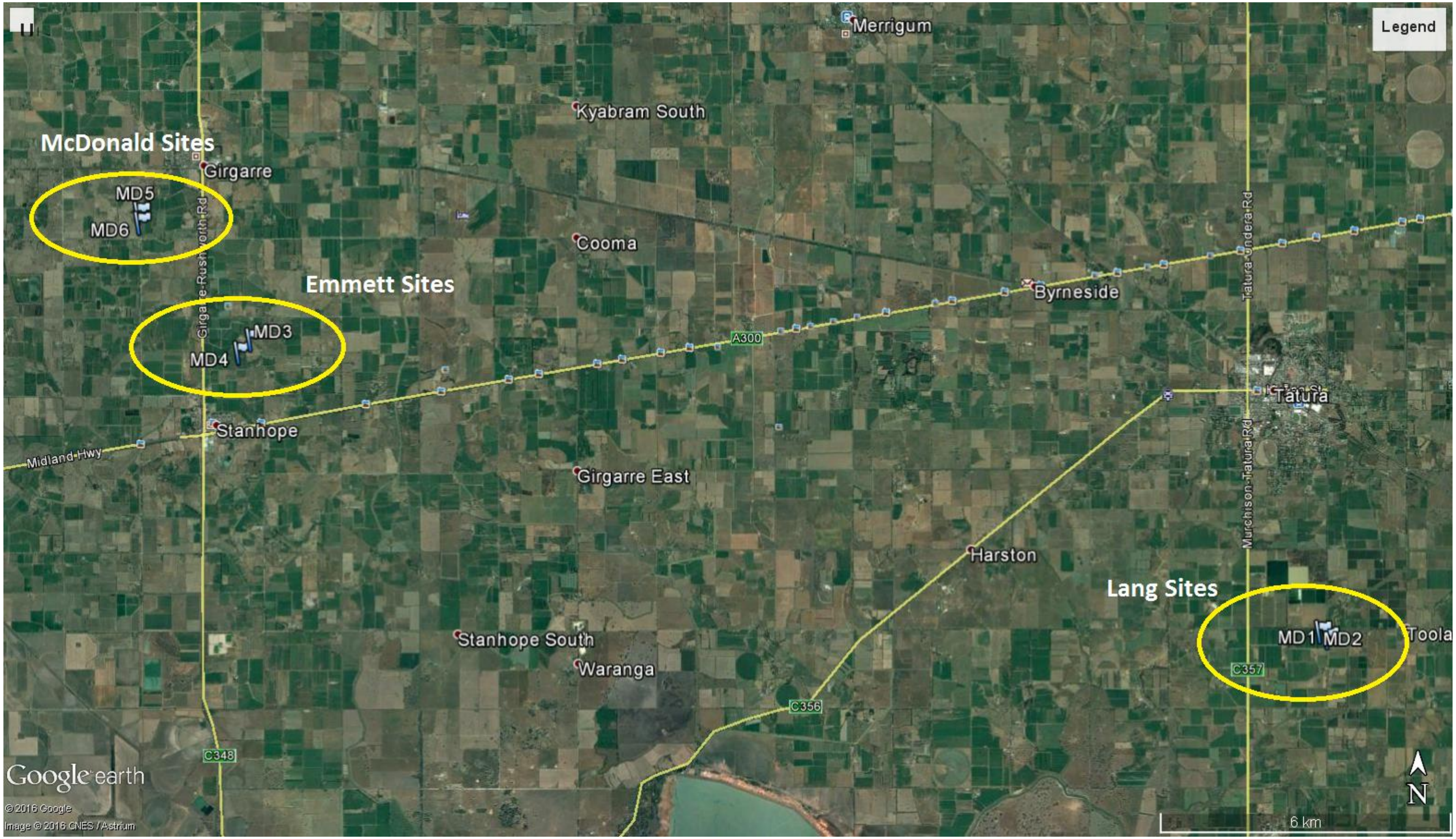


Figure 2. Location of inspected sites for Workshop 1.

2.2.3. Sites 5 & 6. McDonald. Wigg Road.

Site History: The sites are located in the same irrigation bay, with one pit at the top of the slope and one on a mid-lower slope position. The sites are close to the dairy and are used as a day or night paddock. The site has been devoted to perennial pastures for over 20 years with minimal disturbance.

Key Issues:

- Sloping site on the levee of a prior stream with border check irrigation
- Waterlogging results from dense soil and poor profile drainage with above average rainfall and low evapotranspiration in winter
- Site devoted to perennial pastures
- Intensively grazed site close to the dairy
- Saturated soils exist on all sections of the slope or catena
- Problems with infiltration and permeability have existed for some time
- Soil types mapped as Shepparton Fine Sandy Loam (Skene & Poutsma, 1962).

3. SOIL CATENA & SOIL TYPE DESCRIPTIONS.

3.1. Typical Soil Catena.

Figure 3 is an extract from Skene & Poutsma (1962) showing a typical soil catena found across the Goulburn Valley. Information is provided to help landholders understand that soils are formed in sequence on what is referred to as a catena. The soil types occur in sequence with respect to prior streams (Butler, 1950).

The primary process of soil formation in this region is alluvial deposition. The depth of topsoil or sand content in the upper horizons generally decreases with distance from prior stream beds. Aeolian deposits have influenced the formation of soils and the presence of calcium carbonate is indicative that clays are influenced by material of an aeolian origin (Butler, 1956; Butler & Hutton, 1956). In the presence of aeolian clay, alkaline conditions generally prevail associated with the presence of lime.

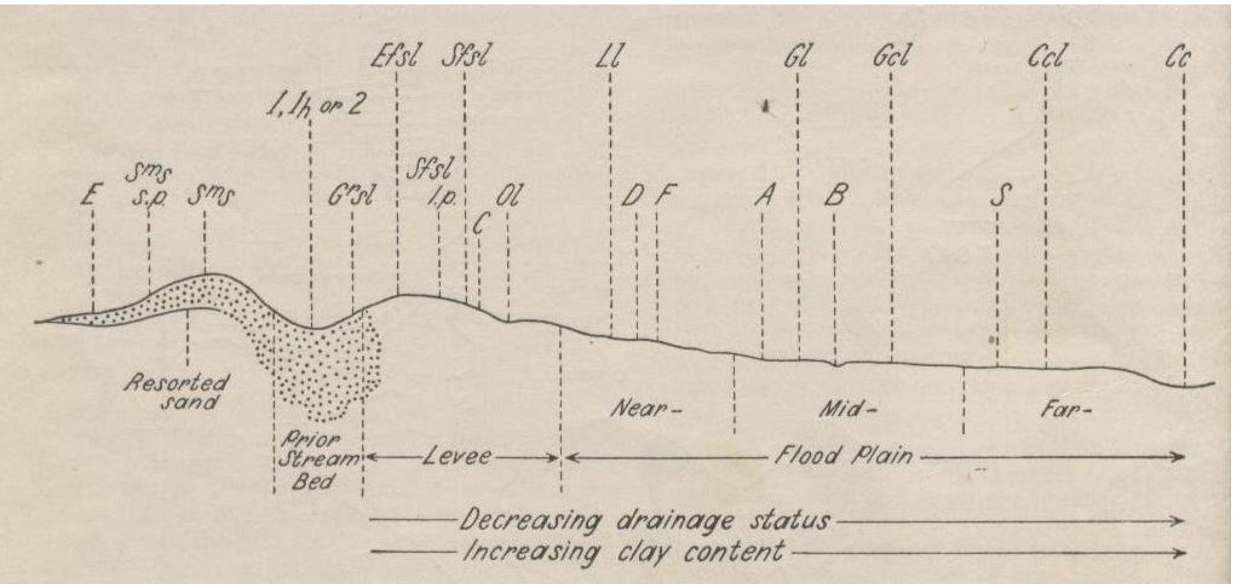


Fig. 3. Toposequence of soil types on the prior stream landscape.

Ccl = Congupna clay loam ; Cc = Congupna clay ; Efsl = East Shepparton fine sandy loam ; Gl = Goulburn loam ; Gcl = Goulburn clay loam ; Grsl = Grahamvale sandy loam ; Ll = Lemnos loam ; Ol = Orrvale loam ; Sms = Sandmount sand ; Sfsl = Shepparton fine sandy loam ; Types A, B, C, D, E, F, S ; l.p. = light phase ; s.p = shallow phase.

Figure 3. Soil catena described by Skene & Poutsma (1962).

3.2. Soil Types.

Mapped soil types covering the sites for Workshop 1 include:

- Shepparton Fine Sandy Loam (Sfsl)
- Lemnos Loam (Ll)
- Goulburn Loam (Gl)

By observation of Figure 3, the soils are positioned on the levee, near and mid reaches of the floodplain. These soils are duplex profiles with a texture contrast between the A and B horizons. Clay dominant surface textures were not observed at any sites. Landholders should become familiar with the soil types that exist and relate field characteristics with soil type and soil horizon. Descriptions of Shepparton Fine Sandy Loam, Lemnos Loam and Goulburn Loam are included below along with photographs as examples of each soil type.

SHEPPARTON FINE SANDY LOAM.

Surface soil.

A_1 0 to 5 inches; brown (5YR 4/4) fine sandy loam or loam; sharply separated from:

A_2 5 to 7 inches; weakly bleached light brown fine sandy loam (this horizon may be absent); sharply separated from:

Subsoil.

B_1 7 to 20 inches; red-brown (2·5YR 4/6) medium clay; grades into:

20 to 27 inches; brown or yellowish brown light clay; grades into:

B_2C 27 to 48 inches; mottled brown, yellow-grey fine sandy clay, clay loam or fine sandy clay loam; moderate subangular blocky structure; friable when moist; slight soft concretionary calcium carbonate; grades into:

48 to 72 inches +; textures as above or lighter: these rest on dense, poorly permeable clay at depths ranging from 4 feet to more than 25 feet.

Figure 4. Description of Shepparton Fine Sandy Loam (Skene & Poutsma, 1962).

Figure 5. Example of a Shepparton Fine Sandy Loam Soil (SESW).

LEMNOS LOAM.

Surface soil.

A 0 to 5 inches; brown to dull or greyish brown (5 to 7·5YR 4/4) loam, occasionally clay loam, occasionally with weak bleaching in the lower part; at 4 to 7 inches sharply separated from:

Subsoil.

B_1 5 to 18 inches; reddish brown (2·5 to 5YR 4/6) medium or heavy clay; weak to moderate angular blocky structure, peds 1 to 3 inches; consistence varying from friable to hard; grades into:

18 to 24 inches; brown or yellowish brown (7·5YR 4/6) medium clay; less well structured and more friable than above; sometimes slight calcium carbonate; grades into:

B_2C 24 to 48 inches; mottled brown, yellow and grey light, occasionally medium, clay; friable when moist; slight soft and concretionary calcium carbonate; grades into:

48 to 72 inches +; variably mottled; textures usually clay, but occasionally micaceous fine sandy clay or clay loam.

Figure 6. Description of Lemnos Loam (Skene & Poutsma, 1962).

Figure 7. Example of a Lemnos Loam Soil (SESW).

GOULBURN LOAM.

Surface soil.

A 0 to 5 inches; grey-brown (10YR 4/2) loam; sometimes with slight buckshot and weakly bleached in lower part; at 4 to 7 inches sharply separated from:

Subsoil.

B_1 5 to 21 inches; yellowish brown (7·5 to 10YR 5/6) medium or heavy clay; massive or weak angular blocky to prismatic structure; labile or plastic when moist; grades into:

B_2C 21 to 48 inches+; yellow-brown or diffusely mottled yellowish grey (2·5YR 5/2) and yellowish brown (10YR 5/4) medium, occasionally light clay; crumbly when moist; slight soft inclusions and concretions of calcium carbonate.

Figure 8. Description of Goulburn Loam (Skene & Poutsma, 1962).

Figure 9. Example of a Goulburn Loam Soil (SESW).

Soil profile descriptions and examples in Figures 4-9 show that the soil types under review contain A horizons topsoils to 12-20cm. Textures include sandy loam, loam or sometimes clay loam. The A horizon topsoil overlies medium or heavy clay subsoil with angular-blocky to prismatic structure.

Deeper subsoils vary from light to medium clay and indicate that the part of the soil profile which contains the highest clay percentage lies between 20-50cm. Soft concretionary calcium carbonate, or nodules of lime, are widespread and exist at approximately 50cm of depth reflecting the presence of aeolian clay.

The soil profiles subject to this workshop are classified in accordance with historic and current methods of classification in Australia, as:

- Red-Brown Earths. Stephens, 1953.
  Skene & Poutsma, 1962.
  Stace et al, 1964.

- Duplex, red clay subsoils. Northcote, 1979.

- Sodosols, or sometimes Chromosols. Isbell, 1996.

4. SOIL PROFILE CHARACTERISTICS FOR RECOGNITION.

Key soil profile characteristics and their identification were a focus of Workshop 1. Primary intentions were to inspect soil profiles and identify factors influencing pasture and crop production. In addition, the discussion covered methods for soil amelioration and priorities for treatment were made.

To describe the process of soil identification, Figure 10 is provided and shows the horizons of a Shepparton Fine Sandy Loam soil profile in the Goulburn Valley used for Lucerne production. Horizon are delineated in accordance with the details provided.

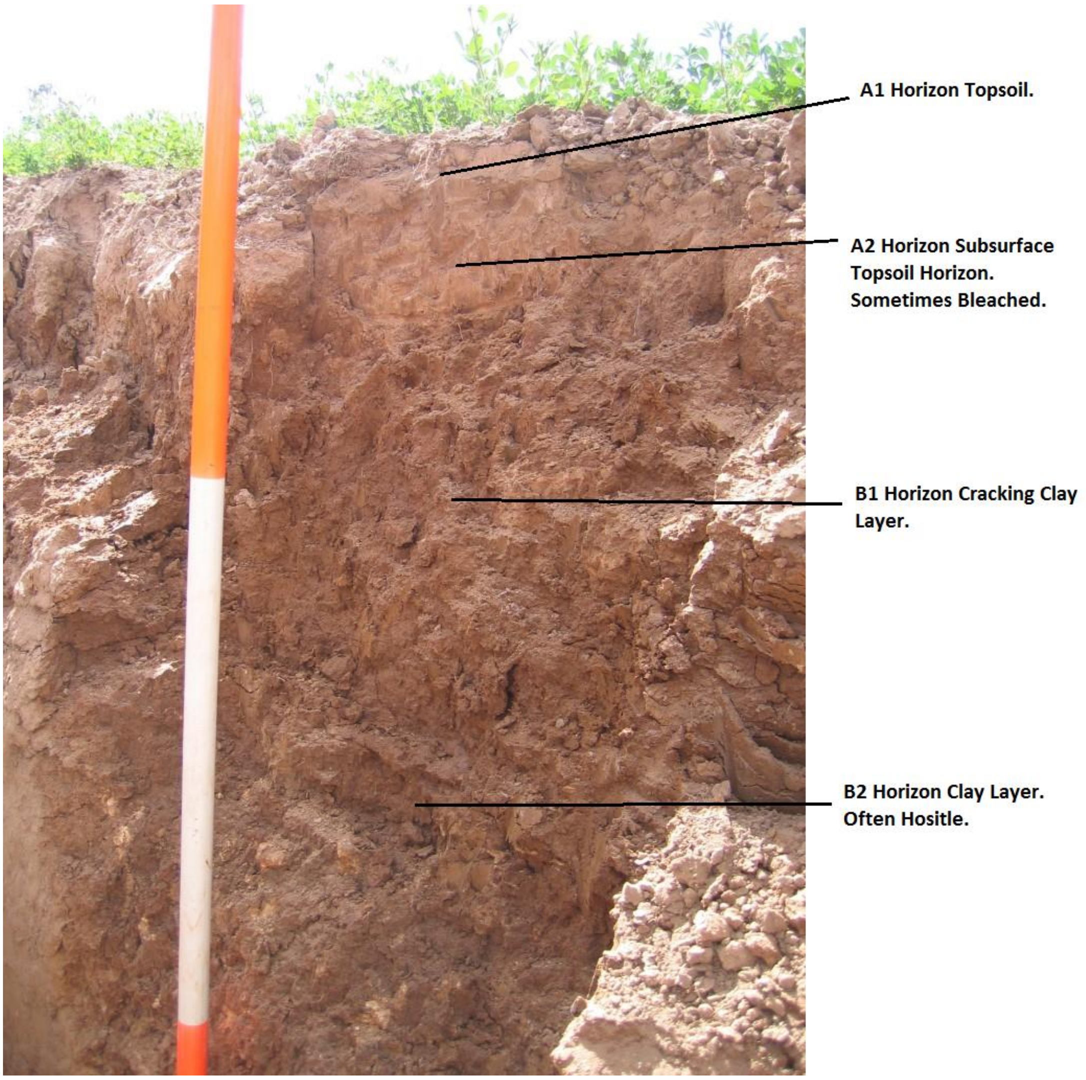


Figure 10. Soil horizons of a Shepparton Fine Sandy Loam soil profile from the Goulburn Valley.

Figure 10 depicts four soil layers within 1.0 metre of the soil surface. Each horizon or layer varies in physical and chemical characteristics and the impact on root elongation is variable between horizons. The layers observed in Figure 10 are consistent with literature provided in Figure 4 (Skene & Poutsma, 1962).

5. SOIL PARAMETRES IMPACTING PRODUCTION AT INSPECTED SITES.

The parameters impacting production show interaction in some situations. As a result, some repetition in the following sections cannot be avoided.

5.1. Depth & Structure of A Horizon Topsoil.

Description of the issue and importance: The depth of A horizon (or depth of topsoil) is the primary soil profile attribute to be assessed for productive pasture or crop growth. As the depth of topsoil increases, improvements in production can be expected from the following:

- Increasing availability of macro-nutrients and trace elements
- Increasing rates of mineralisation of organic matter
- Improved profile drainage
- Higher yield potential for pastures or crops
- Better exploitation of soil water
- Enhanced patterns of root development

The A horizon hosts the plants root system for the first 4-8 weeks after planting. Plant development during this period is critical for establishing yield potential which places emphasis on their structural condition and nutrient levels. The A horizons of duplex soils on the Riverine Plains are lighter textured and a more favourable zone for root growth in comparison to the subsoil, which primarily supports the crop with the supply of water.

Hard, dense, compacted, consolidated or poorly structured topsoil horizons limit access to water, air and nutrients. These aspects are fundamental for improving water use efficiency from rainfall or irrigation water. Cycles of wetting and drying are necessary for optimal soil functioning.

Problem Identification: Dig with a pick or shovel and identify where the transition between the A and B horizons occurs in duplex profiles. Ideally, all A horizon topsoils throughout irrigation areas of the Riverine Plains will function to a high level if they:

1. Are well-structured with defined soil aggregates that show evidence of plant roots and organic material. Figure 11 shows variable types of soil structure (McMullen, 2000).

2. Do not contain soil with a ‘platy’ or plate-like structure (McMullen, 2000).

3. Evince bulk density levels of less than 1.3 t/m^3, but preferably between 1.1-1.2 t/m^3 (Brady and Weil, 2008; Charman and Murphy, 1991; McKenzie *et al*, 2004). Bulk density testing can be performed using a simple weight to volume process with hand tools, drying and scales (Australian Standards, 1980).

4. Are free of bleached and impervious subsurface layers that restrict or impede root elongation.

5. Contain a surface layer which is free from dispersion and crusting, which may impact on the germination of planted seed.

Maintenance of soil structure and amelioration of problems that exist can be difficult to overcome in the short term and may take some time. Previous land-forming practice and the degree of cut and fill land forming may also play a role.

Sites with less than 12cm of A horizon topsoil overlying clay dominant subsoil commonly suffer from poor drainage and become problematic during periods when rainfall exceeds evapotranspiration, particularly where soils are at or near field capacity. Figure 12 is an example of a soil profile observed in Workshop 1 suffering waterlogging, where less than 10cm of A horizon topsoil is observed overlying medium clay subsoil.

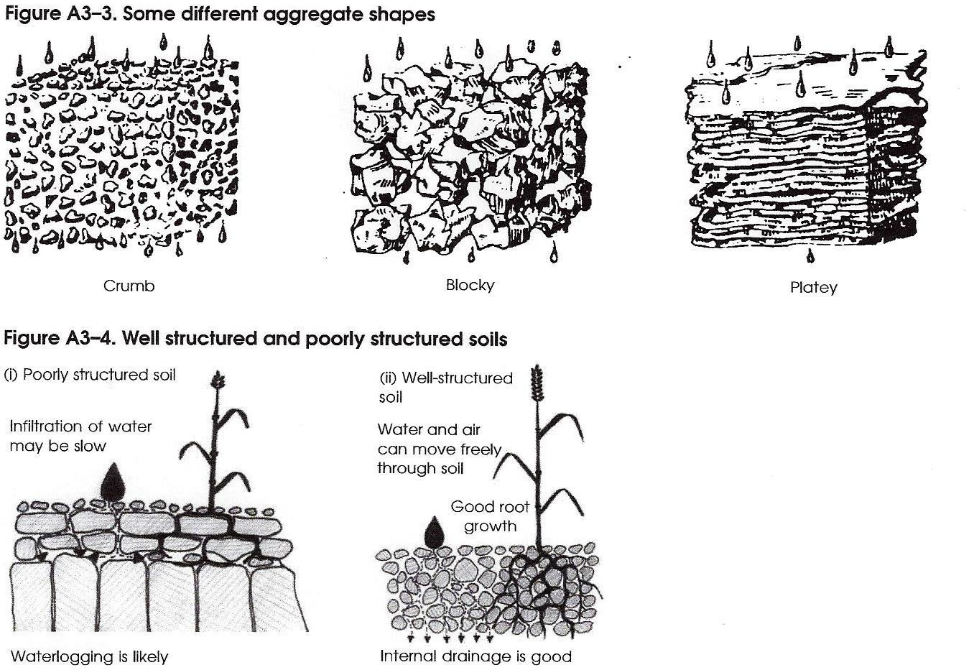


Figure 11. Various aggregate shapes and structures (McMillen, 2000. Vegetable Soilpak, NSW DPI).

Figure 12. Photograph of a profile inspected with less than 10cm of A horizon topsoil overlying medium-heavy clay. The site is waterlogged even though it lies on a slope. This is a permanent pasture site mapped as Shepparton Fine Sandy Loam. The soil presents as a Lemnos Loam however it may have been disturbed by landforming.

Management options: Management of topsoil depth is difficult particularly where the natural depth is already shallow. Based on literature and experience in this region, the average depth of topsoil depth can range from 8-20cm. Areas of shallow topsoil require topsoiling to ensure topsoil is replaced at a uniform depth upon completion. Topsoiling involves full removal of the topsoil, land forming clay subsoil and replacement of topsoil at a uniform thickness.

Re-land forming existing border check irrigation areas is an expensive option but should be considered where growth is impeded by minimal topsoil. In cases where there is nil topsoil from complete removal, ameliorants and gypsum may also have minimal impact on improving soil condition.

Maintenance of soil structure where topsoil is prevalent is assisted by the application of organic matter and soil ameliorants including gypsum and lime. Where sub-optimal structure is a problem, mechanical effort may be required to shatter aggregates along with ameliorant application to stabilise soil aggregates. Stabilising aggregates from dispersion or slaking allows plants to extend their roots throughout aggregated soil. Clay dominant subsoil should not be mixed with topsoil. Ideally, the bleached layer requires shattering without raising material or mixing with the surface layer.

Detailed assessment of the soil profile and amelioration of topsoil layers should occur prior to physical amelioration. Identification of problems is essential for success and generally involves shallow digging with a pick or shovel. Auger ole testing is commonly undertaken by some agronomists and landholders. This type of sampling is suitable for revealing soil texture, but provides a lack of detail on structure once augured material is shattered and mixed.

The approach of doing nothing is unlikely to yield a long-term outcome which is productive, sustainable or profitable.

5.2. Effective Root Zone Depth & Available Water Content.

<u>Description of the issue and importance:</u> Effective Root Zone Depth (ERZ), measured in millimetres (mm) and the Available Water Content (AWC) measured in mm/cm of soil, need to be understood with respect to identifying a crop or pastures water requirement and irrigation interval as well as the variability expected in plant growth. Crop water requirement and irrigation scheduling are dependent on a sound understanding of these measurements and their variability. Variability in growth within irrigation bays and across a property is a challenge and the abovementioned parameters play a major role.

The AWC is calculated by multiplying the depth of each layer within the crop root zone by an available water factor. An example of Available Water Factors that can be adopted are listed in Table 1. Data is compiled from a range of references including Kramer (1983), Weatherby (1992), Dalgliesh & Foale (1998) and Lawrence & Dalgliesh (2013). These guidelines are subject to variation depending on soil parameters unique to individual sites such as soil structure.

Table 1. Available water in mm/cm for various soil texture classes.

Soil Type (Texture)	**Wilting Point** (mm/cm)	**Field Capacity** (mm/cm)	**Available Moisture** (mm/cm)
Sand	0.2	0.4 - 0.8	0.2 - 0.6
Loamy Sand	0.4	0.8 - 1.7	1.4 - 1.3
Sandy Loam	0.8 - 1.3	1.7 - 2.5	0.8 - 1.3
Fine Sandy Loam	1.2 - 1.7	2.5 - 3.3	1.3 - 1.6
Clay Loam	1.2 - 1.7	2.5 - 3.3	1.3 - 1.6
Clay	1.7 - 2.5	3.3 - 5.0	1.6 - 2.5

Where variability occurs, difficulty may be experienced with achieving uniform yield and quality and soil type may not necessarily depict the boundaries of zones with variable AWC. Soils mapped by Skene and Poutsma (1962) have been modified extensively and within soil type the AWC may vary by up to 20mm. Depth of topsoil and land-forming practices play a major role in influencing AWC.

<u>Identification of the ERZ and AWC:</u> ERZ and AWC are measured by visual assessment by inspection of a pit, where soil horizons, textures and the depth of the root zone can be assessed. The ERZ is not the deepest extent of a plant root observed in a soil profile, but the point where roots are likely to extract all the available water from a soil at any time from the presence of plant roots. The AWC can be calculated mathematically based on soil data and an AWC factor covering various soil moisture levels.

For soils inspected during Workshop 1, Table 2 summarises the ERZ and AWC values of each profile as a guide to the level of variability that can be expected.

Table 2. Effective Root Zone Depth and approximate Available Water Content for profiles inspected during Workshop 1.

	SITE 1	**SITE 3**	**SITE 5**
	Lang Site 1	**Emmett Site 1**	**McDonald Site 1**
A_1 Horizon	Depth 0-9cm, total 9cm.	Depth 0-14cm, total 14cm.	Depth 0-10cm, total 10cm.
	Texture SCL	Texture FSCL	Texture FSCL
	AWC at 40 kPa = 0.62 mm/cm	AWC at 40 kPa = 0.66 mm/cm	AWC at 40 kPa = 0.66 mm/cm
	Total AWC = 5.58mm	Total AWC = 9.24mm	Total AWC = 6.6mm
B_1 Horizon	Depth 9-30cm, total 23cm	Depth 14-50cm, total 36cm	Depth 10-40cm, total 30cm
	Texture MC	Texture MC	Texture MC
	AWC at 40 kPa = 0.46 mm/cm	AWC at 40 kPa = 0.46 mm/cm	AWC at 40 kPa = 0.46 mm/cm
	Total AWC = 10.58mm	Total AWC = 16.56mm	Total AWC = 13.8mm
B_2 Horizon	Depth 30-60cm, total 30cm	Depth 50-70cm, total 20cm	Depth 40-80cm, total 40cm
	Texture MC	Texture MC	Texture MC
	AWC at 40 kPa = 0.46 mm/cm	AWC at 40 kPa = 0.46 mm/cm	AWC at 40 kPa = 0.46 mm/cm
	Total AWC = 13.8mm	Total AWC = 9.2mm	Total AWC = 18.4mm
B_3 Horizon	**ERZ 65cm.**	**ERZ 75cm.**	**ERZ 80cm.**
	Depth 60-65cm, total 5cm	Depth 70-75cm, total 5cm	
	Texture SC	Texture SC	
	AWC at 40 kPa = 0.46 mm/cm	AWC at 40 kPa = 0.46 mm/cm	
	Total AWC = 2.3mm	Total AWC = 2.3mm	
Indicative AWC (mm)	**32.26 mm**	**37.3mm**	**38.4mm**

Management options: The potential ERZ depth of a soil profile is an inherent property, limited by the depth to unfavourable or hostile subsoil. The AWC is often lower than the potential where impedances exist in the upper horizons, restricting root growth. These situations can be ameliorated however deeper constraints below 300mm are difficult to treat. AWC should be calculated based on the depth to hostile material, plus a root zone depth of no more than 100mm into a hostile layer. Any physical impeding layer within 300mm of the surface can normally be treated using ripping. Hostile layers below 500mm that suffer impacts from a fluctuating perched water table are regional are also issues that impact the ERZ and these cannot be solely addressed at a farm level.

There are not the range of options available to increase the ERZ and AWC resulting from a shallow depth to unfavourable or hostile material. The primary option discussed in Workshop 1 is the practice of improved cycles of wetting and drying, or swelling and shrinking. Shrinkage of clays promotes cracks and structured units, allowing for the movement of topsoil, organic matter, nutrients and soil ameliorants to depth with the movement of moisture. This is similar to the process that occurs in self-mulching clay soils, where surface material falls to depth through cracks, promoting improved growing conditions deeper in the profile. In this case of duplex, Red-Brown Earths, a similar process should be emanated to encourage deeper rooting of irrigated pastures and crops.

The process may require a kick-start using a dryland crop or pasture for sacrificial purposes. The pasture or crop will need to suffer drought stress or function below the point of Deficit Available Water (DAW) to utilises water from depth and shrink subsoil clay.

Agronomic practices may be modified in some situations to promote greater capacity to store winter rainfall. Winter crops may be planted earlier, or irrigation adjusted to ensure the soil profile is not at field capacity leading into winter. This is easier said than done, however opportunities often present which can be capitalised on. Periods of prolonged saturation of the subsoil should be avoided. Under these circumstances, plant roots often establish a shallow root system and perform or yield below their potential.

Measurement of a soils ERZ and calculation of the AWC on a range of profiles is essential for understanding the variability that exists. Variable Rate Technology (VRT) can be applied to specific zones of production for improving efficiency of nutrients to meet yield potential. Irrigation water application can also be better managed under pressurised irrigation systems, including sprinkler or drip.

Moisture probes are of greater benefit to the landholder and agronomist in the interpretation of soil water content, drawdown and refill where they are calibrated to a soils AWC in mm, specific to soil horizons or set depths. Matching crop water requirement to a soils AWC per horizon aids the understanding of the water volumes being utilised in each soil horizon.

Figure 13 highlights the horizons and ERZ depth for Site 3 of Emmett's property as an example.

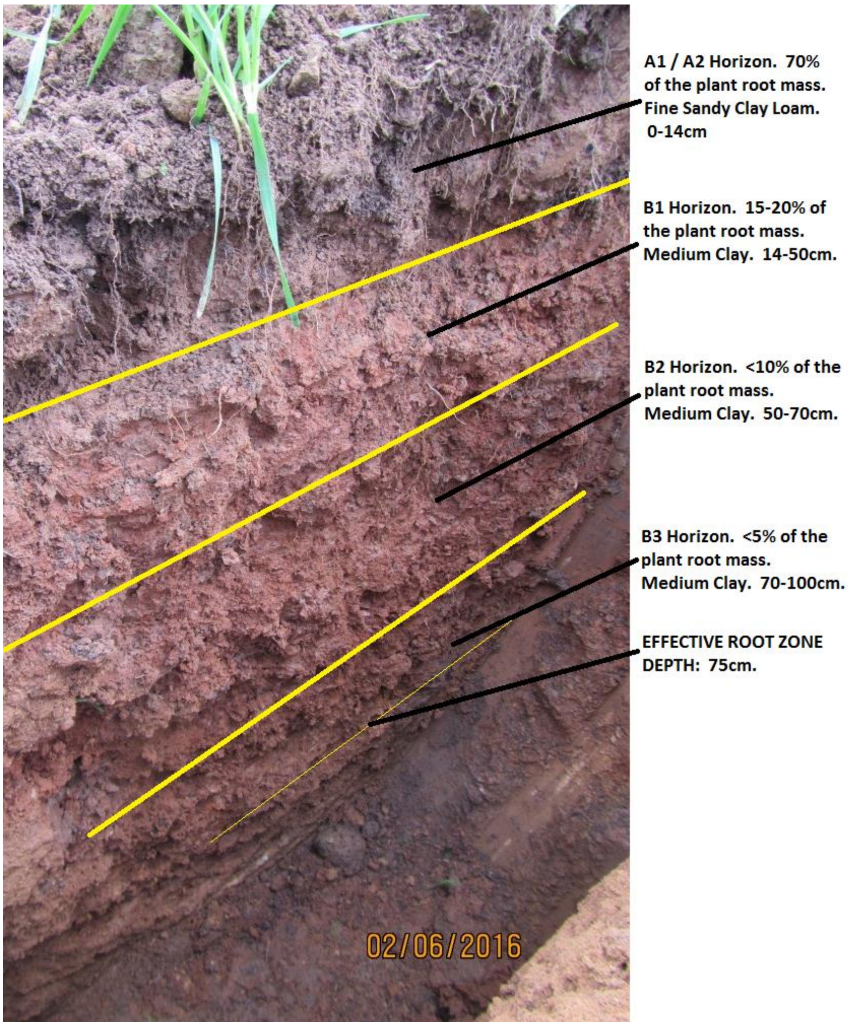


Figure 13. Site 3 inspected during the workshop on Emmett's property.

5.3. Waterlogging, Surface & Profile Drainage.

<u>Description of the issue and importance:</u> Poor drainage and waterlogging can influence the production of pastures and crops for dairy production through the following processes:

- Slow, impeded or stagnant growth
- Yellowing from saturation and dilution of available nutrients, limiting availability
- Lack of trafficability from livestock or machinery
- Potential for pasture or crop loss
- Limited root zone development in the early stages of crop development
- Increased prevalence of weeds that favour wet conditions
- Yield potential reduction
- Increased prevalence of pugging.

<u>Problem Identification:</u> Some of the indicators and causes of waterlogging and poor surface and profile drainage include:

- Free water on the soil surface for more than 6-8 hours after an irrigation or rainfall
- Clay dominant textures or exposed subsoils
- Shallow topsoils
- Flat grades and/or poor slope on border check irrigation bays
- Pugging by cattle
- Excess organic matter on the soil surface
- Inconsistency between irrigation application rate and time in relation to soil infiltration rate, or soil water storage capacity
- Presence of a water table within 2.0 metres of the natural surface on clay soils
- Soils that suffer from sodicity or dispersion
- Hoof imprinting
- Loss of clover, lucerne or patchy lucerne growth.

A sound understanding of the soils AWC and the soil water content at any one time is required to determine the likelihood of waterlogging resulting from irrigation or rainfall. Figure 14 is a photograph of border check irrigation bays suffering from waterlogging observed during Workshop 1.

Figure 14. Waterlogged border check irrigation bay inspected during Workshop 1.

Management options: Drainage is a critical element of management that must be considered for prevention of waterlogging prior to land-forming. Post land-forming, the options for drainage are limited.

Pre-land forming, considerations into soil type, slope, crop types to be grown, bay width and length, outlet size and flow rate and drainage time can be considered. All available options for drainage should be evaluated upon land surveying, no matter how expensive the option is. Often the best option for achieving drainage may not be the cheapest but it may yield a more profitable outcome for long term pasture or crop production.

During the growing season of a pasture or crop, spinner cuts can be installed as a short-term fix. The drains created by spinner cuts should be spaced on an interval that ensures the cuts provide a 'plughole' effect. Spinner cuts should be installed at planting time prior to wet conditions, given that access for installation may be compromised once a site is waterlogged.

Historic site characteristics and the likelihood of wet conditions prevailing should be considered prior to seeding pastures or crops. At sowing, during pre-irrigation or post-irrigation, fertiliser application can assist with promoting early growth and the drawdown of soil moisture prior to winter months when rainfall is likely to exceed evaporation. Historic rainfall data shows that rainfall exceeds evaporation in the Goulburn Valley during winter months and evapotranspiration (ET) rates are poor during this period. The drying of soils is difficult without plant biomass to extract water.

Careful monitoring of soil moisture is necessary where soils may suffer from poor drainage. Understanding crop water use and a soils capacity to hold water is necessary to anticipate:

- The potential impact of forecasted rainfall on pastures or crops
- The potential impact of additional irrigation on pastures or crops
- The likely effect of rainfall after an irrigation.

The option of doing nothing generally yields a poor outcome.

5.4. Consolidated, Compacted or Beached Subsurface Horizons, Including the "A_2" Horizon.

Description of the issue and importance: Consolidated, compacted and dense subsurface horizons can restrict the movement of water, air and plant roots into and out of subsoil horizons. Under such conditions there is often limited pore space, moisture movement and air for roots to access and grow. It is initially important to determine if the subsurface layer impeding growth exhibits a similar texture to the A_1 horizon. If so, this usually indicates that the layer is an A_2 horizon and the restrictive layer is likely to be consolidated topsoil, rather than subsoil.

Primary mechanisms contributing to the development of such layers include:

- Deep A horizon topsoil of more than 12cm, overlying low permeability subsoil clay. As topsoil remains saturated after subsoils reach field capacity, the lower part of the A horizon becomes saturated, consolidated and often bleached from waterlogging.
- Leaching of bases such as calcium, magnesium, sodium, potassium and aluminium from the lower part of the A horizon, caused by cycles of seasonal saturation and slow leaching, resulting in bleaching of the layer.
- Slaking of aggregates resulting from a lack of organic matter and limited plant root mass, causing consolidation.
- Dispersion of the clay fraction, causing suspension of clay fines and consolidation.
- Fluffing of the A_1 horizon from tillage equipment, where the clay fraction leaches below the tilth zone and forms a plough pan.
- Subsurface compaction from cattle in wet conditions
- Subsurface compaction from vehicle traffic under wet conditions

Problem Identification: Methods for identification and indicators of such conditions can be determined from both visual and measured methods. These include:

1. Bulk density testing of each layer, identifying material of high density in the A_2 horizon. Details on soil density are provided in Tables 3 and 4.

2. Visual identification of poorly structured layers, either:
   - Massive (structure less)
   - Platy (horizontal, plate-like layers

3. Grey or bleached conditions between the A_1 and B_1 horizons

4. Poor plant rooting or a plant root score less than that of the layer above and below

5. Grey, 'spew' layers observed when machines are bogged or when paddocks receive traffic when wet

6. Sodic or dispersive conditions within the problem layer or the B_1 horizon subsoil clay

A hand penetrometer generally fails to aid characterisation of the restrictive layer. When wet, there is minimal resistance to penetration from a reduction in soil strength. When dry, there is high level of resistance to penetration, however cracking may improve soil structure.

Visual Assessment: Figure 15 is an example of a Goulburn Loam soil profile from the region evincing a thin, bleached A_2 horizon layer. The A horizons are a homogenous texture, however the structure of the material within the A_1 and A_2 horizon varies significantly. Figure 15 shows a higher level of tilth and organic matter close to the surface. The A_2 horizon is structureless and contains limited plant roots.

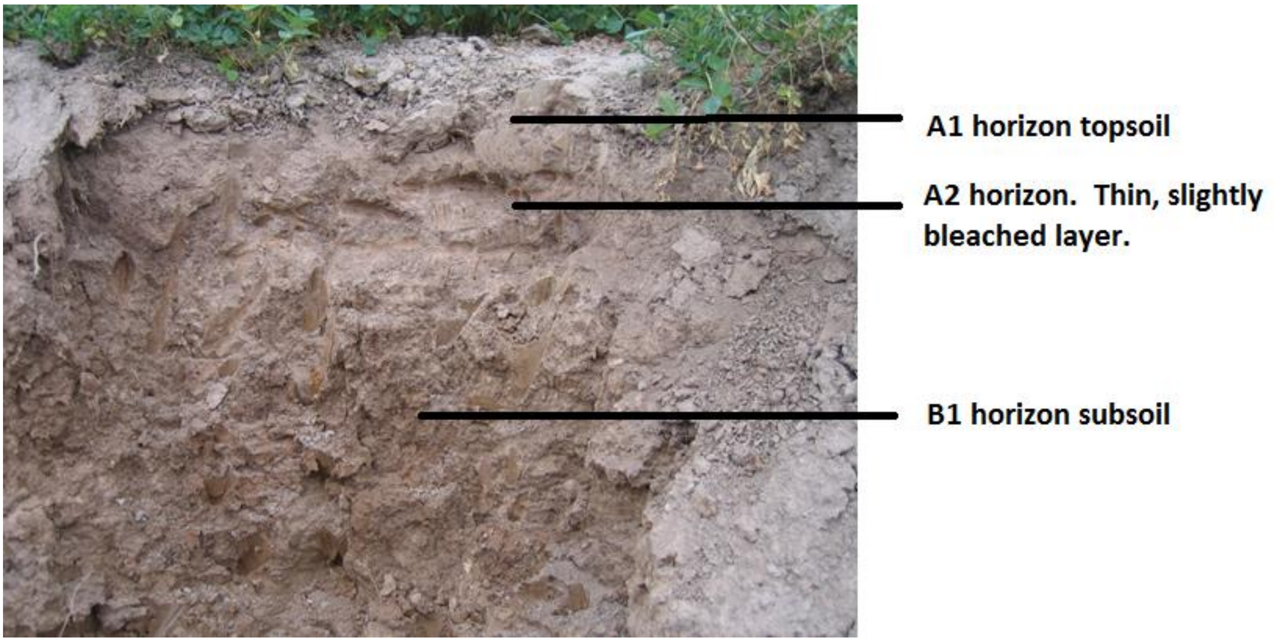


Figure 15. Example Goulburn Loam soil profile.

Table 3 is a copy of the results of bulk density testing of various soil horizon from pits assessed in Workshop 1. The results show that the A_2 horizons are the densest layers where present, recorded at levels above guidelines provided in Table 4.

Table 3. Bulk density test results from sites inspected during Workshop 1.

Sample ID	Bulk Density (tonnes/m^3)
Lang 1 A1 Topsoil	1.24
Lang 1 B1 Subsoil	1.49
Lang 2 A1 Topsoil	1.21
Lang 2 B1 Subsoil	1.52
Emmett 3 A1 Topsoil Ripped	1.16
Emmett 3 A2 Hard Pan Clods	1.63
Emmett 3 B1 Subsoil	1.47
Emmett 4 A1 Topsoil Ripped	1.12
Emmett 4 B1 Subsoil	1.44
McDonald 5 A1 Topsoil Shallow	1.18
McDonald 5 B1 Subsoil	1.46
McDonald 6 A1 Topsoil Shallow	1.27
McDonald 6 A2 Hard Pan	1.51
McDonald 6 B1 Subsoil	1.43

Green: Optimal bulk density
Yellow: Slightly dense, some limitation to root growth expected.
Orange: High density, limited root growth likely in loams and clay loams.

Table 4 is a guide to the interpretation of soil bulk density and the impact of levels registered on plant growth for a range of soil examples. Data is compiled from a range of sources including Brady and Weil (2008, p. 157) and Charman and Murphy (1991, p. 234-237), McKenzie *et al* (2004), Davies and Lacey (2011) and others.

Table 4. Interpretation guide for soil bulk density results.

Bulk Density (tonnes/m^3)	Interpretation	Impact on Root Growth	Example Soils
<0.8	Extremely low.	Low-nil. Possible drought effects from good drainage and evaporation	Silts and peats.
0.8-0.9	Very low	Nil. Could cause drought effects from drainage and evaporation.	Self-mulching clay or topsoil.
1.0-1.1	Low	Nil. Optimal for most agricultural and horticultural soils. Soil density should not restrict root growth.	Self-mulching clay or topsoil. Loose sand with organic matter Ameliorated clays and loams
1.1-1.3	Acceptable	Low-Moderate. Generally, not an impediment to root growth on clay-loam soils.	Ameliorated clays and loams. Well-structured clays. Compacted sandy loams
1.4-1.5	High	Moderate-high. Will restrict root development of most crops. Physical and chemical amelioration required. <u>NOT ALWAYS RELEVANT FOR CRACKING CLAY SUBSOILS.</u>	Clay loams high in Na and Mg suffering consolidation or compaction. Typical of heavy clays with reasonable structure.
1.6-1.8	Very high.	High restriction to root development. Soil requires shattering to reduce aggregate size and to increase root mass. Chemical stabilisation also required.	Poorly structured clays. Highly compacted sands and clay loams.
<1.8	Extreme.	Indicative of an impermeable condition.	Compacted soils.

<u>**Management options:**</u> Options for correction of consolidated, compacted, dense or bleached subsurface layers are listed below. These are directed towards improving soil structure and depth of the A horizon to secure higher available water and nutrient levels for pastures or crops. Where the problems are below 300mm of depth, options available are limited.

Where soil physical amelioration using ripping is required, care must be exercised to ensure that when the layer is fractured, aggregates are stabilised. This can occur if a combination of processes occurs simultaneously, listed below.

Ripping and shattering can:

- Improve soil structural conditions
- Mix A_1 horizon topsoil throughout the problem layer
- Mix organic matter from crop residues and plant roots
- Mix soil ameliorants including gypsum, lime, manure, straw and compost
- Mix fertilizers and crop nutrients deeper in the profile.

Bleached layers should not be raised and exposed on the soil surface. Cloddy material remaining after ripping may require treatment to secure a seed bed. From experience, the option of doing nothing generally yields a poor outcome. The primary role of soil physical amelioration in these situations is to break the back of the problem.

5.5. Permeability of Medium & Heavy Clay Subsoils.

Description of the issue and importance: The permeability rate and internal drainage characteristics of Riverine soils are controlled by the presence of medium and heavy clay subsoil. Given their low or slow rates of permeability, the primary mechanism for allowing moisture movement into clay soils is the immediate flow of water down cracks created from drying of the profile. Medium and heavy clay subsoils are often sodic and dispersive, which further reduces the speed of water movement into and through clay layers.

Problem Identification: The simplest method for determining the presence of low permeability clay subsoils is to dig with a shovel or pick and expose the subsoil. If the subsoil sample contains any of the following characteristics, low permeability is expected:

- Medium or heavy clay textures
- Massive or poorly structured material
- Saturated conditions
- Dispersive conditions determined by jar testing
- Sodic or high exchangeable sodium percentages, determined by laboratory testing
- Presence of manganese staining on the faces of peds
- Presence of calcium carbonate nodulation
- Presence of gypsum crystals
- High chlorides
- Moist conditions from capillary rise of moisture from a shallow water table.

Apart from some relatively well-drained subsoils of Shepparton Fine Sandy Loam soils, most subsoils within the three soil types inspected evince low rates of permeability. Ignoring the abovementioned characteristics, saturation of the A horizon after rainfall is a good indicator of the presence of low permeability clay. Figure 16 is a photograph of a soil profile inspected during Workshop 1 on Lang's property evincing medium clay subsoil, with sodic and dispersive conditions noted.

Figure 16. Clay dominant soil profile from Lang's property.

Management options: Heavy clay subsoils are an inherent and fixed property that require monitoring with respect to moisture content and chemistry. There are options for chemical management however the most practical option is to manage soil moisture content and ensure subsoils are constantly shrinking and swelling (moving), which aids the development of structured aggregates provide space for air, water and plant roots to colonise. The shrinking and swelling of clays also promotes slickensides, where clay aggregates rub together, forming a polished face.

Surface drainage is the first step to managing the moisture content of medium and heavy clay subsoils, along with the production of a pasture or crop to ensure water is being utilised on the site.

Chemical amelioration using high rates of gypsum can improve the growing conditions of medium and heavy clay subsoil. Gypsum is the primary soil ameliorant used for rendering dispersive soil non-dispersive. Calcium obtained from gypsum displaces sodium, magnesium and potassium, creating a more stable condition with reduced dispersion. Gypsum also elevates the EC (salinity) level of clay. Upon application and dissolution with water, a flocculation or ‘fluffing’ effect occurs to clay, favouring improved soil structure.

Gypsum treatment of subsoils can be cost-prohibitive however rates below that required for full remediation often prove successful for improving growing conditions.

Leaching of gypsum from surface soils into deeper clay subsoils has been trialled as a soil chemical ameliorant with limited success. Until the A horizon contains an abundance of calcium, the attraction between available calcium and clay is strong and leaching will occur once most clay exchange sites that can be held by calcium are exploited, leaving surplus calcium to leach to the layer below. Typical rates of 2.5 t/ha rarely achieve leaching of the calcium fraction within gypsum, unless sandy loams with limited clay content are the dominant topsoil material.

Subsoil manuring has been trialled in the low to medium rainfall zone with limited success. This process deposits manure in the upper B horizon and creates an abundance of nutrient along with an increase in EC (soil salinity). Further work is required to determine the true effects of subsoil manuring on soils in this region for improving hydraulic conductivity, porosity and bulk density.

The do-nothing approach along with careful moisture management may yield the most productive outcome for improving performance of heavy clay subsoils. Soil moisture monitoring is a critical component.

EM38 mapping is known to correlate with soil ESP which may provide an indicator of subsoil drainage patterns.

5.6. Dispersive or Sodic Topsoils or Subsoils.

Description of the issue and importance: Dispersive and/or sodic soil horizons and layers can impact directly on crop or pasture performance, even when visual symptoms are not obvious. Indicators of a dispersive or sodic soil include:

A Horizons:

- Soil crusting and germination problems
- Surface infiltration problems including slow infiltration speed, even on loam or clay-loam surface textures with a high percentage of sand
- Nutrient uptake issues and deficiencies
- Drought stress as the surface horizon dries out
- Irregular pasture or crop growth issues, usually observed in the early stages of crop growth
- Waterlogging caused by instantaneous surface soil sealing upon rainfall.

B Horizons:

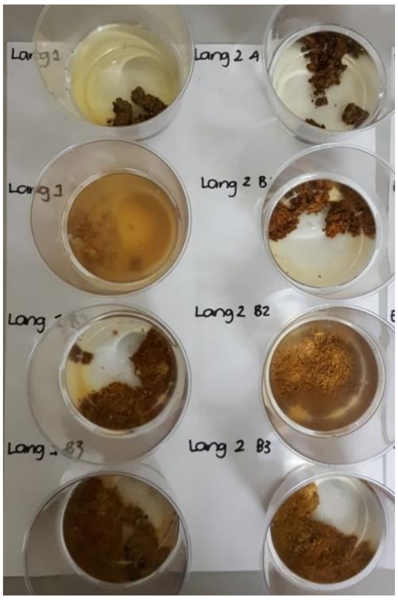
- Restrictions with soil permeability
- Limited plant root growth.

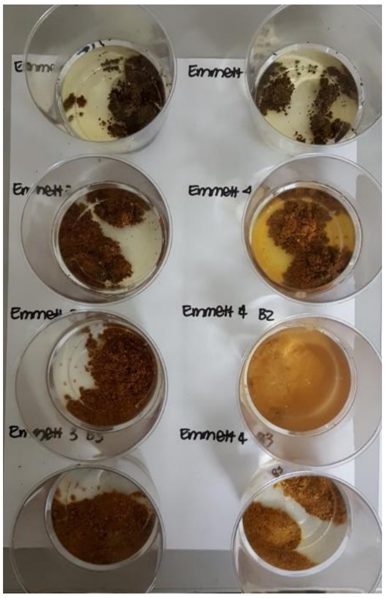
Problem Identification: Dispersive or sodic soil are identified using the following methods:

1. The Emerson Dispersion Test. This test involves placing an aggregate of soil in deionised water or tank water and assessing the condition after 6 hours and 24 hours. Figures 18-20 show the dispersion test from all horizons from the six sites inspected for Workshop 1. Collection of soils is undertaken by hand. Figures 17-19 are photographs of dispersion tests carried out on A and B_1 horizon samples from sites inspected.

2. Testing soils for exchangeable cations and determining the Exchangeable Sodium Percentage (ESP). Soils with an ESP level of 6% or greater are deemed to be ‘sodic’ by Australian definition (Isbell, 2016). Results of soil testing for the six sites inspected for Workshop 1 are included as Appendix A. The results show sodic conditions in 50% of the tested samples.

3. Visual inspection of fields showing crusting from the effect of rainfall. This is more common where soils are cultivated and an absence of organic matter exists. Figure 20 is a photograph of a duplex soil from the Goulburn Valley evincing crusting after rainfall associated with dispersion.





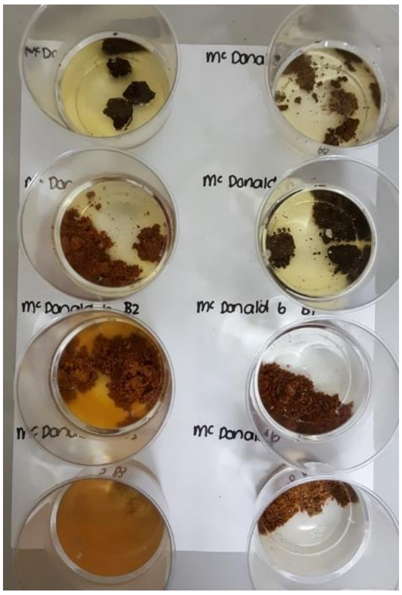


Figure 17. Dispersion tests for pits on Lang's property.

Figure 18. Dispersion tests for pits on Emmett's property.

Figure 19. Dispersion tests for pits on McDonald's property.

By observation of Figures 17-19, most profiles contain a dispersive B horizon layer within the top 1.0 metre of the soil profile. In most cases this is the B_1 or B_2 horizon. Amelioration of subsoil dispersion is difficult and comes at a high cost.

Figure 20. Example of a duplex, Red Brown Earth soil profile from the Goulburn Valley with crusting problems caused by sodic soil in contact with rainfall on cultivated soil.

Figure 20 is an example of a duplex Red Brown Earth soil with dispersive topsoil causing crusting. Ameliorating dispersive topsoil with gypsum and organic matter can be achieved cost effectively.

Management options: Dispersive and sodic soils can be corrected using calcium ameliorants, where calcium is supplied to the soil to displace sodium from exchange sites on clays. Once sodium is displaced it may leach with the movement of moisture. Gypsum is the primary soil ameliorant used to ameliorate sodic soils. Fine lime helps to lower soil ESP but is less effective than gypsum and the response time is slower. Lime is also less soluble than gypsum. The use of lime for ameliorating soil problems other than soil pH is becoming increasingly popular.

Gypsum can be applied based on rule-of-thumb approaches or modelled volumes based on displacement of other cations. Modelled volumes are consistent with the rates that many laboratories recommend which account for volumes of calcium required to displace excessive sodium, potassium and magnesium. Often these rates are cost prohibitive which is why the rule-of-thumb methods remain standard practice.

The do-nothing approach generally yields a poor outcome where there is an absence of organic matter. Under the presence of organic matter, improvements in surface soil stability are achieved and dispersive soils can be managed. Applications of calcium ameliorants speed up the process of soil amelioration and use of these ameliorants with retained organic matter has proven to be successful under similar circumstances.

5.7. Hostile Subsoil.

Description of the issue and importance: "Hostile subsoil" is a broad term to describe deeper soil constraints that limit the depth of pasture or crop root systems. Hostile subsoil layers can impact production by:

- Limiting the depth of the root system
- Limiting the available water content
- Providing a toxicity or drought stress effect on pastures, if moisture from the hostile layer is up-taken by pastures or crops
- Reducing yield potential to a point where a change of land use may be required.

Hostile subsoils are not always identified by visual appraisal of the root zone. Soil chemical testing is often required to determine the extent of soil chemical constraints.

Problem Identification: A visual inspection of crop uniformity generally provides an indication where constraints may exist in the deeper sections of the root zone, particularly during the mid-later stages of the growing season. Confirmation of the problems requires installation of a small pit to 1.0 metre in an affected and non-affected area, then comparing the physical and chemical constraints at depth between sites. Horizons containing calcium carbonate, crystalline gypsum, elevated salinity and adverse soil chemistry can be revealed. In most cases laboratory testing is required to determine the magnitude of a toxicity with some including boron and chloride. Strongly alkaline pH levels also play a role in limiting nutrient availability. Yield maps can provide an indication of areas where hostile subsoils may exist. A yield map from an average rainfall season is a good starting point.

Figure 21 is a photograph of a Lemnos Loam soil profile from the Goulburn Valley containing calcium carbonate and gypsum at depth forming a hostile layer.

Figure 21. Lemnos Loam soil profile from the Goulburn Valley containing calcium carbonate and gypsum at depth.

Management options: Management of hostile subsoils should be focused towards understanding the range of issues causing hostile conditions, the depth of hostile and the magnitude of the problems. There is nothing that can be practically implemented to change or ameliorate the soils to reduce the hostility of deeper subsoil layers. Improving cycles of wetting and drying which encourage the movement of material to depth may improve deeper subsoil conditions, however crops may suffer drought stress in this process.

Changes in management are likely to yield successful outcomes. Selection of crops with a higher tolerance to the toxicity may improve production. Deep rooted pastures including Lucerne should be trialled with caution.

Variable Rate Technology can be employed where deep hostile layers are present impacting on yield potential. A significant investment into mapping and soil testing is required to establish zones.

5.8. Acidic Topsoils.

Description of the issue and importance: Acid topsoils are common throughout northern Victoria where annual rainfall exceeds 450mm/year. Soil acidity within loam and clay loam textured topsoils is common and acidity is influenced by leaching of irrigation water containing cations including calcium, nitrogen and sulphur.

As soil acidity increases, several processes occur:

- Essential macro-nutrients and trace elements have reduced availability for pastures or crops. Over-application of nutrients typically counterbalances poor availability.
- The availability of exchangeable aluminium increases, which can prune or limit pasture or crop root development. A restricted root system then limits the AWC and level of available nutrient.
- The environment for plant growth is less favourable under an acidic condition.
- The environment for soil biological functioning is less favourable and mineralisation of organic matter may decline as soil pH becomes more acid.

Problem Identification: Indicators to determine the presence and extent of acid soils include:

1. Soil test results showing soil pH (water) levels of less than 6.5 or pH (CaCl2) levels of less than 5.5.
2. Soils that show strong responses to lime application.
3. Poor plant root growth in the A horizons.
4. Pastures or crops that show strong responses to applied fertilisers.
5. Pastures or crops that perform poorly.
6. Limited biological activity.
7. Duplex soil conditions where the A horizons are light textured. Textures include sandy loams, light sandy clay loams and sandy clay loams.

It is important that the depth of the acidic layer is revealed by testing soil pH down the profile, with depth measurements confirmed and boundary between acidic and non-acidic horizons defined. A hand soil pH test kits can be used to determine the approximate soil pH (water) level. Figure 22 is a photograph of samples from the Shepparton region tested with a hand test kit.

Figure 22. Photograph showing samples tested for soil pH (water) using the hand test kit. Samples on the left are A_1 and B_1 horizon samples showing acidic soil pH levels.

Management options: Most growers and agronomists are familiar with the presence of acid soils and the best approaches for management. Liming is accepted industry practice for adjustment of acid soils. Agricultural lime is ground and screened calcium carbonate. When applied, soil in contact with lime which is acidic dissolves the surface of lime particles, then hydrogen in the soil exchanges for calcium on clay exchange sites. The carbonate fraction converts to CO2 (carbon dioxide) a greenhouse gas uptaken by plants. Free hydrogen and oxygen join and form water. This process in an acidic soil yields an increase in soil pH, increased nutrient availability and improved conditions for plant growth and biological activity.

Lime rates for soil amelioration should be based on a volume of lime required to neutralise soil by a set rate. Traditional lime volumes are applied using a rule of thumb formula:

1.0 t/acre or 2.5 t/ha is required to raise soil pH by 1.0 unit per 100mm of soil.

This formula is a guide only and varies depending on the starting soil pH level. As soil pH is a logarithm of the hydrogen ion concentration, the rule of thumb is a guide only. Using this guide, the total volume of lime required to raise soil pH by 1.0 unit for 150mm of topsoil is approximately 3.75 t/ha. This approach may not prove cost effective for many businesses and a lower rate approach applied on a more intensive basis may yield a productive and sustainable outcome.

Lime particle size should also be considered in the process of selection. In general, the finer the lime, the more effective it is at neutralising soil pH. Effective Neutralising Values (ENV's) of 90% or greater should be targeted.

In all cases where soils require amelioration, an evaluation of the cost-effectiveness of liming for adjustment of pH should be evaluated compared to the application of gypsum to address dispersive and sodic soil. The most significant impact on production should be treated as a priority, followed by the other factors which may impact to a lesser degree.

The do-nothing approach can be maintained for some time and is common practice on many farms. As plants require calcium and there is calcium export from intensive production systems, calcium is inevitably required for application at some point in a pasture or crop rotation or cycle. The do-nothing approach will fall short of the plants calcium requirement aside of the associated soil problems that exist. After soil pH (water) levels decline below 5.5, root growth is severely impeded and production is likely to be impeded.

Use of nitrates and sulphate based fertilizers will also exacerbate soil acidification.

Crops and pastures can be selected to better handle acidic soil pH levels. Some of these varieties include phalaris, cocksfoot, oats or triticale.

6. CONCLUSION.

This report summarises the key soil management issues identified from evaluation and discussion of five selected profiles inspected during Workshop 1 of Murray Dairy's Accelerating Change soil program for 2016-2017. Each soil management issue identified is described along with methods for identification and management options. The key messages are not isolated to those discussed in this report.

Critical to the success of any soil assessment process is basic understanding of soil agronomy. This is not difficult and usually relies upon a visual assessment and basic soil chemistry. In the case of amelioration, it is important for landholders to understand that it is not just about the next product that can be applied, but more related to the identification of soil related issues and methods for simultaneously treating problems in a cost-effective and practical manner. Often the best option may not be the cheapest.

Landholders should question their current methods of problem identification with their soils and understand that the can obtain industry assistance with the types of issues discussed in this report. It is proposed that landholders read the document and use the details as a guide for their own irrigated pastures or crops within the Murray Dairy region of the Riverine Plains in northern Victoria and southern New South Wales.

Further information can be sourced from the Dairy Soils & Fertilizer Manual at
http://fertsmart.dairyingfortomorrow.com.au/wp-content/uploads/2013/07/Dairy-Soils-and-Fertiliser-Manual-complete-reduced-file-size-3.pdf

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APPENDIX A. SOIL TEST RESULTS SPREADSHEET.

Murray Dairy Soil Test Summary. **July 2016.**

	Sample	1. LANG	1. LANG	2. LANG	2. LANG	3. EMMETT	3. EMMETT	4. EMMETT	4. EMMETT	5. MCDONALD	5. MCDONALD	6. MCDONALD	6. MCDONALD
	Depth (cm)	A1. 0-9	B1. 9-30	A1. 0-12	B1. 12-35	A1/A2. 0-14	B1. 14-50	A1 . 0-13	B1. 13-45	A1. 0-10	B1. 10-40	A1/A2. 0-20	B1 20-60
pH (1:5 Water)		8.8	9.0	7.4	7.8	5.9	7.3	6.3	8.7	6.3	8.2	5.9	7.1
pH (1:5 CaCl2)		7.4	7.7	6.2	6.6	5.0	6.3	5.5	7.7	5.4	7.1	5.0	6.0
Electrical Conductivity	*dS/m*	0.19	0.24	0.11	0.16	0.06	0.08	0.09	0.21	0.1	0.13	0.07	0.05
EC Saturation Index	*dS/m*	1.2	1.5	0.7	1	0.4	0.5	0.6	1.3	0.6	0.8	0.4	0.3
Organic Carbon	*%*	0.99	0.33	1.7	0.43	2.9	0.49	3	0.64	3.4	0.45	1.7	0.4
Chloride	*mg/kg*	25	62	17	73	<10	<10	<10	19	14	12	27	19
Nitrate Nitrogen	*mg/kg*	<0.50	<0.50	2.7	1.4	8	5.6	19	22	3.8	1	1.6	0.6
Ammonium Nitrogen	*mg/kg*	1.5	0.62	2.1	1.4	3.7	0.68	4.8	1.1	3.4	<0.60	1.6	0.88
Phosphorus - Colwell	*mg/kg*	16	6.5	43	6.2	94	5.3	65	8.7	140	90	19	<5.0
Phosphorus Buffer Index - Colwell		120	230	130	160	67	130	94	190	160	140	120	190
Sulfate Sulfur - KCl	*mg/kg*	37	52	20	25	7.6	11	7.2	11	11	8.5	11	4.6
Calcium (Amm. Acet.)	*mg/kg*	1180	1180	1300	1060	1420	1620	1460	1520	1200	1440	1180	1580
Potassium (Amm. Acet.)	*mg/kg*	292.5	226.2	163.8	339.3	159.9	156	378.3	284.7	390	1482	152.1	132.6
Magnesium (Amm. Acet.)	*mg/kg*	348	456	672	936	384	924	480	1320	468	924	384	924
Sodium (Amm. Acet.)	*mg/kg*	713	1219	345	506	34.5	170.2	43.7	713	138	322	64.4	167.9
Aluminium (KCl)	*mg/kg*	9	9	9	9	9	9	9	9	9	9	9	9
Calcium (Amm. Acet.)	*cmol(+)/kg*	5.9	5.9	6.5	5.3	7.1	8.1	7.3	7.6	6	7.2	5.9	7.9
Potassium (Amm. Acet.)	*cmol(+)/kg*	0.75	0.58	0.42	0.87	0.41	0.4	0.97	0.73	1	3.8	0.39	0.34
Magnesium (Amm. Acet.)	*cmol(+)/kg*	2.9	3.8	5.6	7.8	3.2	7.7	4	11	3.9	7.7	3.2	7.7
Sodium (Amm. Acet.)	*cmol(+)/kg*	3.1	5.3	1.5	2.2	0.15	0.74	0.19	3.1	0.6	1.4	0.28	0.73
Aluminium (KCl)	*cmol(+)/kg*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cation Exchange Capacity	*cmol(+)/kg*	12.75	15.68	14.12	16.27	10.96	17.04	12.56	22.53	11.6	20.2	9.87	16.77
Calcium (Amm. Acet.)	*Base Sat %*	46.3	37.6	46.0	32.6	64.8	47.5	58.1	33.7	51.7	35.6	59.8	47.1
Potassium (Amm. Acet.)	*Base Sat %*	5.9	3.7	3.0	5.3	3.7	2.3	7.7	3.2	8.6	18.8	4.0	2.0
Magnesium (Amm. Acet.)	*Base Sat %*	22.7	24.2	39.7	47.9	29.2	45.2	31.8	48.8	33.6	38.1	32.4	45.9
Sodium (Amm. Acet.)	*Base Sat %*	24.3	33.8	10.6	13.5	1.4	4.3	1.5	13.8	5.2	6.9	2.8	4.4
Aluminium (KCl)	*Base Sat %*	0.8	0.6	0.7	0.6	0.9	0.6	0.8	0.4	0.9	0.5	1.0	0.6
Zinc (DTPA)	*mg/kg*	0.73	0.12	1.9	0.23	5.3	0.12	3.2	0.25	5.5	0.38	2.1	0.11
Copper (DTPA)	*mg/kg*	1.2	0.8	2.7	1.1	0.92	1.5	1.4	1.4	2.7	1.6	2	1.2
Manganese (DTPA)	*mg/kg*	25	15	55	15	15	6.6	14	4.2	93	12	58	17
Boron	*mg/kg*	0.7	0.75	1.2	1.2	1.1	2.4	1.5	4.7	1.6	3.9	0.98	2.4
Iron (DTPA)	*mg/kg*	29	14	100	33	320	35	250	28	480	35	250	23
Calcium/Magnesium Ratio		2.0	1.6	1.2	0.7	2.2	1.1	1.8	0.7	1.5	0.9	1.8	1.0

INTERPRETATION:

Very High	(dark red)
High	(red)
Slightly High	(orange)
Acceptable	(green)
Slightly Low	(yellow)
Very Low	(light blue)
Deficient.	(dark blue)