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Soil Benchmarks for Australian Processing Tomato Growers

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INTRODUCTION

The condition of soils can produce major differences in yield. Often an obvious factor such as soil fertility is considered responsible, but soil structure can also affect yield. Soil factors such as compacted topsoil, abrupt texture changes, hardpans or dense subsoil can affect water entry, water holding capacity, root growth and aeration. Processing tomatoes, like most crops, are susceptible to adverse growing conditions, so it is important for crop productivity that soils be managed well.

How is the structure of the soil altered? Often the soil is loosened or cultivated down to a fine tilth by deep ripping, hoeing or discing. Gypsum is generally added to reduce dispersion of the clay, and then the soil may be saturated for prolonged periods during growth of the crop. Some of these processes reduce the amount of soil organic matter. The soil may be compacted further with heavy equipment during harvest, and then the paddock may be rested for several years. During this break, the paddock may have cereal crops or pasture grown on it. The soil structure often improves during the break because of less cultivation, increased levels of organic matter, and drying out and aeration of the soil profile.

Most farmers keep records of the amount of fruit harvested, fertilisers applied, soil fertility, crop management dates, etc. However, are records maintained for soil physical properties such as the level of soil compaction or hardness, denseness of the subsoil, the depth of hardpans and the depth to which plant roots grow?

We generally have an understanding through experience and observation that a particular soil type has good water penetration, water holding capacity or drains well. Our appreciation of the soil properties that influence these conditions is often less understood.

The main aims of this manual are to tabulate (benchmark) the soil physical properties of the major soils used in the Australian processing tomato industry, and to aid growers (through increased awareness) in monitoring those soil properties that can influence their productivity. For some readers the contents may appear very technical, but every effort has been made to describe the measured soil properties in laymen's terms. Less familiar soil terms have been highlighted and defined when first used. The attention of the reader is also drawn to the glossary of soil terms, which is provided at the back of this manual.

The processing tomato industry

The processing tomato industry is based mainly on the clay type soils in northern Victoria and southern New South Wales. In season 1996/97 about 85% of processing tomatoes were grown on clays, with 6% each grown on clay loams and loams. There are five distinct regions where processing tomatoes are grown, and these are described in terms of the nearest major town/s:

1. Boort (Vic)
2. Corop / Colbinabbin (Vic)
3. Jerilderie (NSW)
4. Rochester (Vic)
5. Whitton (NSW).

In each of these regions there are generally one or two major soil types on which the area of tomatoes grown and yields obtained are often above that for other local soil types. Most of these major soil types have been included in this study.

TomCHECK is an industry database that includes, among other things, the soil types that processing tomatoes are grown on. With this in mind the TomCHECK data files from seasons 1995/96 and 1996/97 were used to indicate the most commonly used soil types across the processing tomato industry in terms of area grown and yield. The average yields for the major soil types are shown in Appendix 1. Those soil types which had at least 30 hectares of processing tomatoes grown in the previous two seasons were considered. Digitised GIS soil maps were consulted to confirm the major soil types used in Victoria in season 1997/98 and these have been included in Appendix 2.

A literature search was conducted using GIS soil maps and soil survey reports, to establish what existing information was available on the distribution and physical characteristics of the major soils. This information has been summarised and included in this manual under each soil type listing. Soil types have been listed under their common names as most growers are generally more familiar with these. Each soil type is described in terms of location, soil profile characteristics and occurrence. The existing soils information has also been supplemented by field measurements taken from grower's properties.

Twenty-one sites, covering 12 major soil types, have been used to characterise the soils for all processing tomato growing regions. GPS locations of the 21 sites are listed in Appendix 3.

In the next section, the soil physical properties, which were measured at each site, have been defined and their affects on productivity assessed.

Soil physical properties

Soil is a porous substance that is able to store water, air, elements and nutrients for soil inhabitants and plants. The individual pieces of soil are called ***primary particles*** and these are usually grouped together to form ***aggregates***. Between and within the aggregates are gaps or holes known as ***pores***. The arrangement of soil aggregates and pores determines the ***structure***.

The most obvious feature of a soil is its physical properties such as colour, dustiness, hardness, etc. Although these features are fairly obvious, the farmer or agriculturalist has generally concentrated more on the chemical properties of the soil in the past, mainly because on soils of relatively low fertility, the crop response has been greatest to applied fertilisers. This section aims to introduce the major soil physical properties that can affect the growth of tomato crops.

Soil profile

The ***soil profile*** is essentially a vertical section of soil, which can provide an insight into how the soil may behave under irrigation and cropping. We often concentrate on the upper portion of the soil (or ***topsoil***) as this is where most of the plant roots and nutrients are found. However, for deep rooting crops like tomatoes, we must also have an appreciation of the lower portion (or ***subsoil***), as the subsoil can affect the downward movement of soil water and tomato roots, water storage and the stability of the topsoil as well.

Usually the most obvious feature from a soil profile is the ***colour*** of the soil. Some soil types have several distinct changes in colour with increasing depth, whereas many are uniform in colour. A red profile throughout, such as seen in Colbinabbin clay, generally indicates a well-drained soil. On the other hand a mixture of yellow and grey colours in the subsoil (***mottling***) usually indicates periodic waterlogging and less favourable drainage.

Often, with increasing depth the soil behaves differently when kneaded in the palm of the hand following the addition of water. The soil may feel smooth or sticky or gritty when rubbed between the thumb and forefinger. Or the soil can be rolled into long ribbons without breaking. This soil property is termed ***texture*** and associated with it is the ease with which the soil can be cultivated. Texture also provides a guide to the amount of clay, silt and sand or the ***particle size distribution*** of the soil. Soil textural classes can vary from sands, loams, clay loams, clays, heavy clays to a combination of these types. Most soils used for growing processing tomatoes have a heavy clay texture.

For soil profiles, we often record the ***depth*** at which a distinct change in colour, or texture occurs. The depth refers to the distance from the soil surface to the point of change. We call each layer of soil that is distinguished by a distinct change in the soil profile a ***horizon***. Soil horizons can be divided into A, B and C. Generally the A horizon corresponds with the topsoil, the B horizon corresponds with the subsoil and the C horizon the part of the soil profile that meets with rock or parent material. Birganbigal clay loam for instance, has distinct A and B horizons characterised by colour and texture changes.

Colour changes in the soil profile may be associated with the presence of white streaks caused by patches of ***lime*** (calcium carbonate) or ***gypsum*** (calcium sulphate). We generally associate these with drier climates and with soils that have insufficient winter rainfall to leach the lime or gypsum through the profile. Lime can range from being classed as ***soft***, where it can be broken down easily by hand, to ***hard*** where it behaves like a piece of gravel or rock. Subsoils are normally ***alkaline*** (pH above 7) when they contain noticeable amounts of lime or gypsum. High levels of lime in the soil profile can sometimes reduce the availability of minerals such as iron. Boort clay has been found to have appreciable levels of lime in the subsoil.

Some soils shrink and swell quite markedly during wetting and drying cycles. These soils often have a fine layer of aggregates on the surface as the soil dries out following rain and are described as ***self-mulching***. Most processing tomato soils self-mulch, which is a desirable feature because it results in better seed emergence.

Often we may notice the ease with which a soil can be dug or cultivated. A ***soft*** or more crumbly soil is far easier to dig than a compacted ***hard*** soil. Similarly a soft, crumbly soil requires less cultivations or horsepower to cultivate to a desirable tilth. Generally loams are softer than clays.

A soil may feel soft, consist of many separate particles (aggregates), contain many spaces or pores between these particles, and be classed as having ***good structure*** when it crumbles to good sized soil aggregates. Alternatively, the soil may consist of a solid mass with very few gaps or pores, and be classed as ***structureless***. A structureless, hard soil such as this is termed ***massive***, but a structureless soil can also be loose or incoherent and described as ***single grained***.

Sometimes as the soil dries, horizontal and vertical cracks may appear within the soil profile and the individual clumps of soil may take on a blocky appearance. It is then described as having a ***blocky structure***.

In well structured soil the spaces or voids between the soil aggregates allow for root channels and water flow through the profile.

Soil aggregates can take on a number of different shapes or ***forms***. Natural soil aggregates are commonly referred to as ***peds***. Whereas a ***clod*** is generally an artificially produced soil aggregate formed as a result of cultivation. Cultivated soil can also break down across natural planes of weakness and form ***fragments***.

The degree to which moist soil breaks down into aggregates when disturbed is given the term ***grade***. There are four grades of aggregation and these are apedal (structureless), weak, moderate or strong (Butler, 1955). The shape or ***form*** of soil aggregates or peds can also be described. The most common types of structure observed in processing tomato soils include granular, angular blocky, sub-angular blocky and prismatic. For further information on the grade and shape of soil aggregates refer to Appendix 4 in the back of this manual.

Another important aspect of the soil profile is the depth to which the plant roots grow or the ***rooting depth***. It is useful to observe whether the roots grow downwards or sideways. Depending on the crop, we may conclude that the soil profile contains a hard layer of soil or ***hardpan,*** or some less visible soil property that restricts root depth.

Some of the processing tomato soils studied showed indications of restricted root growth into the subsoil. One example was site #19 on Binabbin clay near Rochester, where tomato roots were found to grow into the subsoil only through deep vertical cracks.

This manual includes complete soil profile descriptions and photographs of the 12 major soil types used in processing tomato production.

Aeration

Aeration and ***drainage*** of the soil is important to provide sufficient oxygen to plant roots, especially during irrigation or when the soil is saturated. An indication of poor soil aeration (often the effect of ***waterlogging***) is when young tomato plant leaves turn purple and growth slows down. ***Air filled porosity*** (AFP) or ***macroporosity*** is a measure of the amount of spaces or voids within the soil through which oxygen can move towards the plant roots and excess soil water, carbon dioxide and other gases can move away. As gases in the soil travel mainly through the largest soil pores (or ***macropores)***, then AFP can provide a useful index of the soil's capacity for gas exchange and drainage.

Another soil property that can affect soil aeration is particle size distribution. As soil particles get larger, the space between them also gets larger. Both aeration and drainage can be improved when a soil has a high proportion of coarse sand or stable aggregates, because of the higher number of large pores (or macropores) between the particles. On the other hand, soils that have a large amount of silt and clay or unstable soil aggregates are generally poorly drained because of the high number of small spaces (or ***micropores***) between the soil particles. Wandella clay near Boort, has a high proportion of coarse sand relative to clay and has good aeration and air filled porosity.

Aggregate stability

Aggregate stability is a useful index of how stable individual soil crumbs or aggregates are to wetting. Stable soil aggregates retain their structure and behave similarly to coarse sand in that they allow good movement of both water and gases around them. There are several tests available that can provide an indication of a soil's ability to withstand structural breakdown during wetting and some of these are listed below.

Organic carbon is the amount of available carbon and indicates the level of ***organic matter*** in the soil. Organic matter is the product of live or dead organisms, and increased levels generally improve aggregate stability and result in better soil structure.
Percentage of water stable aggregates (%WSA) indicates the ability of soil aggregates to withstand breakdown during mechanical wetting, and can provide an indication of how stable a soil is. The test involves wetting the soil and recording the remaining aggregates greater than 0.25 mm. These are classified as being water stable. The highest value for %WSA was seen in Rochester clay and

this soil was also found to have the highest level of organic carbon compared to the other soil types.

Another test determines the ability of air-dried aggregates to withstand rapid wetting. On wetting, the rapid swelling of aggregates and escape of entrapped air within them often results in their breakdown into smaller aggregates. This process is called ***slaking*** and can often be seen as a surface crust on soils following heavy rainfall. Slaking of soil aggregates can lead to structural breakdown of soils and an increase in bulk density and soil hardness. Increasing organic matter levels can reduce the amount of slaking. Of the tomato soils tested, only the topsoils from Rochester and Restdown clays showed resistance to slaking.

Dispersion is the breakdown of soil aggregates into individual soil particles. The cloudiness in irrigation water is an indication of dispersed clay in solution. Dispersed clay can result in blockage of soil pores and structural breakdown of soil. The majority of topsoils studied did not disperse, except when subjected to mechanical shaking. Dispersion can often be reduced through the action of calcium applied as gypsum.

Mechanically dispersible clay (MDC) indicates the amount of clay that can be dissolved out of soil aggregates with mechanical shaking. The percentage of clay in solution provides an indication of soil aggregate breakdown. MDC arises as a result of applying energy or work to a saturated soil, and is analogous with cultivating or working a soil when it is wet. Rochester clay, although having stable topsoil, had subsoil that was particularly susceptible to mechanical dispersion. This indicates that for this soil type, structural breakdown will probably occur when the soil is worked wet.

Root growth

Root growth can be limited by many factors. Two of the most obvious and easily measured soil properties that can affect root growth are soil hardness and bulk density.

Soil hardness or ***penetrometer resistance*** can provide an indication of whether a hardpan exists and whether soil hardness within the soil profile is likely to impede root growth. A metal rod is pushed into the soil and the force required gives an approximate indication of the force needed by the plant root to move through the soil during growth.
Soil hardness also depends on soil water content, as seen when a drying soil becomes progressively harder. A soil with stable structure will show less increase in soil hardness as it dries out compared to a poorly structured one. A possible reason for this may be that in poorly structured soil, the aggregates tend to cement together during drying.

Bulk density provides an indication of how compact the soil is, and is determined from the weight of the soil divided by its ***total volume***. The total volume of soil includes the volume of the individual soil particles and volume of pore space between them. When soil structure declines, the actual mass or weight of soil does not change, but the bulk density increases because there is less pore space or ***porosity*** between soil particles. An increase in bulk density can consequently lead to a reduction in aeration during irrigation and less available water for the plant. Initially cultivation of the soil decreases bulk density. However, cultivation can also make soil aggregates more susceptible to breakdown (slaking and dispersion), so that the spaces or voids between the soil aggregates become smaller, leading to a long-term increase in bulk density.

Water availability

Water availability provides an indication of how much soil water is available to the plant. Imagine that the soil consists of aggregates of different shapes and sizes stacked randomly together with spaces of different sizes between them. These spaces or soil pores can contain water in varying amounts. Generally water moves into and out of the largest soil pores first, and the smaller pores hold onto the water more tightly. A soil that has good water infiltration generally has a high proportion of large soil pores (macropores). Following an irrigation these larger pores are partially or completely filled with water, which is available to the tomato plant. At the same time gravity is pulling some of this water downwards when there is no limiting barrier such as a hardpan. Normally we assume that all of the water within the macropores drains away, at which point the soil reaches a stage known as ***field capacity***. At this stage we can calculate the amount of water available to the plant up to a point were the plant wilts beyond recovery (***wilting point***), or before this stage, the point at which the next irrigation should commence (***refill point***). The amount of soil water available between field capacity and wilting point is commonly called ***total available water (TAW)***, and the amount of soil water between field capacity and the refill point is called ***readily available water (RAW)***.

RAW and TAW are approximate amounts of water that are available to the plant. As mentioned previously, during irrigation the soil may become wetter than field capacity and this excess soil water can quite often be utilised by the plant, although saturated soils have lower available oxygen. This is generally not a problem when the soil water reservoir is such that the plant can extract the excess quickly, such as during periods of warm weather and rapid growth. This is often the case under daily drip irrigation. However, when excess soil water is not removed quickly because of low plant water use, or where a dense layer prevents drainage, then waterlogging will reduce yield and probably alter soil structure.

Both RAW and TAW are highly dependent on the proportions of clay, silt and sand within the soil profile. In general, as the amount of clay in the soil increases both the RAW and TAW also increase. We can therefore gain a fairly reliable estimate of the water holding capacity of a soil from its texture. Other factors that can affect RAW and TAW are changes in bulk density, root depth and the amount of organic matter in the soil. Changes in soil management can influence all of these factors and consequently lead to a change in available soil water. Soil types can also vary quite markedly in RAW and TAW because of large variations in their physical properties.

In this manual, field capacity, refill point and wilting point have been assigned values of -10 kilopascals (kPa), -60 kPa and -1500 kPa. These are levels of soil water tension and the figures can also be expressed as negative values to indicate suction. The higher the number, the more strongly the water is held by the soil, making it more difficult for the plant to extract water. One kilopascal is equivalent to the pressure exerted by a 10 cm column of water. The soil water tension value we are using for the refill point (-60 kPa) is indicative of the point at which furrow irrigation would commonly commence. It should be noted that many growers would irrigate before reaching a soil moisture tension of –60 kPa, and they therefore operate as if they have a lower RAW value than what is listed in this manual.

Chemical and salinity management

Chemical and salinity management can affect soil structure through a number of different mechanisms. The different tomato soils discussed in this manual have been assessed for **pH**, electrical conductivity (**EC**), sodium (**Na**), sodium absorption ratio (**SAR**) and chloride (**Cl**).

Soil ***pH*** can affect nutrient availability to the plant. Tomatoes can tolerate a wide pH range from 5 to 8, but nutrients can become less available above and below these values. Leaching of nitrate (NO_3^-) by over-irrigation following nitrogen applications can lead to a reduction in soil pH. Fortunately some tomato soils such as Wandella and Boort clay contain high levels of calcium (ie they are calcareous) and have good buffering capacity to minimise fluctuations in pH.

EC is a measure of the level of soluble salts in the soil. High EC levels can reduce water uptake by plants, due to an osmotic effect. An osmotic effect means that water moves from low salt concentration towards a higher salt concentration. The overall result is usually less RAW and TAW for the plant.

SAR is the ratio of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the soil. As the level of sodium increases relative to the levels of calcium and magnesium, the soil structure may decline. ***Sodium*** may take the place of calcium on clays and result in dispersion. To overcome this we often increase the level of Ca by adding gypsum.

Excess levels of ***chloride*** (Cl) are associated with salinity in the soil. High levels of Cl can be toxic to plants, as it is often taken up at the expense of other important plant nutrients.

Optimum range for soil physical properties

There are no absolute values for soil physical properties that define an ideal soil type. However this does not prevent us from estimating a range of values that we believe are necessary for maintaining good soil structure for plant growth. These values should also be flexible enough to accommodate variations due to differences between soil types.

Table 1 provides a list of the soil physical properties measured across all processing tomato soil types during 1998, and proposes optimum ranges for the important characteristics of these soils. Allowances should be made for some individual soil types and for some subsoil values. This list is based on the information we currently have on relationships between soil conditions and crop performance.

Table 1. Desirable values for soil physical properties to achieve optimum structure and crop productivity in processing tomatoes.

SOIL CHARACTERISTIC	SOIL PROPERTY*	CRITICAL RANGE[1]		
		POOR	GOOD	EXCELLENT
Aeration	Air filled porosity[2] (AFP) (%)	<10	10 to 15	>15
Aggregate stability	Oxidisable organic carbon[3] (%)	<1	1 to 1.5	>1.5
	Water-stable aggregates (%)	<40	40 to 75	>75
	Aggregates slaked	yes	trace	no
	Aggregates dispersed	yes	trace	no
	Mechanically dispersible clay (%)	>2	1 to <2	<1
Root growth	Penetrometer resistance (MPa)	>3	1 to 3	<1
	Bulk density (Mg/m^3)	>1.4	1.25 to 1.4	<1.25
Water availability	Readily available water (mm/m)	<40	40 to 60	>60
	Total available water (mm/m)	<100	100 to 150	>150
Chemical composition[4]	$pH_{(CaCl_2)}$	<5 or >8	5 to 6 or 7 to 8	6 to 7
	Electrical conductivity (EC) (dS/m)	>0.4	<0.1 or 0.2 to 0.4	0.1 to 0.2
	Sodium absorption ratio (SAR)	>2	<0.5 to 2	<0.5
	Sodium (Na) (mequiv/kg)	>10	2 to 10	<2
	Chloride (Cl) (mg/kg)	>250	10 to 250	<10

[1] The critical range was determined from the most productive soil types and may be interpreted as the effect that a value within that range may have on yield.. Values for air filled porosity (AFP), penetrometer resistance and bulk density were determined at field capacity. Values within the critical range have been colour coded for easy reference.

- POOR- lower yields may result from a soil property within this range.
- GOOD- average yields can be expected as a result of a soil property within this range.
- EXCELLENT- this soil property is within the optimal range and these values may lead to an increased yield.

[2] Critical values for AFP of the subsoil can be 5% lower than for the topsoil.
[3] Organic carbon means the amount of oxidisable organic carbon (%OOC) and % organic matter = (1.72 × %OOC).
[4] pH, EC, SAR, Na and Cl were analysed from 1:5 (soil: water) saturated extracts.
* For further information on Soil Property units refer to the table in Appendix 5.

1. Binabbin clay

Location: Rochester, Corop and Colbinabbin regions.
Sites #1 and #19.

In the 1996/97 season there were 136 ha of processing tomatoes grown on Binabbin clay, producing average yields of 95 t/ha and 85 t/ha under drip and furrow irrigation respectively (TomCHECK 1997). In the 1997/98 season, we examined six drip irrigated soil types and Binabbin clay had the second highest yield at 138 t/ha.

1.1 Soil profile characteristics of Binabbin clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 8	A grades into:	dark grey-brown	heavy clay	crumbles to fine sub-angular blocky	slight $CaCO_3$ may be present	• self mulching. • friable moist, plastic and slightly sticky wet.
8 to 40	B_1 grades into:	dark greyish brown	heavy clay	moderate medium sub-angular blocky	slight $CaCO_3$ usually present	• friable moist, plastic wet. • slight brown gravel present.
40 to 75	B_2 grades into:	dark brown	heavy clay	sub-angular blocky	light $CaCO_3$	• gypsum sometimes present. • soft when moist.
75 to 180	B_2C	brown, passing to reddish brown	heavy clay	angular blocky	light $CaCO_3$	• at variable depths below 180 cm grades into clay containing fragments of weathered rock.

Reference: Skene (1963).

1.2 Occurrence

Binabbin clay (**Map 2** and **Map 3**) is often found in association with Colbinabbin clay loam and Colbinabbin clay on the Cambrian hills, which flank the south west edge of the Deakin irrigation area. Binabbin clay occupies the relatively lower situations on the hill slopes and often adjoins the Waranga Western Channel. Binabbin clay generally has good properties for water penetration, although excessive irrigation of Binabbin clay may result in seepage of water downhill and salinity developing on the adjoining lower soils.

(Reference: Skene, 1963).

Figure 1. Soil profile for Binabbin clay at site #1.

1.3 Soil physical properties of Binabbin clay at site #1

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	6	8
Fine sand (%)	21	21
Silt (%)	19	14
Clay (%)	52	56
Air filled porosity (%)	16	8
Organic carbon (%)	0.7	-
Water stable aggregates (% WSA >0.25 mm)	37	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0	4.7
Average penetrometer resistance[1] (MPa)	0.9	-
Maximum penetrometer resistance[1] (MPa)	1.7	-
Bulk density (Mg/m^3)	1.10	1.23
Readily available water (RAW) (mm/m)	50	-
Total available water (TAW) (mm/m)	150	-
pH $_{(CaCl2)}$	6.8	7.6
Electrical conductivity (EC) (dS/m)	0.5	0.2
Sodium absorption ratio (SAR)	1.2	0.7
Sodium (mequiv/kg)	6.9	5.5
Chloride (mg/kg)	0.9	11.2

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

1.4 Comments for Binabbin clay

The EC level of 0.5 dS/m was high for site #1 under drip irrigation, but this may be a localised result due to fertiliser banding within the centre of the row. Organic carbon was low, and the soil aggregates tended to be unstable to wetting and slaked readily. Additional organic matter should be applied and the number of cultivations kept to a minimum. Soil is soft at field capacity, but tends to harden as it dries out. This suggests a slight deterioration in soil structure during the growing season. Both AFP (aeration) and RAW (water holding capacity) in the topsoil were good. AFP in the subsoil was good compared to other processing tomato soils.

For site #19 under furrow irrigation, both bulk density and penetrometer resistance increased as the season progressed. The levels of chloride and EC were high, indicating that the soil was slightly saline. The proportion of coarse sand at site #19 was nearly twice as high as at site #1. Soil aggregate stability was low, as was the case for site #1. Organic carbon levels were found to be low at site #19, compared to other industry sites. RAW was in the moderate range. Penetrometer resistance was high, and became extremely high as the soil dried out.

Under furrow irrigation at site #19, extensive cracks from drying of the soil profile were necessary for tomato roots to penetrate through a hardpan into the subsoil.

2. Birganbigal clay loam

Location: MIA region.
Site #8.

In the 1996/97 season there were 53 ha of processing tomatoes grown on Birganbigal clay loam, producing an average yield of 70 t/ha under furrow irrigation (TomCHECK 1997). In the 1997/98 season, we examined 9 furrow irrigated soil types and Birganbigal clay loam had the highest yield at 105 t/ha.

2.1 Soil profile characteristics of Birganbigal clay loam

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 15	A_1	light brown	clay loam	sub-angular blocky.		• massive or sometimes weak aggregation in upper 5 to 8 cm.
15 to 30	A_2 sharply distinct from:	brown	medium clay	angular blocky		• massive. • rusty mottling.
30 to 60	B_1 grades into:	brown to reddish brown	heavy clay	angular prismatic breaks down to angular blocky.	slight $CaCO_3$	• moderate grade of aggregation. • little mottling. • sticky moist.
60 to 105	B_2	gradual change to yellowish brown.	heavy clay	angular prismatic	slight $CaCO_3$ decreasing with depth.	• fairly dense clay. • sticky moist. • moderately hard moist. • hard dry.

Reference: Van Dijk (1961).

2.2 Occurrence

Birganbigal clay loam is mainly found on the Dallas clay plain and on slightly elevated plains of the southern portion of the MIA. Birganbigal clay loam is particularly widespread in the horticultural area to the east of Leeton and is also found in a few small areas on the Whitton clay plain between Leeton and Whitton.

Other soil types found in association with Birganbigal clay loam include Thulabin clay, Mundiwa clay and Wamoon clay.

(Reference: Van Dijk, 1961).

Figure 2. Soil profile for Birganbigal clay loam at site #8.

2.3 Soil physical properties of Birganbigal clay loam (site #8)

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	8	7
Fine sand (%)	32	29
Silt (%)	15	12
Clay (%)	43	52
Air filled porosity (%)	20	5
Organic carbon (%)	1.3	-
Water stable aggregates (% WSA >0.25 mm)	55	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0.1	4.1
Average penetrometer resistance[1] (MPa)	0.9	-
Maximum penetrometer resistance[1] (MPa)	2.7	-
Bulk density (Mg/m^3)	1.21	1.43
Readily available water (RAW) (mm/m)	50	-
Total available water (TAW) (mm/m)	135	-
$pH_{(CaCl2)}$	4.7	5.2
Electrical conductivity (EC) (dS/m)	0.3	0.1
Sodium absorption ratio (SAR)	0.4	0.1
Sodium (mequiv/kg)	1.8	0.5
Chloride (mg/kg)	30.2	9.6

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

2.4 Comments for Birganbigal clay loam

The top 15 cm appeared to be moderately saline for site #8 under furrow irrigation. The chloride level was moderate, but not critical. The soil pH was acid in the top 30 cm. Lime may be warranted in the long term. The %WSA is slightly above the industry average, but could be improved further with additional organic matter. The topsoil had a tendency to slake and the subsoil was prone to mechanical dispersion, which could result in surface crusting, reduced seed germination and compaction as shown by the increase in bulk density of the subsoil.

The soil was soft at field capacity, but increased in hardness as it dried out.

Birganbigal clay loam at this site needs careful irrigation management, as salinity and high water-tables may become a problem.

At present the organic carbon levels are good relative to other industry sites, however increased levels should improve soil structure.

Air filled porosity was excellent in the topsoil, but tended to be marginal with increased depth.

Birganbigal clay loam is a red brown earth (RBE).

3. Boort clay

Location: Boort region.
Site #16.

In the 1996/97 season there were 70 ha of processing tomatoes grown on Boort clay, producing an average yield of 90 t/ha under furrow irrigation (TomCHECK 1997).

3.1 Soil profile characteristics of Boort clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 10	A Grades into:	dark brownish grey	light or medium clay	moderate fine sub-angular blocky	traces of $CaCO_3$ concretions	• self mulching. • moderately soft dry.
10 to 90	B_1 Grades into:	brownish yellow grey	heavy clay	weak, coarse angular blocky	slight to light and soft concretionary $CaCO_3$	• moderately hard dry, very friable moist • becomes diffusely yellowish with depth.
90 to 180	B_2	light brownish yellow and brownish yellow grey	medium clay	angular blocky	$CaCO_3$ levels decreasing to slight with depth	• diffusely mottled.

Reference: Skene (1971).

3.2 Occurrence

Boort clay (**Map 1**) occurs in the low woodland areas of black box country between the Lodden River and the wind deposited soils of the Mallee fringe. This area is low lying, but generally not subject to flooding, though some areas are within the high flood influence of the Lodden River. The topography is generally flat, with some areas of gilgai. Soil salinity is low and the penetration of irrigation water is fair, although slow. Boort clay is also found in associations with other soil types such as Minmindie clay and Wandella clay.

(Reference: Skene 1971).

Figure 3. Soil profile for Boort clay at site #16

3.3 Soil physical properties of Boort clay (site #16)

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	9	6
Fine sand (%)	26	23
Silt (%)	12	9
Clay (%)	52	62
Air filled porosity (%)	14	5
Organic carbon (%)	0.8	-
Water stable aggregates (% WSA >0.25 mm)	28	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0	0.95
Average penetrometer resistance[1] (MPa)	1.6	-
Maximum penetrometer resistance[1] (MPa)	3.2	-
Bulk density (Mg/m^3)	1.18	1.48
Readily available water (RAW) (mm/m)	45	-
Total available water (TAW) (mm/m)	130	-
pH $_{(CaCl2)}$	7.8	7.9
Electrical conductivity (EC) (dS/m)	0.4	0.2
Sodium absorption ratio (SAR)	1.5	0.8
Sodium (mequiv/kg)	6.0	4.1
Chloride (mg/kg)	140	48

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

3.4 Comments for Boort clay

The chloride level was moderately high at site #16 under furrow irrigation. The upper 30cm was slightly saline as indicated by EC. Organic carbon levels are low, compared to other industry sites and could be improved. An increase in organic matter may be warranted, as only 28% of soil aggregates were water stable.

Soil aggregates were less susceptible to dispersion than in some of the other processing tomato soil types. Mechanically dispersible clay was less than 1% in the subsoil. One reason for this could be the relatively high levels of calcium through the profile.

Soil hardness was moderate at field capacity, but increased markedly on drying. Soil strength was extremely high below a depth of 15 cm once the soil dried out. Bulk density was excellent for the topsoil, however it increased markedly with depth and was poor in the subsoil. Introduction of or changes to the practice of deep ripping the subsoil may be warranted.

Water penetration into the tomato beds was slow during irrigation and requires careful management. Once this is accomplished however, both RAW and TAW are good. Air filled porosity was good in the topsoil and was moderate in the subsoil.

4. Colbinabbin clay loam

Location: Colbinabbin, Corop and Rochester regions.
Sites #6 and #20.

In the 1996/97 season there were 85 ha of processing tomatoes grown on Colbinabbin clay loam, producing average yields of 97 t/ha and 93 t/ha under drip and furrow irrigation respectively (TomCHECK 1997).

4.1 Soil profile characteristics of Colbinabbin clay loam

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 15	A sharply separated from:	dark reddish brown	clay loam	crumbles to fine sub-angular blocky		• very friable moist. • sticky wet.
15 to 53	B_1 grades into:	dark reddish brown	heavy clay	moderate to strong medium sub-angular blocky		• hard dry, friable moist. • sticky wet.
53 to 83	B_2 grades into:	reddish brown	heavy clay	as above	slight to light decreasing with depth.	• hard dry. • sticky wet.
83 to 210	B_2C	red-brown	heavy clay			• gypsum may be present. • weathered rock can occur at 120cm depth or onwards.

Reference: Skene (1963).

4.2 Occurrence

Colbinabbin clay loam (**Map 2)** extends as a fringe below the Waranga Western Main Channel where it flanks the Cambrian hills. Above the channel, Colbinabbin clay loam is quite extensive on the hill slopes facing eastward. Associated soil types include Binabbin clay and also Colbinabbin clay. Colbinabbin clay loam appears to have good properties for water penetration. However, over-irrigation of Colbinabbin clay loam may result in the development of high water-tables and the risk of salinity occurring lower down the slope.

(Reference: Skene, 1961).

Figure 4. Soil profile for Colbinabbin clay loam at site #20.

4.3 Soil physical properties of Colbinabbin clay loam at site #20

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	5	2
Fine sand (%)	26	23
Silt (%)	14	15
Clay (%)	53	60
Air filled porosity (%)	13	6
Organic carbon (%)	0.9	-
Water stable aggregates (%WSA >0.25 mm)	48	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	6.2	1.84
Average penetrometer resistance[1] (MPa)	1.4	-
Maximum penetrometer resistance[1] (MPa)	3.1	-
Bulk density (Mg/m^3)	1.12	1.25
Readily available water (RAW) (mm/m)	60	-
Total available water (TAW) (mm/m)	165	-
pH $_{(CaCl2)}$	5.9	7.3
Electrical conductivity (EC) (dS/m)	0.2	0.2
Sodium absorption ratio (SAR)	0.7	0.6
Sodium (mequiv/kg)	2.5	3.8
Chloride (mg/kg)	15.9	8.0

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

4.4 Comments for Colbinabbin clay loam

Both sites #6 and #20 were drip irrigated. Organic carbon levels were high (above industry average) for site #6, but slightly below the industry average for site #20. Organic matter could be increased for site #20. Aggregate stability also reflected the levels of organic matter at site #6 compared to site #20, as there was a 25% difference in %WSA between the two sites.

Soil aggregates from both sites dispersed when subjected to mechanical action. Both sites had high levels of mechanical dispersion in the topsoil (3.3% for site #6 and 6.2% for site #20). These levels were generally high compared to other drip irrigated soil types, and suggest that the soil would be prone to structural breakdown when cultivated wet.

Penetrometer resistance was generally high for site #6 and low to moderate for site #20. Bulk density was good at both sites.

Colbinabbin clay loam is a red brown earth.

5. Cornella clay

Location: Corop and Colbinabbin regions.
Sites #3, #4 and #21.

In the 1995/96 season there were 35 ha of processing tomatoes grown on Cornella clay, producing an average yield of 95 t/ha and 50 t/ha for drip and furrow irrigation respectively (TomCHECK 1996).

5.1 Soil profile characteristics of Cornella clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 13	A grades into:	dark grey	medium clay	strong medium or fine sub-angular blocky	often slight fine $CaCO_3$ concretions may be present	• self mulching when slightly moist.
13 to 50	B_1 grades into:	dark grey	heavy clay	strong coarse prismatic	light soft, and a few concretions	• very friable moist. • deep vertical cracking.
50 to 90	B_2 grades into:	dark grey	heavy clay	sub-angular blocky	light, soft and concretions decrease with depth	• pockets of yellowish brown increasing with depth.
90 to 210		yellow grey	heavy clay	sub-angular blocky		• weakly mottled . brown. • black inclusions often prominent with depth.

Reference: Skene (1963).

5.2 Occurrence

Cornella clay (**Map 2**) is found on the poorly drained, low-lying gilgai plains south of Lake Cooper. In some places it occurs intermingled with the treeless plain soil types such as Koga clay loam and Yuga clay. Given good drainage, the soil profile of Cornella clay has a favourable structure for root and water penetration. Cornella clay is often the dominant soil type with Yuga clay, Carag clay and Wallenjoe clay in the depressions, and with Koga clay loam on the slightly elevated areas.

Cornella clay is often very variable and the surface colours can range from grey brown to grey, while a yellowish-brown, calcareous, deep subsoil may occur within 30 cm of the surface. Not all types of Cornella clay are self-mulching.

(Reference: Skene, 1963).

Figure 5. Soil profile for Cornella clay at site #21.

5.3 Soil physical properties of Cornella clay at site #21

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	2	1
Fine sand (%)	17	17
Silt (%)	22	14
Clay (%)	59	67
Air filled porosity (%)	17	1
Organic carbon (%)	0.8	-
Water stable aggregates (%WSA >0.25 mm)	49	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	yes
Mechanically dispersible clay (%)	0.05	3.5
Average penetrometer resistance[1] (MPa)	1.5	-
Maximum penetrometer resistance[1] (MPa)	2.8	-
Bulk density (Mg/m^3)	1.08	1.32
Readily available water (RAW) (mm/m)	40	-
Total available water (TAW) (mm/m)	135	-
pH $_{(CaCl2)}$	7.7	8.1
Electrical conductivity (EC) (dS/m)	0.5	0.4
Sodium absorption ratio (SAR)	1.0	1.9
Sodium (mequiv/kg)	4.7	12.9
Chloride (mg/kg)	67	285

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

5.4 Comments for Cornella clay

All of the sites monitored on Cornella clay were furrow irrigated.

The soil was slightly saline for all of the sites, with site #3 having an EC level of 1.2 dS/m in the top 15 cm. Both chloride and sodium levels were high at all sites.

The level of organic matter was moderate for all sites and was slightly above the industry average for sites #3 and #4, and slightly below the industry average for site #21. The percentage of water-stable aggregates was close to the industry average for all sites, except for site #3, which was less. Additional organic matter would probably improve soil structure.

Soil aggregates from all three sites were prone to mechanical dispersion, which implies that the soil should not be cultivated when wet.

Penetrometer resistance was initially low at all sites, but as the season progressed, the soil tended to increase in hardness, especially at sites #3 and #4. Bulk density was generally good in both the topsoil and subsoil at all sites.

In the topsoil, air filled porosity was excellent for all sites. However in the subsoil AFP was poor, which would lead to poor aeration, poor drainage and possible water logging problems. All sites on Cornella clay had a self-mulching surface.

6. Restdown clay

Location: Rochester region.
Site #18.

In the 1996/97 season there were 56 ha of processing tomatoes grown on Restdown clay, producing average yields of 70 t/ha and 72 t/ha under drip and furrow irrigation respectively (TomCHECK 1997).

6.1 Soil profile characteristics of Restdown clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 5	A sharply separated from:	greyish brown to grey brown	light clay or clay loam	weak sub-angular blocky		• hard dry.
5 to 45	B_1, grades into:	dark brown to dark grey brown	heavy clay	moderate coarse angular blocky		• hard dry, tough and sticky moist.
45 to 70	B_2 grades into:	brown to yellowish brown	heavy clay	sub-angular blocky	slight to medium $CaCO_3$	• uniform colour or diffusely mottled. • gypsum sometimes present.
70 to 120		brown and greyish yellow-brown	heavy clay	sub-angular blocky	slight $CaCO_3$	• diffusely mottled.

Reference: Skene and Harford (1964).

6.2 Occurrence

Restdown clay (**Map 3**) is found mainly in gilgaied situations on the treeless plains landscape unit west of the Echuca south fault line. In the undisturbed state Restdown clay displays areas of crumbly clay (puff), which are slightly raised, and less friable than the surrounding flat (shelf) land. Restdown clay can display various forms ranging between these two extremes, and only the shelf profile has been discussed here.

The texture of Restdown clay is mostly heavy clay throughout the profile, which often leads to poor infiltration under irrigation. Both water intake and root penetration can be improved by the extensive cracking that occurs when the soil becomes dry.

The shallow and often heavily textured surface is not amenable to easy grading, while the subsoil may have a moderate, and in some cases high salt content. Soils associated with Restdown clay include Koyuga clay, Koga clay loam and Rochester clay.

(Reference: Skene and Harford 1964).

Figure 6. Soil profile for Restdown clay at site #18.

6.3 Soil physical properties of Restdown clay (site #18)

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	4	4
Fine sand (%)	26	25
Silt (%)	10	11
Clay (%)	58	61
Air filled porosity (%)	16	6
Organic carbon (%)	1.1	-
Water stable aggregates (% WSA >0.25 mm)	80	-
Aggregates slaked	no[2]	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0.01	6.26
Average penetrometer resistance[1] (MPa)	1.6	-
Maximum penetrometer resistance[1] (MPa)	4.2	-
Bulk density (Mg/m^3)	1.26	1.40
Readily available water (RAW) (mm/m)	40	-
Total available water (TAW) (mm/m)	110	-
$pH_{(CaCl2)}$	6.9	7.3
Electrical conductivity (EC) (dS/m)	0.5	0.2
Sodium absorption ratio (SAR)	0.6	0.7
Sodium (mequiv/kg)	3.4	4.8
Chloride (mg/kg)	25.7	39.5

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.
[2] Aggregates did not slake at 0 to 15cm depth, but slaked at 15 to 30cm depth.

6.4 Comments for Restdown clay

Restdown clay at site #18 was furrow irrigated. The EC level indicated that the soil was slightly saline in the top 15 cm. The soil aggregates at this site were quite resistant to slaking when compared to most of the other soil types within the industry. However, for the subsoil the soil aggregates were quite susceptible to mechanical dispersion. This suggests that the soil is liable to dispersion and should not be deep ripped or cultivated unless the profile is dry.

The level of organic carbon was good compared to other industry sites. Air filled porosity was excellent in the topsoil and fair to good in the subsoil.

Penetrometer resistance was moderate and slightly above the industry average, and was high in the subsoil. Bulk density was also bordering on high in the subsoil.

Water availability was good, however the heavy clay content of the soil means that the soil water is held fairly tightly.

Both pH and SAR were in the excellent range.

As Restdown clay is self-mulching, seedling emergence should not be inhibited.

7. Rochester clay

Location: Rochester region.
Sites #2 and #7

In the 1996/97 season there were 168 ha of processing tomatoes grown on Rochester clay, producing an average yield of 103 t/ha and 108 t/ha under drip and furrow irrigation respectively (TomCHECK1997).

7.1 Soil profile characteristics of Rochester clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 13	A sharply separated from:	dark grey	medium clay	moderate medium sub-angular blocky		• diffusely mottled with rusty colours. • hard and cracks when dry.
13 to 50	B_1 grades into:	dark brownish grey	heavy clay	moderate angular blocky		• hard dry, tough and sticky moist.
50 to 120	B_2	brownish grey or yellowish grey-brown	heavy clay	angular blocky	slight soft $CaCO_3$ and fine concretions	• hard dry. • friable moist.

Reference: Skene and Harford (1964).

7.2 Occurrence

Rochester clay, like Restdown clay occurs in gilgaied situations. In the undisturbed state Rochester clay is marked by areas of crumbly clay (puff) slightly raised above surrounding less friable, flat land (shelf) or depressions. Rochester clay can display various forms ranging between these two extremes and only the shelf profile has been discussed here.

Rochester clay (**Map 3**) is found on the treeless plain landscape west of the Echuca south fault line. The other soil type intermingled with Rochester clay is Restdown clay, although Rochester clay is usually more heavily gilgaied and difficult to manage. Both the infiltration rate and water intake and root penetration are less in Rochester clay compared to Restdown clay. The subsoils of Rochester clay have low to moderate salinity levels, which are generally lower than for Restdown clay.

Rochester clay can also be quite variable in that it may consist of a deep subsoil, where the colour may vary between uniform yellowish brown, reddish brown or brown below 60 cm depth. The soil may also be described as being heavily gilgaied in some locations.

(Reference: Skene and Harford, 1964).

Figure 7. Soil profile for Rochester clay at site #2.

7.3 Soil physical properties of Rochester clay at site #2

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	12	12
Fine sand (%)	25	17
Silt (%)	7	14
Clay (%)	57	56
Air filled porosity (%)	14	0
Organic carbon (%)	1.6	-
Water stable aggregates (% WSA >0.25 mm)	87	-
Aggregates slaked	no[2]	yes
Aggregates dispersed	no	trace
Mechanically dispersible clay (%)	4.5	22.4
Average penetrometer resistance[1] (MPa)	0.8	-
Maximum penetrometer resistance[1] (MPa)	1.7	-
Bulk density (Mg/m^3)	1.30	1.48
Readily available water (RAW) (mm/m)	35	-
Total available water (TAW) (mm/m)	135	-
pH $_{(CaCl2)}$	5.4	6.4
Electrical conductivity (EC) (dS/m)	0.3	0.2
Sodium absorption ratio (SAR)	0.9	0.7
Sodium (mequiv/kg)	4.6	5.6
Chloride (mg/kg)	8.4	78.4

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.
[2] Aggregates did not slake at 0 to 15 cm depth, but slaked at 15 to 30 cm depth.

7.4 Comments for Rochester clay

For Rochester clay, sites #2 and #7 were drip and furrow irrigated respectively.

Organic matter levels at site #2 were the highest recorded across all of the monitored industry sites. Values were only moderate at site #7. Both sites had a high proportion of water-stable aggregates. For site #2 the %WSA was 87%, which was the highest for all of the industry sites studied. Rochester clay was also found to have soil aggregates in the topsoil (0-15 cm) that resisted slaking.

At both sites the soil aggregates were prone to mechanical dispersion, which indicates the likelihood that they would be damaged if tilled wet. Cultivation of this soil should therefore be avoided under wet conditions. Soil aggregates from site #2 were especially prone to mechanical dispersion registering 4.5% in the topsoil and 22.4% in the subsoil.

Penetrometer resistance was low to moderate for site #2, but was very high under furrow irrigation at site #7. Bulk density also tended to be relatively high at both sites, particularly in the subsoil at site #2. Air filled porosity (AFP) in the topsoil was good for site #2, but poor for the subsoil. For site #7, AFP was excellent in the topsoil and was good in the subsoil.

RAW was low at both sites on Rochester clay, and was generally lower than for the other processing tomato soil types studied.

8. Tragowel clay

Location: Boort region.
Site #13.

In the 1996/97 season there were 33 ha of processing tomatoes grown on Tragowel clay, producing an average yield of 80 t/ha under furrow irrigation (TomCHECK, 1997).

8.1 Soil profile characteristics of Tragowel clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 30	A grades into:	slightly yellowish grey	heavy clay	strong or moderate fine, passing to medium, sub-angular blocky.	Trace of fine concretions of $CaCO_3$ present	• friable dry. • moderately plastic moist.
30 to 120	B_1 grades into:	yellowish grey	heavy clay	moderate coarse blocky	Slight soft and concretionary $CaCO_3$.	• sticky moist.
120 to 200	B_2	yellowish grey or greyish yellow	heavy clay		Slight $CaCO_3$	• diffusely mottled. • becomes more yellowish with depth.

Reference: Skene (1971).

8.2 Occurrence

Tragowel clay is often gilgaied and exists in the self-mulching phase in the Boort area.

Tragowel clay (**Map 1**) occurs in low-lying areas that are subject to flooding and is found adjacent to the Lodden River. There is little difference between soil profiles from the different sections of the gilgai complex. The soil profile is generally well structured with good infiltration characteristics. Salt content near the surface is generally low, however some subsoils have shown quite high levels of salinity.

(Reference: Skene, 1971).

Figure 8. Soil profile for Tragowel clay at Site #13.

8.3 Soil physical properties of Tragowel Clay (site #13)

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	6	6
Fine sand (%)	19	23
Silt (%)	6	10
Clay (%)	68	62
Air filled porosity (%)	17	15
		-
Organic carbon (%)	0.6	-
Water stable aggregates (%WSA >0.25 mm)	31	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0.02	4.28
Average penetrometer resistance[1] (MPa)	1.0	-
Maximum penetrometer resistance[1] (MPa)	2.5	-
Bulk density (Mg/m^3)	1.11	1.18
Readily available water (RAW) (mm/m)	50	-
Total available water (TAW) (mm/m)	135	-
pH $_{(CaCl2)}$	7.5	7.7
Electrical conductivity (EC) (dS/m)	0.5	0.2
Sodium absorption ratio (SAR)	1.7	0.7
Sodium (mequiv/kg)	7.5	4.1
Chloride (mg/kg)	187	65.1

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

8.4 Comments for Tragowel clay

Site #13 on Tragowel clay was drip irrigated. Air filled porosity was excellent for both the topsoil and subsoil.

Soil aggregate stability was low following wetting and the aggregates slaked quite readily. Organic matter was also low, which indicates that structure may be improved by its addition.

The subsoil was prone to mechanical dispersion and therefore should not be cultivated or ripped unless fairly dry.

Both bulk density and soil hardness were excellent, and were well below the average of all the sites studied.

The chloride level in the top 15cm was the highest recorded across all sites studied and should be closely monitored. Electrical conductivity was also high, especially in the top 15 cm, which indicates that the upper part of the soil profile is moderately saline.

Readily available water was good and is adequate for either drip or furrow irrigation.

9. Wallenjoe clay

Location: Colbinabbin and Corop.
Sites #5 and #15.

In the 1996/97 season there were 73 ha of processing tomatoes grown on Wallenjoe clay, producing average yields of 107 t/ha and 77 t/ha under drip and furrow irrigation respectively (TomCHECK 1997).

9.1 Soil profile characteristics of Wallenjoe clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 10	A grades into:	grey	heavy clay	moderate angular blocky	very little visible	• very hard dry, sticky wet. • slight buckshot. • surface gilgaied. • rusty mottling along root channels.
10 to 60	B_1 grades into:	steel grey or dark yellowish grey	heavy clay	moderate large angular blocky		• very hard dry, very sticky moist.
60 to 120	B_2	as above	heavy clay	as above		• very hard dry, very sticky moist • slight concretions present occasionally

Reference: Skene (1963).

9.2 Occurrence

Wallenjoe clay is the soil of the red gum swamp country located east and south east of Corop (**Map 2**), and in pockets to the south east of Echuca. Some of this country contains wetlands that can remain inundated for extended periods. Wallenjoe clay is also frequently associated with other heavy soil types such as Yuga clay and Moora clay. As drainage of these areas has improved, more of this soil type has become available for processing tomato production. The surface of Wallenjoe clay is generally gilgaied.

(Reference: Skene, 1963).

Figure 9. Soil profile for Wallenjoe clay at Site #5.

9.3 Soil physical properties of Wallenjoe Clay at site #5

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	2	2
Fine sand (%)	18	16
Silt (%)	11	12
Clay (%)	67	70
Air filled porosity (%)	20	14
Organic carbon (%)	1.2	-
Water stable aggregates (% WSA >0.25 mm)	68	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0.06	1.8
Average penetrometer resistance[1] (MPa)	1.4	-
Maximum penetrometer resistance[1] (MPa)	2.9	-
Bulk density (Mg/m^3)	1.10	1.24
Readily available water (RAW) (mm/m)	40	-
Total available water (TAW) (mm/m)	105	-
$pH_{(CaCl2)}$	6.5	6.9
Electrical conductivity (EC) (dS/m)	0.8	0.2
Sodium absorption ratio (SAR)	0.4	0.2
Sodium (mequiv/kg)	2.8	1.1
Chloride (mg/kg)	11.2	11.2

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

9.4 Comments for Wallenjoe clay

Both sites #5 and #15 on Wallenjoe clay were drip irrigated. For site #5, air filled porosity was excellent for both the topsoil and subsoil. For site #15, AFP was very good at each depth.

Organic carbon levels were good for site #5 and poor for site #15. Additional organic matter would benefit both sites, especially site #15. Aggregate stability was well above the industry average at site #5 and slightly above the industry average at site #15.

Both sites had some mechanically dispersible clay (MDC) in the topsoil and site #5 had a moderate level of MDC of the subsoil. In comparison, site #15 had 4.8% MDC in the subsoil, which was poor.

Soil hardness was generally low to moderate at both sites, and soil strength tended to display a moderate increase as the soil dried out.

Bulk density was excellent at both sites in the topsoil and subsoil.

Readily available water was good at both sites.

The EC level was elevated in the topsoil and good in the subsoil at site #5 and was good at both depths for site #15. The elevated levels at site #5 could have been due to sampling within a fertiliser band. Soil pH was excellent and sodium levels were good at both sites.

10. Wandella clay

Location: Boort region.
Sites #12, #14 and #17.

For the 1996/97 season there were 106 ha of processing tomatoes grown on Wandella clay, producing an average yield of 83 t/ha under furrow irrigation (TomCHECK 1997). In the 1997/98 season, site #14 on Wandella clay had the highest yielding crop of 155 t/ha under drip irrigation.

10.1 Soil profile characteristics of Wandella clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 8	A grades into:	grey to dark grey	medium clay	strong, medium blocky	slight soft and concretionary $CaCO_3$	• slight rusty mottling. • friable dry, and very plastic moist.
8 to 50	B_1 grades into:	yellowish grey	heavy clay	moderate medium blocky	slight soft and concretionary $CaCO_3$	• hard dry, very plastic moist.
50 to 150	B_2	yellow grey	heavy clay	moderate coarse blocky	Soft and concretionary $CaCO_3$	• diffusely mottled with yellow, brown or grey. • hard dry, very plastic moist.

Reference: Skene (1971).

10.2 Occurrence

Wandella clay is a gilgaied soil type and the puff profile has smaller structural peds or aggregates than the shelf profile. The puff profile is generally more friable and resembles Tragowel clay.

Wandella clay (**Map 1**) occurs in the low lying black box woodland and drainage ways to the north of Boort. Wandella clay is subject to intermittent flooding from the Lodden River and its tributaries and often acts as a terminal drainage basin. Lignum and red gum are two other types of native vegetation that are found to grow on this soil. Wandella clay is often found adjacent to Boort clay and Swamp type 4 clay.

(Reference: Skene, 1971).

Figure 10. Soil profile for Wandella clay at Site #14.

10.3 Soil physical properties of Wandella clay at site #14

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	19	18
Fine sand (%)	23	20
Silt (%)	12	6
Clay (%)	45	56
Air filled porosity (%)	18	17
Organic carbon (%)	0.7	-
Water stable aggregates (%WSA >0.25 mm)	26	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	2.5	1.8
Average penetrometer resistance[1] (MPa)	1.2	-
Maximum penetrometer resistance[1] (MPa)	2.0	-
Bulk density (Mg/m^3)	1.18	1.20
Readily available water (RAW) (mm/m)	50	-
Total available water (TAW) (mm/m)	165	-
$pH_{(CaCl2)}$	7.8	7.6
Electrical conductivity (EC) (dS/m)	0.5	0.3
Sodium absorption ratio (SAR)	2.1	0.7
Sodium (mequiv/kg)	8.5	3.7
Chloride (mg/kg)	225	106

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

10.4 Comments for Wandella clay

Three sites were studied on Wandella clay; sites #12 and #14 were drip-irrigated and site #17 was furrow irrigated.

All three sites on Wandella clay had almost equal proportions of sand and clay in the topsoil. At sites #14 and #17, the air filled porosity was excellent, and at site #12 the AFP was good.

Organic carbon was poor at all sites and could be improved. This was also indicated by the low values for %WSA, which ranged from 25 to 32% for the three sites. Fortunately Wandella clay is self-mulching and surface crusting is not a major problem.

At all three sites, the soil was susceptible to mechanical dispersion, although not spontaneous dispersion. Soil should therefore not be cultivated when wet.

Penetrometer resistance was good and bulk density was excellent at all three sites.

RAW and TAW were good at all three sites.

EC was poor at site #14 and good at the other two sites. Chloride was very high at site #14 and moderate to high at the other two sites.

The pH was good at all three sites, ranging between 7 and 8. SAR was poor and sodium relatively high at site #14, but was good at sites #12 and #17.

11. Willbriggie clay loam

Location: Whitton and Jerilderie regions.
Site #11.

In the 1996/97 season there were 27 ha of processing tomatoes grown on Willbriggie clay loam, producing an average yield of 90 t/ha under furrow irrigation (TomCHECK 1997).

11.1 Soil profile characteristics of Willbriggie clay loam

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 10	A sharply separated from:	light brown grey	clay loam or light clay	granular to sub-angular blocky		• compact and brittle.
10 to 30	B_1 grades into:	dark brown	medium clay	angular blocky		• hard dry.
30 to 50	B_2 grades into:	brown	heavy clay	angular blocky	slight $CaCO_3$ present	• traces of gypsum with depth.
50 to 130		light brown	heavy clay	angular to sub-angular blocky	soft $CaCO_3$ present	• gypsum crystals present. • friable and soft moist. • moderately hard dry.

Reference: Churchwood and Flint (1956).

11.2 Occurrence

Willbriggie clay loam is one of the gilgaied soils found on the open, almost treeless plains of the southern Riverina. Willbriggie clay loam can occur in both the puff and shelf forms. The surface soil is non-calcareous. Willbriggie clay loam is often found in association with Willbriggie clay. Willbriggie clay loam has a similar profile to the clay form except for a 5 to 10 cm depth of clay loam on the surface and more gypsum at depth. Other soil types found in association with Willbriggie clay loam include co-dominant Coree clay and sub-dominant Wunnumurra and Yooroobla clays.

(Reference: Churchwood and Flint, 1956).

Figure 11. Soil profile for Willbriggie clay loam at site #11.

11.3 Soil physical properties of Willbriggie clay loam (site #11)

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	10	6
Fine sand (%)	24	17
Silt (%)	6	10
Clay (%)	58	67
Air filled porosity (%)	16	1
Organic carbon (%)	1.1	-
Water stable aggregates (% WSA >0.25 mm)	52	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	yes
Mechanically dispersible clay (%)	0.3	4.6
Average penetrometer resistance[1] (MPa)	1.8	-
Maximum penetrometer resistance[1] (MPa)	4.6	-
Bulk density (Mg/m^3)	1.19	1.45
Readily available water (RAW) (mm/m)	45	-
Total available water (TAW) (mm/m)	135	-
pH $_{(CaCl2)}$	5.9	7.8
Electrical conductivity (EC) (dS/m)	0.4	0.4
Sodium absorption ratio (SAR)	1.2	1.5
Sodium (mequiv/kg)	5.6	9.9
Chloride (mg/kg)	14.5	18.3

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

11.4 Comments for Willbriggie clay loam

Site #11 on Willbriggie clay loam was furrow irrigated. In general the topsoil had excellent structure, however there were several problems associated with the subsoil.

Air filled porosity was excellent for the topsoil, but very poor for the subsoil. This would reduce root growth at depth and result in less soil water for the crop, which would in turn necessitate more frequent irrigations.

Willbriggie clay loam had good levels of organic carbon, and the level of %WSA was close to the industry average. Soil aggregates from the subsoil had a tendency to slake and were prone to both spontaneous and mechanical dispersion. The percentage of mechanical dispersible clay was high and therefore considered poor for the subsoil.

Both penetrometer resistance and bulk density were poor for the subsoil. For the topsoil, penetrometer resistance was good and bulk density was excellent.

RAW in the topsoil was good, although as mentioned previously, irrigation problems may arise due to less root growth into the subsoil.

The chemical properties were generally good, except for EC (salinity), which was high (ie poor) at 0 to 15 cm depth. Sodium levels also require careful monitoring, as they were bordering on high in the subsoil.

Willbriggie clay loam is a red brown earth.

12. Wunnumurra clay

Location: Jerilderie and Whitton regions.
Sites #9 and #10.

In the 1996/97 season there were 239 ha of processing tomatoes grown on Wunnumurra clay, producing average yields of 74 t/ha under both drip and furrow irrigation (TomCHECK 1997).

12.1 Soil profile characteristics of Wunnumurra clay

Depth (cm)	Horizon	Colour	Texture	Structure	$CaCO_3$	Comments
0 to 10	A_1 grades into:	yellowish grey to brownish grey	heavy clay	sub-angular blocky	$CaCO_3$ sometimes present.	• sticky wet. • hard dry.
10 to 30	A_2	yellowish grey	heavy clay	strong angular blocky	slight $CaCO_3$	• sticky wet. • hard dry.
30 to 70	B_1	yellow grey	heavy clay	strong angular blocky	slight concretionary $CaCO_3$	• massive. • hard dry.
70 to 100	B_2	yellowish grey	heavy clay	angular blocky		• yellowish grey mottling increasing with depth. • gypsum not present.
100 to 160		yellowish brown	heavy clay	angular blocky		• hard dry. • sticky wet.

Reference: Churchward and Flint (1956).

12.2 Occurrence

Wunnumurra clay is widespread throughout the southern Riverina. Wunnumurra clay is a grey calcareous crumbly soil occurring mostly as the "puff" component of the grey plains and swamps. Wunnumurra clay is found in soil associations consisting of plain and swamp forms. In the plain form, Wunnumurra clay can have from 30 to 100% puff profiles. Generally in the plain form, Wunnumurra clay is co-dominant with Yooroobla clay. Sub-dominant soil types in association with Wunnumurra clay include Willbriggie clay or clay loam and Coree clay or clay loam. Wunnumurra clay in the swamp form occurs as a number of small swamps and gilgai micro-reliefs and is the dominant soil type in association with Wandook clay loam as sub dominant.

(Reference: Churchward and Flint, 1956).

Figure 12. Soil profile for Wunnumurra clay at site #9.

12.3 Soil physical properties of Wunnumurra clay at site #9

SOIL PROPERTY	DEPTH (cm)	
	0-30	30-50
Coarse sand (%)	7	6
Fine sand (%)	19	19
Silt (%)	11	11
Clay (%)	63	64
Air filled porosity (%)	17	2
Organic carbon (%)	0.7	-
Water stable aggregates (%WSA >0.25 mm)	55	-
Aggregates slaked	yes	yes
Aggregates dispersed	no	no
Mechanically dispersible clay (%)	0	0.2
Average penetrometer resistance[1] (MPa)	1.4	-
Maximum penetrometer resistance[1] (MPa)	2.8	-
Bulk density (Mg/m^3)	1.21	1.48
Readily available water (RAW) (mm/m)	40	-
Total available water (TAW) (mm/m)	105	-
pH $_{(CaCl2)}$	5.4	7.2
Electrical conductivity (EC) (dS/m)	0.8	0.3
Sodium absorption ratio (SAR)	0.4	0.5
Sodium (mequiv/kg)	2.9	1.8
Chloride (mg/kg)	24.0	25.2

[1] Penetrometer resistance was measured at 0-45 cm depth at field capacity.

12.4 Comments on Wunnumurra clay

There were two sites monitored on Wunnumurra clay. Sites #9 and #10 produced the second and third highest yielding crops under furrow irrigation in season 1997/98 respectively.

For the topsoil, air filled porosity (AFP) was excellent at site #9 and good for site #10. For the subsoil, both sites had poor AFP values, which tends to suggest that this soil type may be susceptible to waterlogging and requires careful irrigation management.

Organic carbon levels were poor for both sites and need to be increased for long term sustainability. Low levels of organic carbon were reflected in the %WSA, which for site #9 was marginally above and for site #10 below the industry average.

At both sites, Wunnumurra clay was quite resistant to both spontaneous and mechanical dispersion. Penetrometer resistance was good at both sites and bulk density of the topsoil was excellent. Bulk density of the subsoil was much higher than the topsoil at both sites and was poor at site #9.

RAW was good, but slightly below the industry average.

EC (salinity) was poor at site #9 and good at site #10. The pH was inclined to be acid and should be closely monitored in future with perhaps the addition of lime if needed.

APPENDICES

Appendix 1

Most productive soil types in seasons 1995/96 and 1996/97

Tomato yields for all soil types, under drip and furrow irrigation for seasons 1995/96 and 1996/97 are shown below. Only those soil types that had at least 30 hectares of processing tomatoes grown for each season are shown. The data was averaged across both seasons for each soil type listed in the TomCHECK 1997 datafiles.

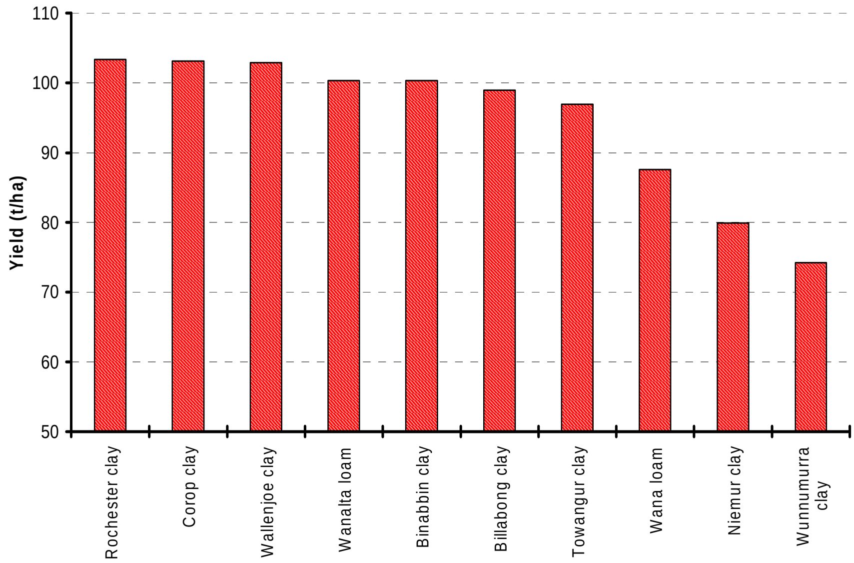


Figure 13. Tomato yields from drip irrigated soil types in seasons 1995/96 and 1996/97.

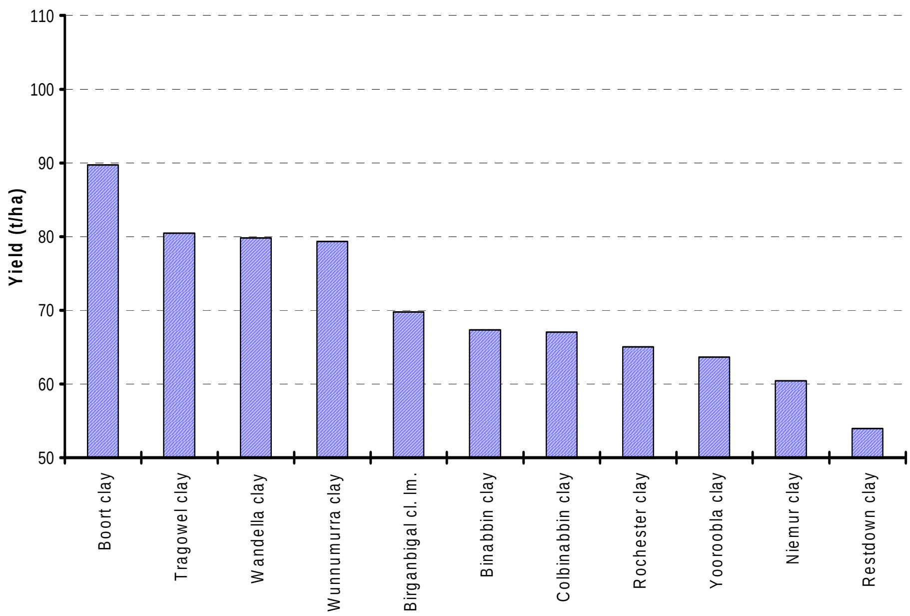
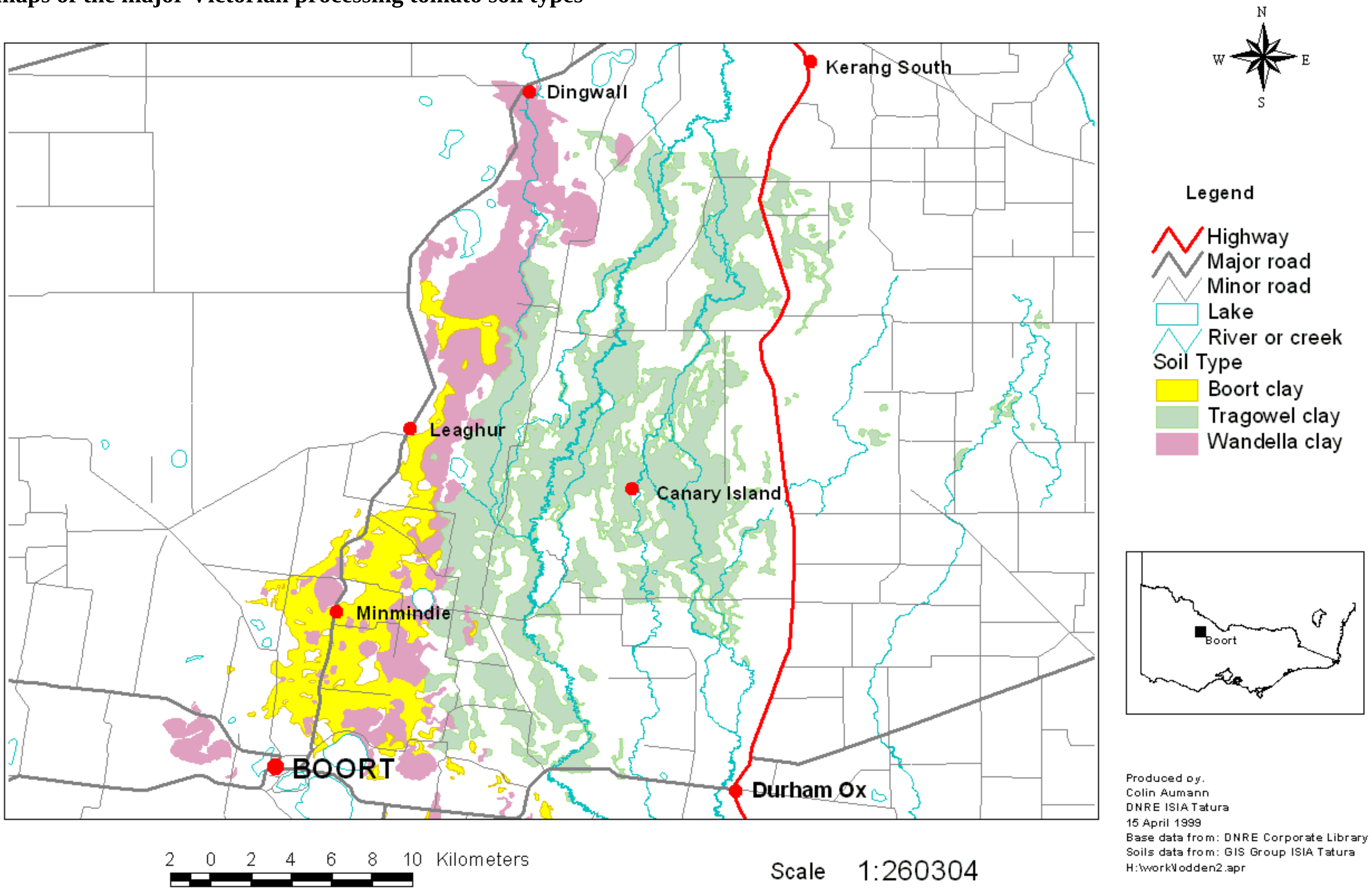


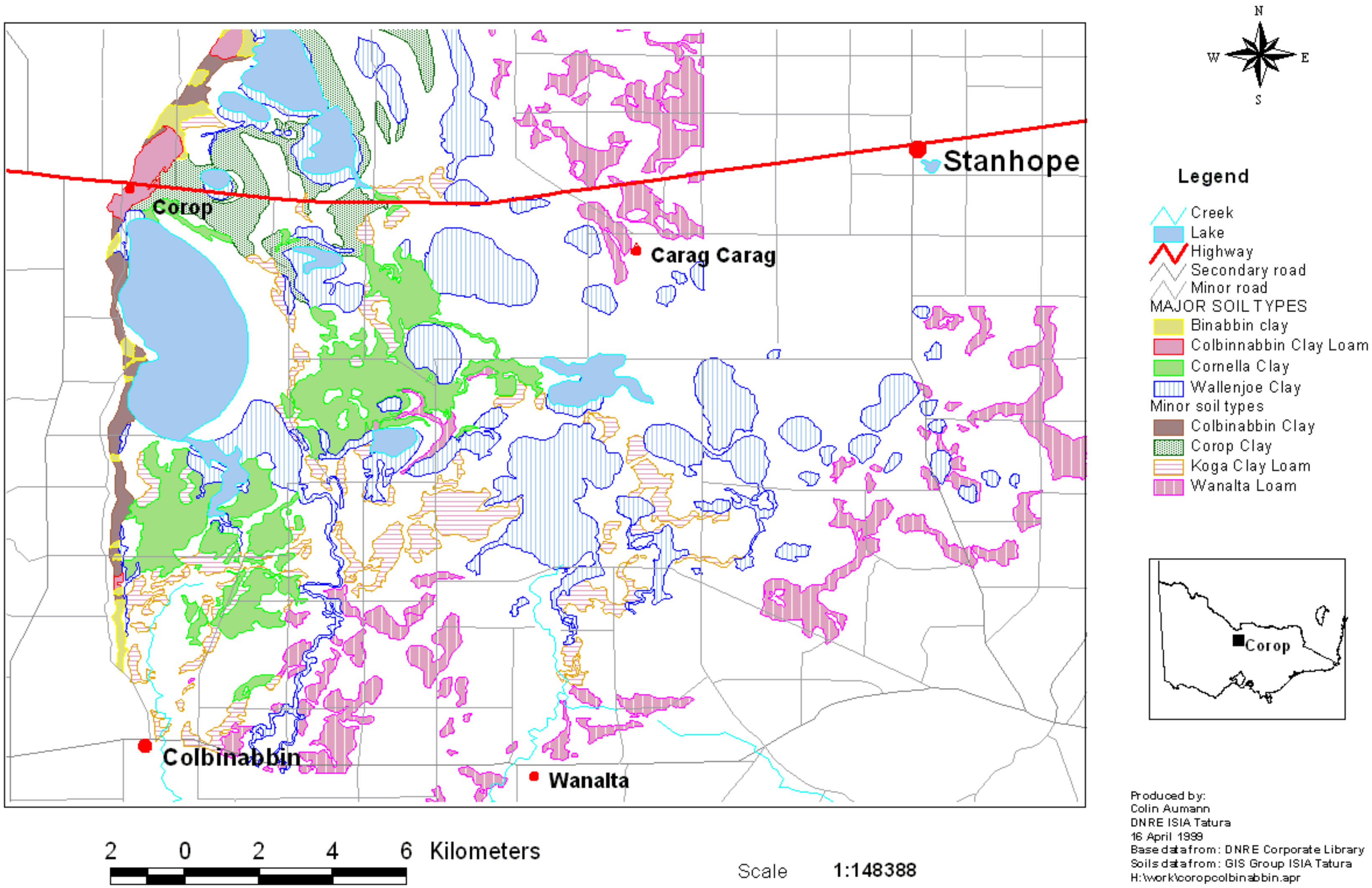
Figure 14. Tomato yields from furrow irrigated soil types in seasons 1995/96 and 1996/97.

Appendix 2

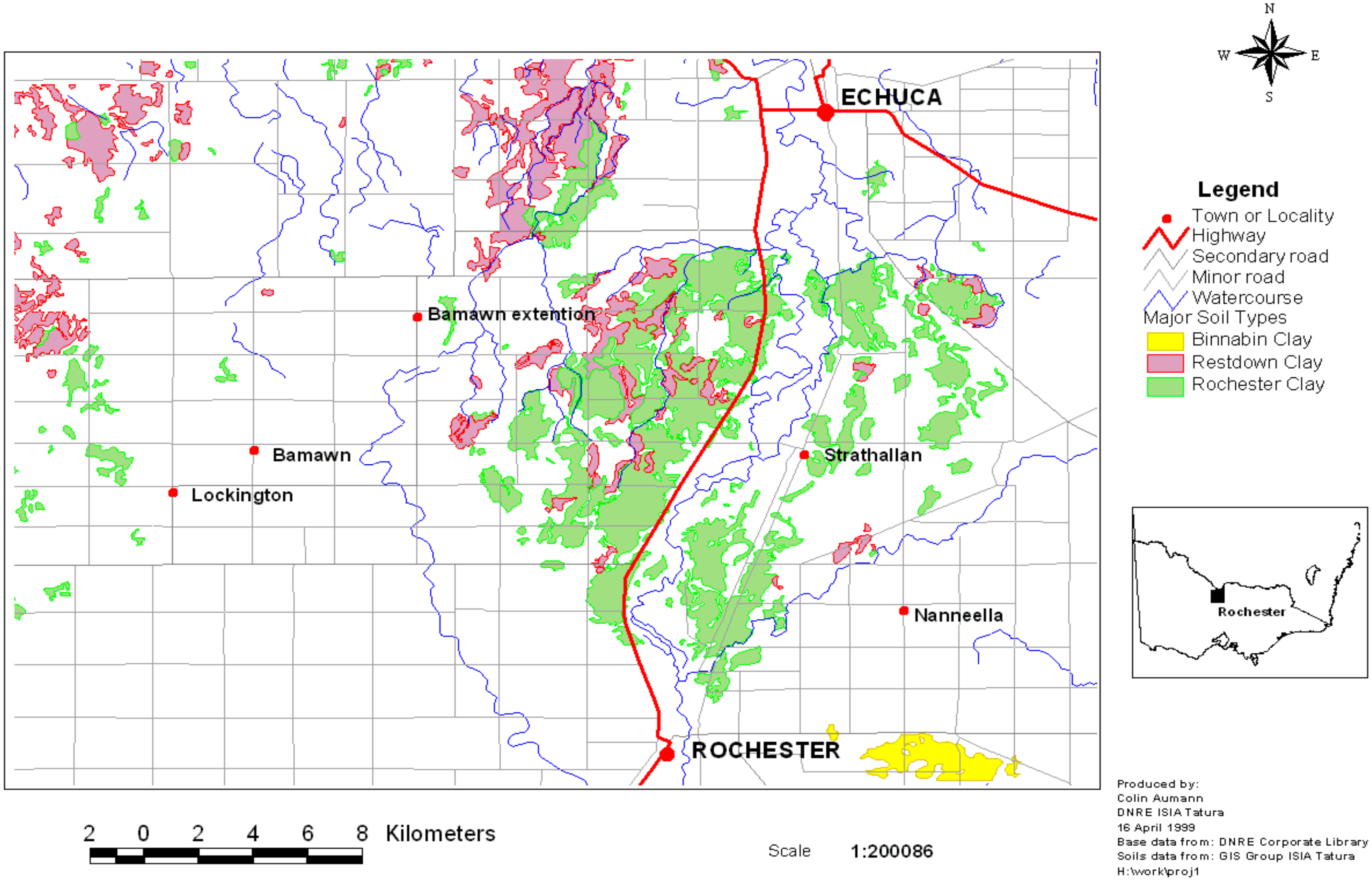
Soil maps of the major Victorian processing tomato soil types



Map 1. Major processing tomato soils near Boort



Map 2. Major processing tomato soils around Corop



Map 3. Major processing tomato soils near Rochester

Appendix 3

GPS location of sites

Site locations are reported using Australian Map Grid (AMG metric) and sites are listed in terms of Grid zone number and Easting and Northing co-ordinates.

Site #	Soil type	Grid zone #	Eastings[1]	Northings[1]
1	Binabbin clay	55	na	na
2	Rochester clay	55	295,629	5,988,945
3	Cornella clay	55	304,815	5,952,630
4	Cornella clay	55	305,084	5,952,621
5	Wallenjoe clay	55	308,009	5,961,267
6	Colbinabbin clay loam	55	300,454	5,951,642
7	Rochester clay	55	294,263	5,986,537
8	Birganbigal clay loam	55	438,427	6,183,174
9	Wunnummurra clay	55	426,224	6,176,011
10	Wunnummurra clay	55	386,014	6,078,024
11	Willbriggie clay loam	55	386,410	6,077,955
12	Wandella clay	54	na	na
13	Tragowel clay	54	754,454	6,015,441
14	Wandella clay	54	751,699	6,014,627
15	Wallenjoe clay	55	308,350	5,958,469
16	Boort clay	54	756,082	6,005,173
17	Wandella clay	54	750,993	6,015,095
18	Restdown clay	55	292,187	5,982,872
19	Binabbin clay	55	296,538	5,971,417
20	Colbinabbin clay loam	55	300,927	5,951,649
21	Cornella clay	55	305,389	5,952,657

[1] na: Co-ordinates not available for sites #1 and #12

Appendix 4

Soil aggregate descriptions

Moist soil aggregates or peds are normally categorised according to their abundance, shape and size. In technical terms peds or soil aggregates are classified by grade (or abundance), shape (or form) and size (or class) in a moist state. In this manual, we have described the structure of peds in terms of their grade and shape.

Grade

The four grades of peds are structureless, weak, moderate and strong.

1. ***Structureless*** means there is no observable aggregation or peds.
2. ***Weak*** means that some peds are visible and when a soil profile is dug less than one third of the profile consists of peds.
3. ***Moderate*** means that peds are clearly visible and when a soil profile is dug between one to two thirds of the soil consists of peds.
4. ***Strong*** means that peds are clearly visible and when a soil profile is dug more than two thirds of the soil consists of peds.

Shape

Ped shape or form refers to the most common shapes used to describe soil structure and have been listed below.

Granular peds

Granular peds are soil aggregates that are mainly found in the topsoil. They are generally sphere shaped and can be classed as either ***crumbs*** when they are of a porous structure, or as ***granules*** when they are non-porous.

Angular blocky ped

Angular blocky peds are cube shaped aggregates that have relatively flat faces. They are often found in the subsoil and their sides or faces are generally mirror images of surrounding peds. The vertices or edges of aggregates are angular, not rounded.

Sub-angular blocky peds

Sub-angular blocky peds consist of aggregates with flat or rounded faces and rounded vertices or edges. The sides or faces of peds generally fit together with the faces of adjacent peds.

Prismatic peds

Prismatic peds are soil aggregates that are generally arranged around a vertical axis. They are mainly flat faced and have sharp edges or vertices. Prismatic peds are mainly found in the B-horizon and can indicate a soil that is susceptible to waterlogging.

Columnar peds

Columnar peds are similar to prismatic peds in that they are also arranged around a vertical axis, but they differ because of a dome shaped top. They are commonly found in the B-horizon and can often indicate high levels of sodium in the subsoil.

Platy peds

Platy peds are generally flat-plate shaped soil aggregates. They have a mainly horizontal plane and are generally found in the lower part of the A-horizon or near the top of the B-horizon when soil becomes compacted.

Size

The average least dimension of peds is used to determine their class size (McDonald *et.al.* 1990). The least dimension refers to the diameter of granular peds; the vertical plane for platy peds, and the horizontal plane for blocky, prismatic and columnar peds. Class ranges for peds up to 100 mm are listed below.

Class number	Size (mm)
1	<2
2	2 to 5
3	5 to 10
4	10 to 20
5	20 to 50
6	50 to 100

Reference: McDonald *et.al.* (1990).

Appendix 5

Commonly used units in soil property descriptions

Measurement	Unit	Symbol	Conversions
Length	metre	m	
	centimetre	cm	0.01 m
	millimetre	mm	0.001 m
Volume	cubic metre	m^3	
	cubic centimetres	cm^3	$\times 10^{-6}$ m
Mass	kilogram	kg	
	gram	g	0.001 kg
	megagram	Mg	1000 kg
	tonne	t	1000 kg
Bulk density	megagrams per cubic metre	Mg/m^3	
	tonne per cubic metre	t/m^3	1 Mg m^3
	grams per cubic centimetre	g/cm^3	1 t/m^3
Pressure or suction	pascal	Pa	
	kilopascal	kPa	1000 Pa
	megapascal	MPa	1000 kPa
	bar	bar	100 kPa
	one metre of water	1 m	9.81 kPa
Soil water	millimetres per metre	mm/m	
	cubic metre per cubic metre	m^3/m^3	1000 mm/m
	millimetres per 10 centremetres	mm/10 cm	0.1 mm/m
Electrical conductivity	deciseimens per metre	dS/m	
	milliseimens per metre	mS/m	0.01 dS/m
	microsiemen per centremeter	µS/cm	0.1 mS/m
Chemical concentration	milliequavalents per kilogram	mequiv/kg	
	millimole of single charge per kg	mmol/kg	mequiv/kg (single charge)
	milliequavalents per 100 gram	mequiv/100g	0.1 mequiv/kg (single charge)
Mass fraction	milligrams per kilogram	mg/kg	
	parts per million	ppm	1 mg/kg

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GLOSSARY

Aggregate. Cluster or group of soil particles held together. See also *Ped*.

Aggregation. Combining of soil particles together to form aggregates.

A horizon. Layer of soil or topsoil distinguished from the subsoil by either a change in colour or texture. The topsoil or A horizon is denoted by the letter A. It can also be subdivided into A_O (denoting a layer of decomposing litter), A_1 (denoting a layer of topsoil containing no colour or texture changes) and A_2 (denoting a bleached layer).

Air filled porosity. The volume of air filled pores within the soil profile at field capacity.

Air porosity. The volume of air within the soil profile. At field capacity it is equivalent to the air filled porosity.

Angular peds. Block-like soil aggregates or peds having six relatively flat equal sized faces and sharp angles or vertices. See also ***Sub-angular peds***.

Apedal. Soil having no aggregation or structure. See also ***Structureless*** and ***Massive***.

Association. Term used to describe a group of soils that follow a common pattern and occur commonly together.

B horizon. Layer of soil or subsoil distinct from the surface soil due to either a change in texture or colour.

Bleached. White or pale section of soil compared to adjacent soil.

Blocky. Six-sided structure of soil aggregates.

Bulk density. The oven dry mass of soil divided by its total volume. In general, as the soil structure declines the bulk density increases.

C horizon. Parent material or weathering rock.

Calcareous. Soil containing an abundance of calcium.

Class. Soil aggregates or peds are assigned to different classes depending on the size of their least dimension.

Clay. Primary soil particle with a diameter less than 0.002 mm. Feels sticky and gives soil a plastic texture when moist.

Clod. An artificially produced soil aggregate, with a diameter of more than 100mm, formed by cultivation.

Coarse fragments. Fragments larger than 2 mm and less than 100mm diameter: for example gravel or stones.

Colour. The hue or colour of soil. Most often determined from a moist sample of soil.

Columnar peds. Soil aggregates or peds with the vertical axis being the longest dimension. Often have dome shaped tops.

Crumb. A soft, porous often rounded soil aggregate.

Dispersion. Separation or breakdown of soil aggregates into primary soil particles (clay, silt or sand components).

Extract. A term used to indicate the removal of some measurable soil property from a soil sample. For example a 1:5 saturated soil water extract means that five parts of water is added to one part of soil, and following shaking for one hour, the solution is removed and can then be measured for pH, EC, Na, etc.

Field capacity. The amount of water that a free draining soil can hold, following two days of drainage after saturation due to irrigation or rainfall.

Form. Expression used to denote the shape of a ped or individual soil aggregate.

Fragment. An artificially produced soil aggregate formed by breaking down of soil across planes of natural weakness to form smaller pieces less than 100mm in diameter. See also *Clod*..

Friable. Term used to indicate a soil that crumbles easily when worked dry or wet.

Gilgai. Term used to describe a soil that shrinks and swells and produces circular or linear depressions surrounded by or adjacent to a raised profile. The depression and raised profile are called "Puff" and "Shelf" profiles, respectively. The puff profile usually contains appreciable amounts of calcium carbonate.

Gleyed. A grey or greenish discolouration of the subsoil due to poor drainage.

Grade. Term used to denote the amount and strength of soil aggregation. There are four grades according to the manner in which they behave when disturbed. See also ***Structureless***, ***Weak***, ***Moderate*** and ***Strong***.

Granular peds. Soil aggregates that are spherical or round shaped. Most often found in topsoil. See also ***Crumbs*** and ***Granules***.

Gravel. Primary soil particles larger than 2 mm diameter.

Gypsum. Calcium sulphate ($CaSO_4.2H_2O$) is applied to improve soil structure by increasing the concentration of calcium ions and reducing the number of clay particles within the soil solution.

Horizon. Layer of soil, usually parallel with the surface. Many soil profiles can be separated into 3 different soil horizons (A, B and C). Soil horizons can be distinguished from one another by either a distinct change in texture, colour or some other property. Different parts of a soil horizon can also be separated by a subscript for example A_1 and A_2. See also ***A, B*** and ***C horizons***.

Inorganic carbon. Carbon compounds found within the soil such as carbonate (CO_3).

Inundation. Subject to flooding.

Micro-relief. The small-scale plane or contour of the land surface.

Massive. Term used to describe a soil profile that has no visible structure and is coherent or solid.

Matric potential. The potential or force that water is held within the soil. Can also indicate how much work or force is required by the plant roots to extract water from the soil.

Moderate. Term used to describe a soil profile in which peds are clearly visible. Following disturbance individual peds or soil aggregates make up between one to two thirds of the soil.

Organic matter. Carbon compounds found within the soil and derived from live or dead organisms. The amount of organic matter in the soil is usually assumed to equal (1.72 × %OOC). See also ***Inorganic carbon***.

Osmosis. The flow of water from a lower to a higher salt concentration.

Oven dried soil. Soil dried in an oven at 105^0C for 24 to 48 hours (until a constant weight is achieved).

Oxidisable organic carbon (%OOC). Carbon derived from a once living organism.

Ped. An individual natural soil aggregate.

Penetrometer. An instrument used to measure soil hardness.

Penetrometer resistance. A measurement of soil hardness and indicator of the resistance it presents to plant root growth.

pH. A measure of the hydrogen activity in soil. The equation used to quantify pH is: -log $[H^+]^{-1}$ where $[H^+]$ is the hydrogen ion concentration. A decrease of one pH unit means a ten-fold increase in H^+ ion concentration.

Plastic. A soil property term used to indicate a soil that can be manipulated or moulded without breaking or cracking.

Platy peds. Flat, plate-shaped soil aggregates that have mainly horizontal faces or edges.

Pores or ***pore space***. The space or void between solid soil particles. Used to conduct air and water through the soil. As pores become smaller or less numerous, both air and water movement is reduced.

Porosity. Expressed as a percentage to indicate the volume of pores within the soil.

Primary soil particle. Clay, silt or sand particles.

Prismatic peds. Soil aggregates that have a long vertical axis and mainly vertical flat-faced sides.

Puff. The mound or raised part of soil within a gilgai complex. See also ***Shelf***.

Readily available water. The amount of water within the soil profile that is available to the plant. Often measured as the amount of water within the soil pores between field capacity and the refill point.

Red brown earth (RBE). A red brown loam or clay loam overlying red or yellow clay.

Refill point. Term used to indicate a thresh-hold or critical value for soil water at which point the next irrigation should commence. Varies with different crops.

Sand. A primary soil particle of 0.2 to 2 mm diameter. Often recorded as fine sand (0.02 to 0.2 mm) and coarse sand (0.2 to 2 mm). Gives soil a gritty feeling when rubbed between the fingers.

Saturation. State of soil when all of the soil pores are filled with water.

Secondary particle. Soil particles formed from a combination of sand, silt, clay and/or organic matter. See also ***Soil aggregate***.

Self-mulching. The ability of the soil to form crumbs or aggregates on the soil surface following wetting and drying cycles.

Shelf. The flat or hollow part of a gilgai complex. See also ***Puff***.

Silt. A primary soil particle of 0.002 to 0.02mm diameter. Gives soil a silky smooth texture when rubbed between the fingers.

Single grained. Term used to describe the structure of a soil profile that has no observable aggregates and is non-coherent or loose. See also ***Structureless*** and ***Massive***.

Slaking. Breaking up of dry soil aggregates into smaller aggregates or primary particles following rapid wetting. Mainly due to the swelling of clay aggregates and the rapid escape of air.

Sodium absorption ratio (SAR). Ratio of sodium relative to calcium and magnesium. High sodium values compared to calcium can result in poor soil structure. SAR can be reduced by the addition of calcium (generally as gypsum).

Soil. A solid matrix of primary and secondary particles, minerals and organic matter.

Soil aggregate. Crumb-like particle found in soil and consisting of a combination of primary and secondary particles.

Soil profile. A vertical section of soil through the different horizons.

Soil water characteristic. Relationship between the soil water content and the matric potential or force with which soil water is held within the soil.

Soil water. The water contained within the soil profile.

Strong. Term used to describe the structure of a soil profile in which there are clearly visible soil aggregates. After disturbance more than two thirds of this soil would be composed of individual soil aggregates or peds.

Structure. The arrangement of soil particles and pore space.

Structureless. Term used to describe soil which has no observable aggregates. See also ***Massive*** and ***Single grained***.

Sub-angular peds. Block-like soil aggregates having either flat or round faces or sides and rounded vertices or edges. See also ***Angular peds***.

Subsoil. Soil below the top0soil. Often assumed to be the B- horizon or the soil below the ploughed or cultivated layer.

Texture. Size distribution of the mineral particles of the soil. Often determined by manipulation of moist soil between the fingers (eg. clay loam, medium clay, heavy clay, etc.).

Total porosity. The proportion of the total soil volume occupied by pores.

Uniform. Term used to describe a soil profile that has little change in colour or texture throughout its depth.

Voids. Spaces or gaps between soil particles. See also ***Pores*** and ***Porosity***.

Vertices. Meeting point of lines that form the angles or the edge of soil aggregates.

Volumetric water content. The volume of water held within the total volume of soil. At saturation point, the volumetric water content is equal to the total porosity (ie all soil pores are filled with water).

Water-stable aggregates (%WSA). Soil aggregates that are stable to wetting.

Weak. Term used to describe a soil structure where some peds are visible. When this soil is disturbed, it will consist of less than one third of individual soil aggregates or peds.

Weathered rock. Parent material or rock that soil is formed from. Often denoted by the letter C or referred to as part of the ***C horizon***.

Notes

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