Supporting the uptake and application of EMI technologies on cotton farms

Collaborative research between the Queensland Department of Natural Resources and Mines and Black Earth Cotton Company (Darling Downs)

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1 Getting soil water from your EM38 readings – developing a soil calibration

EM38's are easy to use geophysical surveying instruments that provide a rapid measure of soil apparent electrical conductivity (ECa). Soil calibrations or qualitative assessments can be used to convert the readings to estimates of soil water in the root zone. This information provides accurate knowledge of soil PAW which is vital for farm management decisions.

How conductive a soil is mostly depends on the clay content of the soil, the type of clay, the porosity, the salinity of the soils pore water and the degree of saturation. There are also other factors that can influence ECa but these are not significant in the context of measuring soil water. Clay soils are better conductors than sandy soils because they naturally hold more water and the pore spaces within the soil are mostly small and water filled. Whereas the pore spaces in sandy soils are mostly large and air filled. Salts in the soil water also increase the conductivity because they turn the water into a conductive electrolyte.

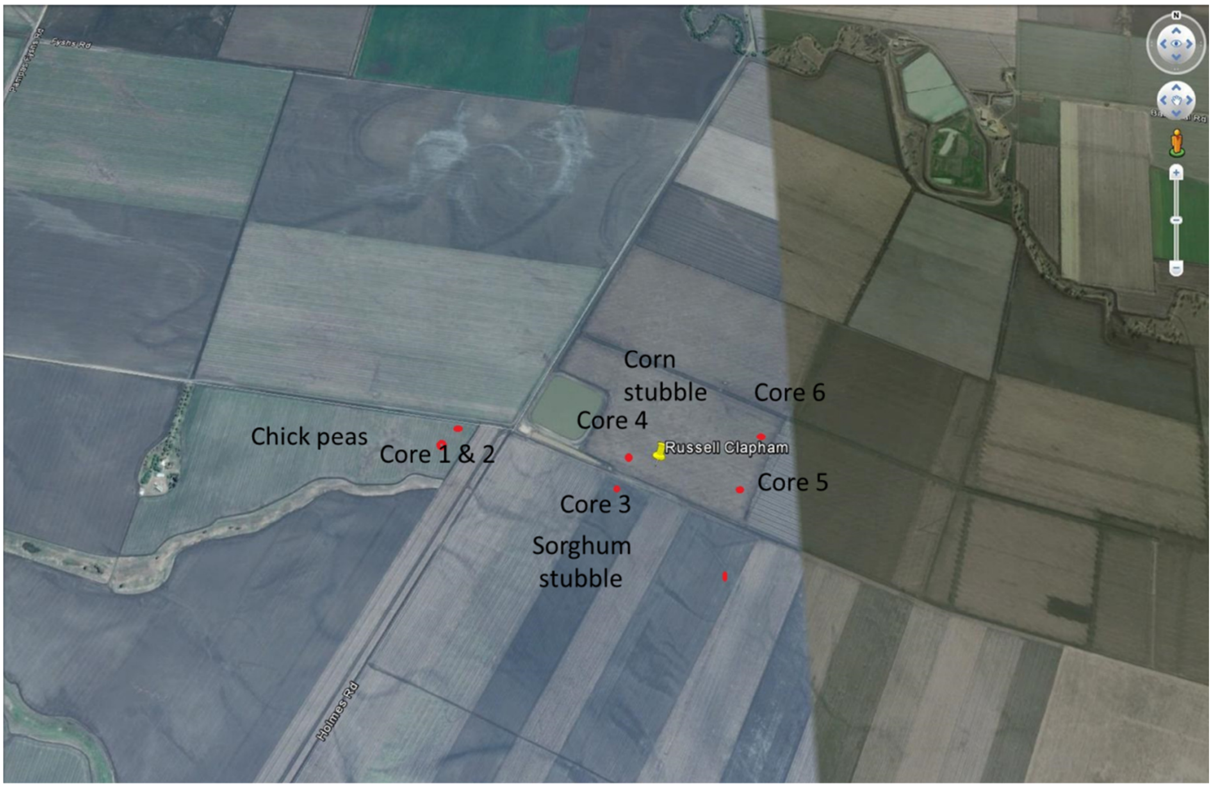
During a growing season or watering cycle the only attribute that will change is the degree of saturation. As the soil becomes saturated the electrical conductivity of the soil will increase (Kelly and Acworth, 2005).

To track water movement and re-distribution throughout a growing season, repeated measures at the same locations within the paddock, with salt and clay remaining constant (unless the quality of the irrigation water significantly alters), allows for any changes in ECa to be attributed to changes in soil water.

ECa readings can be converted to mm of stored water with a 'soil calibration'. This calibration is a simple linear function (straight line) that describes the relationship between ECa and the total mm of soil water in the soil profile. The relationship varies from one soil type to the next in response to changing clay content, soil texture and other properties. A single calibration can be used for each paddock or the whole farm if the soil is reasonably uniform.

1.1 Brookstead soil/paddock calibration

1.1.1 Location



Map 1 Soil sampling locations at Brookstead

1.1.2 Site sampling

To get a soil calibration, EM38 readings and soil cores are taken together. The soil cores are weighed before and after drying. The core length and diameter are also recorded at the time of core sampling. This allows for conversion of gravimetric SWC to volumetric SWC. The volume of water per volume of soil is what the EM38 actually senses and measures.

Sampling at a range of wet to dry paddock conditions provides the best calibration e.g. after irrigation and after harvest. As few as six sampling points gathered across a range of soil moistures may be sufficient to develop a calibration that provides a very good estimate of soil water.

To develop a site/soil specific calibration for the Black Vertosol at Brookstead EM38 readings (ECa, mS/m) were recorded from two EM38's (EM38MK2 – DNRM; EM38 – BECC) at 6 close-by locations shown on Map 1.

Several adjacent paddocks were sampled to get a range of moistures, including a paddock planted to chickpea, and fallow paddocks after sorghum and corn crops (see Photo 1).

After taking EM38 measurements the exact locations were marked and soil cores were collected using a soil coring rig. Duplicate cores were taken to 1.5 m depth at each of the six locations. Cores were sampled in 0.2 m increments for BD and gravimetric SWC (see Photo 2).

Samples were also taken from the duplicate cores for particle size analysis, soil suction (soil water potential) and to estimate PAWC.

Photo 1 Fallows paddocks where soil cores were taken

1.1.3 Ways to measure soil water

There are a number of ways the measure how wet a soil is and describe a soils inherent water holding capacity and they will be used in this report:

1. Gravimetric soil water content (g/g) – gravimetric SWC
2. Volumetric soil water content (v/v) – volumetric SWC
3. Soil suction (or soil water potential) (kPa or Bar)
4. Bulk density (g/cm3) - BD

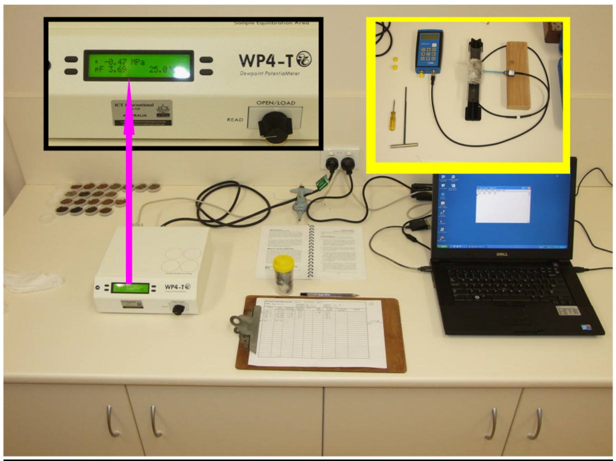
Gravimetric SWC is a measure of the weight of water over the weight of dry soil (grams of water per grams of dry soil). A gravimetric measurement will vary with varying bulk densities of different soils. To be able to compare the water contents of different soils or to calculate a soil water deficit or irrigation requirement, a volumetric measurement is needed.

The volumetric SWC is calculated from the gravimetric SWC by multiplying it by the bulk density (BD). It is the volume of water (cubic cm or mm) per volume of soil (cubic cm or mm).

Photo 2 Sampling methods

Core were sampled for -

a) BD and gravimetric SWC. The BD/water content samples are approximately 20 cm core lengths (length and width of each core accurately recorded) taken either side of the samples to be used for chemistry.



b) chemistry - a series of 5 cm long core sections are sampled and analysed to determine soil texture (particle size analysis) and also the soil water potential and the soil water characteristic (measured using a WP4-T dewpoint potentiometer and UMS T5 mini tensiometers).

The soil suction is a measure of the tension at which the water is held in the soil. As the soil becomes drier, the water is held more tightly and more energy is needed by a plant to extract it. This energy is expressed in kilopascals (kPa) or Bars. Irrigation can be managed to maintain soil water suction within the correct range so that the crop is not stressed. However, trial and error is needed to determine the volume of water to be added.

The soil BD is the weight of dry soil (mineral solids) divided by the total soil volume (the combined volume of solids and pores which contain air and water). It can be used to determine how much water a soil can hold and is a useful indication of a soils physical condition, suitability for root growth and soil permeability. A low BD (<1.5 g/cm3) (Hunt and Gilkes, 1992) is optimal for the movement of air and water through the soil.

1.1.4 Gravimetric/volumetric SWC and BD

The 0.2 m core samples were weighed and dried at 105°C for one week, then re-weighed, to determine gravimetric SWC. The core volume measurements were used to calculate BD and volumetric SWC. The BD measures were also used to estimate the wet end component of the PAW, the drained upper limit (DUL) using the following formula -

Total Porosity (TP) = 1–(BD/2.65)

Soil at saturation (SAT) = TP – entrapped air (~3%)

DUL = SAT – Drainable Porosity (DP)

Drainable Porosity is ~2-5 % for heavy clay soils.

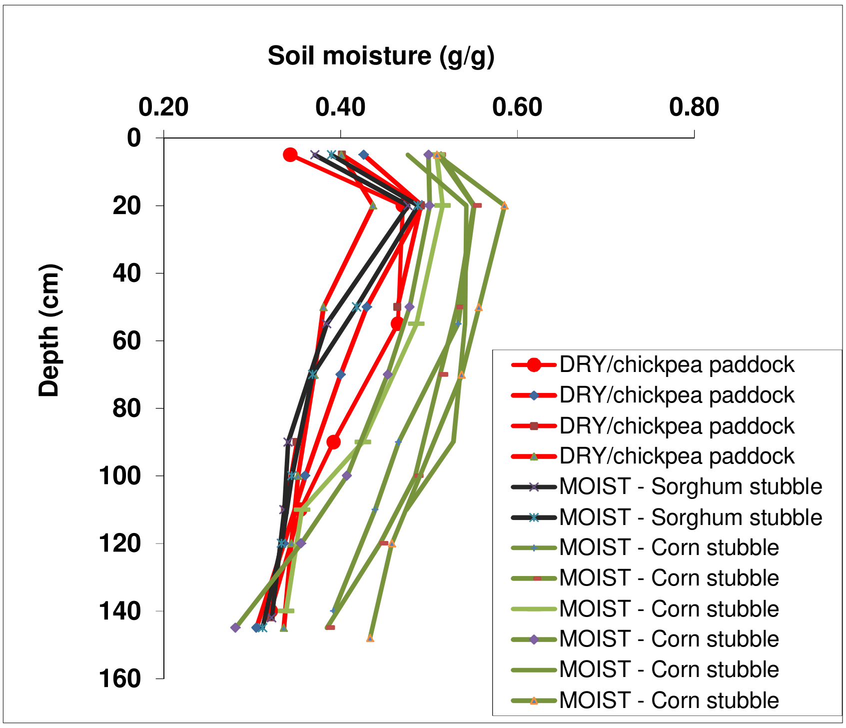


Figure 1 Gravimetric SWC's for the 6 cores taken at Brookstead

Gravimetric SWC for each core is provided in Figure 1. The chickpea paddock and the sorghum stubble paddock have lower gravimetric SWC's at all depths than the corn stubble. However these paddock also had higher BD's (see Figure 3) and so the volumetric SWC's between paddocks was more uniform.

All paddocks were quite 'wet' below 20 cm (Figure 2). The 20-140 cm volumetric SWC's were lower in the chickpea and sorghum stubble paddocks than the corn stubble paddock, due to these paddocks having a higher BD, and therefore lower porosity. The degree of saturation was actually quite similar between the paddocks.

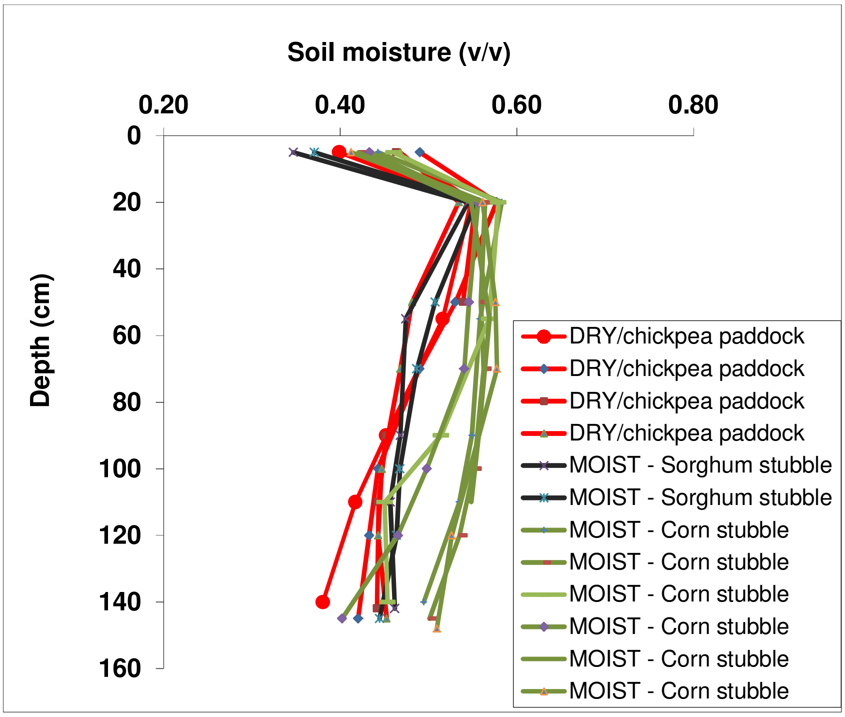


Figure 2 Volumetric SWC's for the 6 cores taken at Brookstead

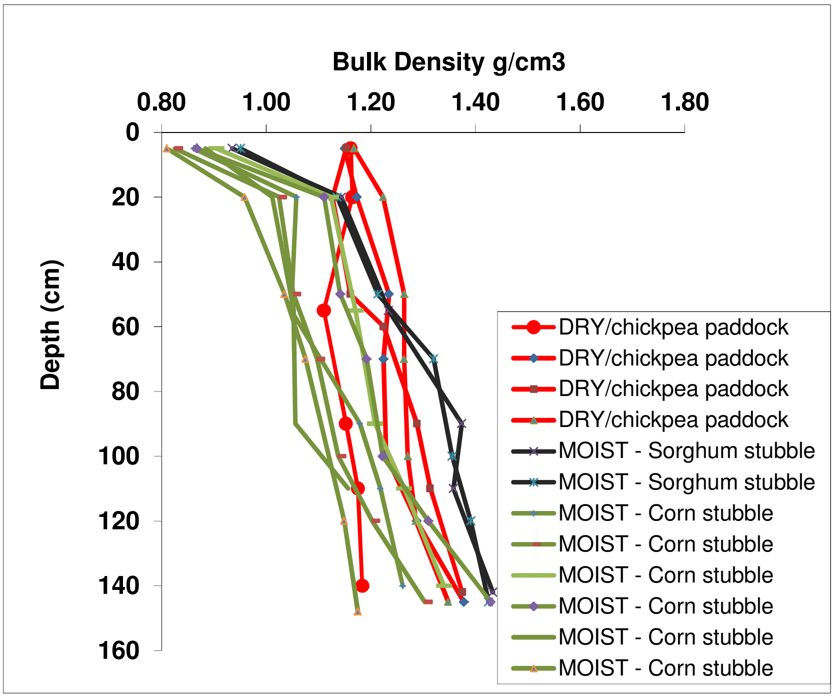


Figure 3 Soil bulk density for the 6 cores taken at Brookstead

1.1.5 Soil water suction and lower limit

The relationship between volumetric water content and suction is called the soil water characteristic or the water retention curve. One of the most accurate and rapid methods for determining this and estimating the theoretical LL15 (15 Bar Lower Limit) is the dewpoint method (Gee et al. 1992; Campbell et al. 2007). This method is used to measure a soil's inherent volumetric SWC-soil suction relationship in the drier range (100-10000 kPa or 1-100 Bar) (Leong et al. 2003; Agus and Schanz 2007).

Wet in-situ samples were measured using UMS mini-tensiometers (see the measured points < 1 Bar in Figure 4). In the method described here, sampling and measurement procedures are designed to obtain a theoretical lower limit from the plotted graph of volumetric SWC against the logarithm of soil suction (Figure 6). LL15 is defined as 15 Bar or 1500 kPa suction. Any desired water content in the drier range can be accurately estimated from this curve.

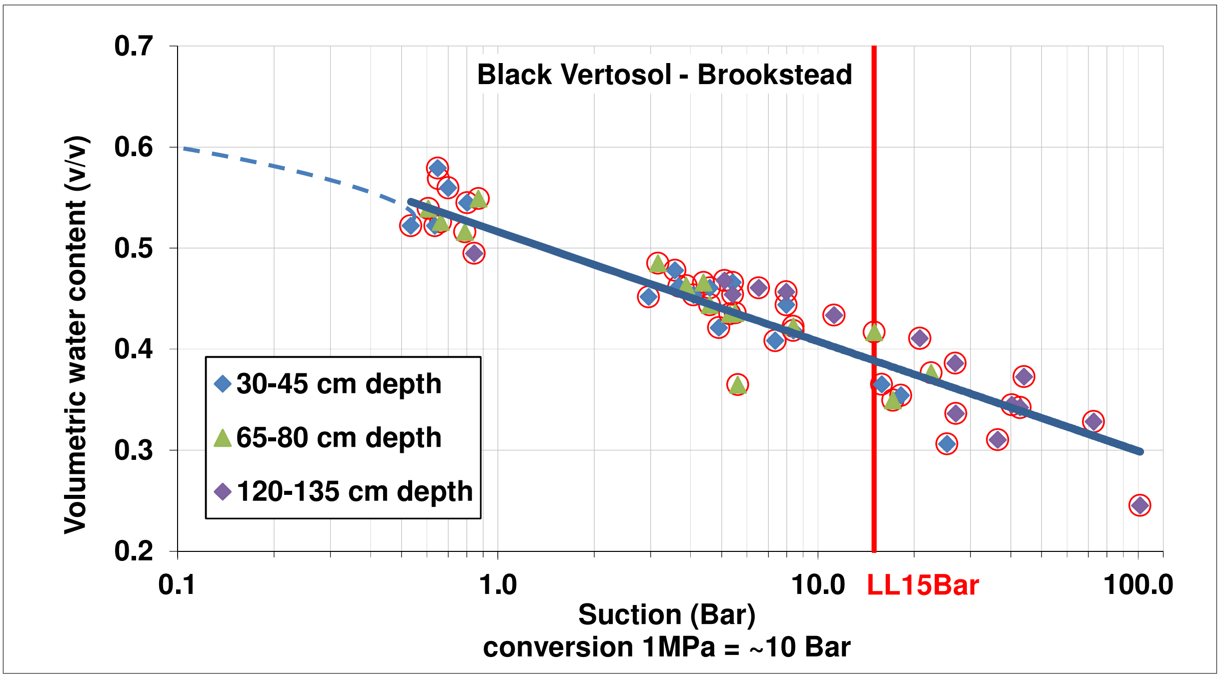


Figure 4 Soil water characteristic curve for a Black Vertosol soil from Brookstead

For this Black Vertosol the predicted LL15 is between 35 – 39%. This is fairly high compared to reported crop LL for wheat, cotton and sorghum on nearby soils (from the APSOIL database). This is probably due to these crops being able to extract soil moisture beyond the LL15 value, i.e. they can dry the soil down to more than 15 Bar suction.

We can now estimate a PAWC for this soil based on a calculated SAT and DUL calculated from data collected in the field and the LL15 derived in the lab (see Figure 5 and Table 1).

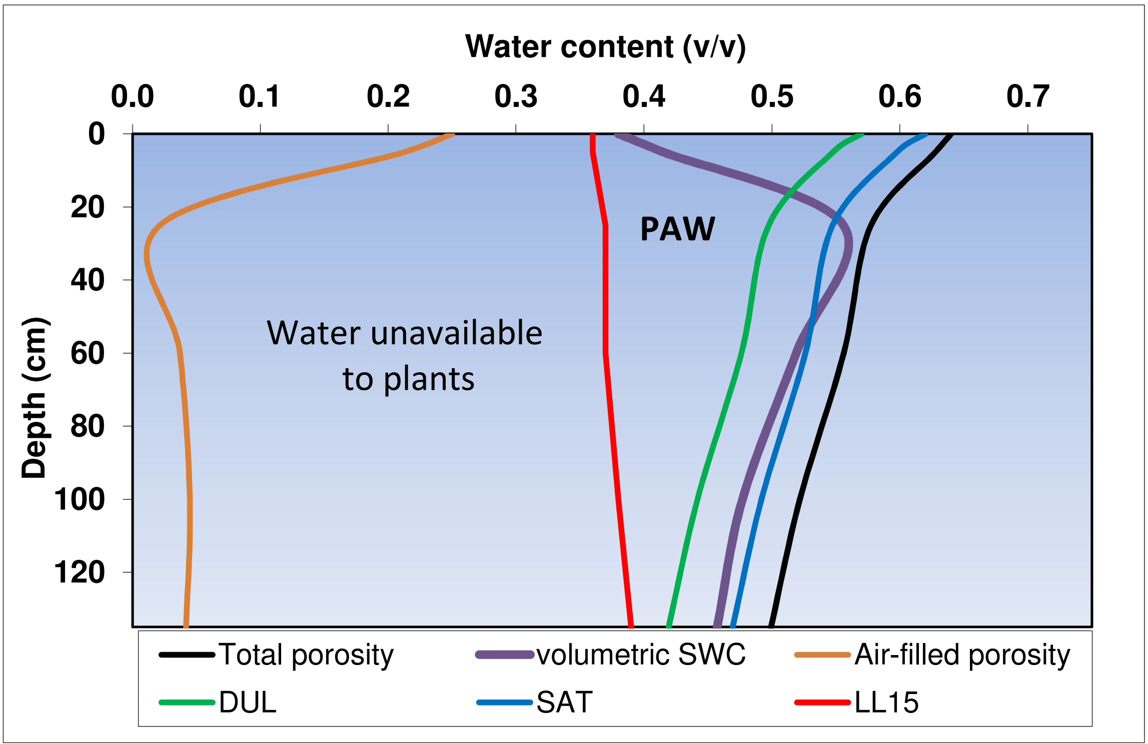


Figure 5 Soil characterisation and PAWC – averaged for the 3 paddocks sampled at Brookstead

Table 1 Estimate of theoretical PAWC

Depth (cm)	Total Porosity %	DUL %	Cumulative mm	PAW (mm)
0-10	64	56	56	21
10-40	58	53	160	55
40-80	59	54	215	75
80-120	53	49	196	40
120-150	51	47	140	23
150-180	50	46	139	22
Theoretical 15 Bar **LL= 35 – 39%**				
PAWC 1 m		**171 mm**		
PAWC 1.5 m		**214 mm**		
PAWC 1.8 m		**236 mm**		

1.1.6 Soil Texture and particle sizes

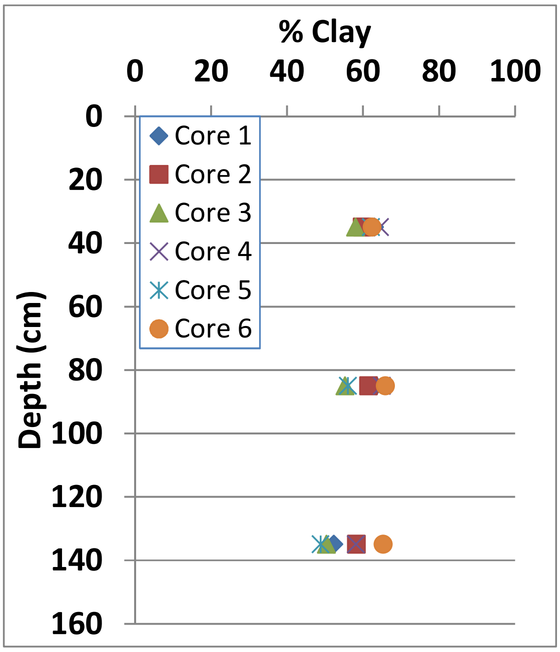
The percentage of soil in each particle size class was determined for soil samples taken every 50 cm down the profile by particle size analysis using the Pipette Method (**Table 2)** (Klute 1986).

Table 2 Particle size fractions for a Black Vertosol soil at Brookstead, Queensland

Soil Core	Depth (cm)	Clay %	Silt %	Sand %
Core 1	30-40	63	27	10
	80-90	64	26	10
	130-140	52	29	19
Core 2	30-40	60	28	12
	80-90	62	26	12
	130-140	58	29	13
Core 3	30-40	58	27	15
	80-90	55	24	21
	130-140	51	28	21
Core 4	30-40	65	25	10
	80-90	65	24	11
	130-140	58	25	17
Core 5	30-40	62	26	12
	80-90	56	30	14
	130-140	49	30	21
Core 6	30-40	62	31	7
	80-90	66	29	5
	130-140	65	28	7

The average particle size analysis for the site is -

- **62% clay 27% silt 11% sand**



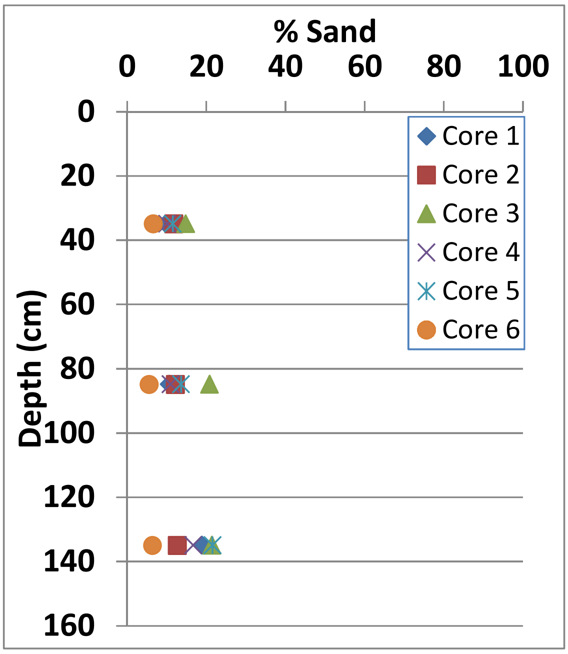


Figure 6 Particle size fractions for the cores sampled - clay % and sand %

Clay was consistent across the six locations at each of the depths sampled (see Figure 6 and Table 2). *This is highly advantageous as it allows a single EM38 soil calibration to be used with confidence across the whole site.* Any variations in ECa readings will be more strongly linked to soil water changes than soil texture variability.

1.1.7 EM38 soil calibration

In the vertical position, the EM38 effectively measures ECa to 1.5 m and in the horizontal position to 0.75 cm. So to get calibration equations for these depths the cumulative mm of soil water are calculated from the volumetric water contents at each depth sampled. A linear calibration curve is then calculated using regression analysis. A good alternative if stats packages are unavailable is to insert a linear trend line to the graphed data in an excel spreadsheet (see Figure 7).

A start was made on developing a soil calibration for this soil. ECa readings for the two EM38's and their corresponding cumulative mm of water are shown in Figure 7.

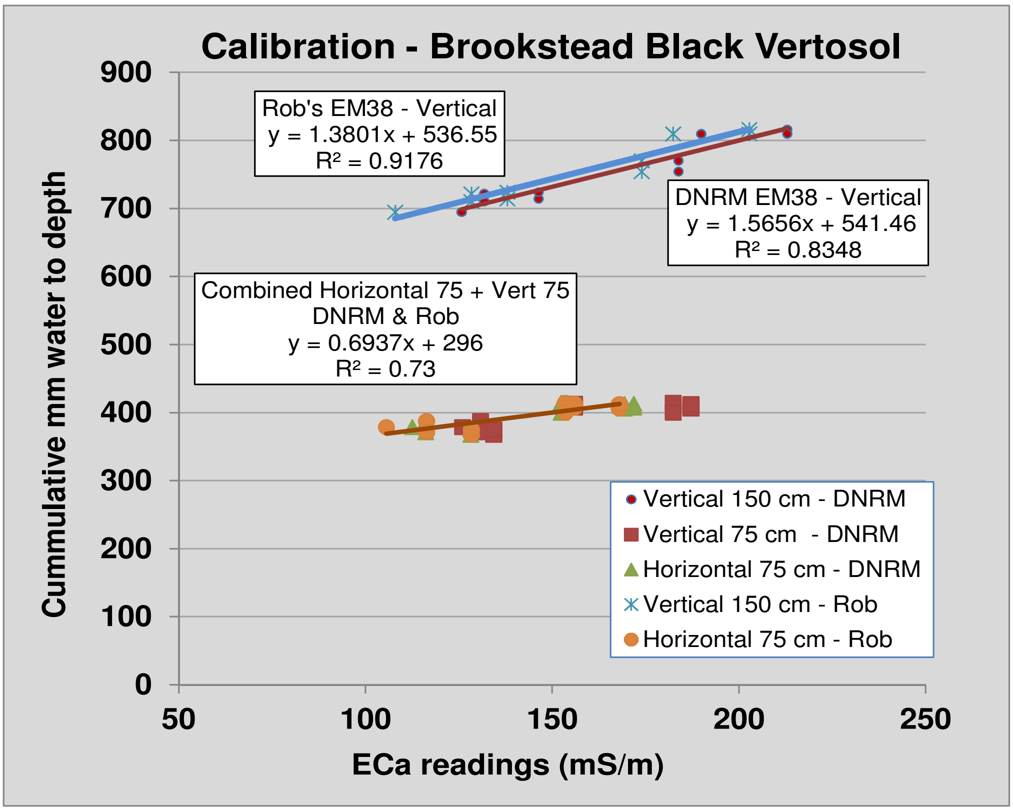


Figure 7 Temperature adjusted EM38 soil calibrations for a Brookstead Black Vertosol

Both EM38's gave very similar readings (except for the 7-10 mS/m machine offset in one dipole - Rob's instrument). Because of the closeness of the readings, a single calibration curve for both instruments could be used. These calibrations are given in Figure 8.

However, the curves are rather 'flat' (small slope values) especially in the horizontal dipole. Compare their shape to the steeper curves derived from nearby Black Vertosols (Pampas and Krieg's property at Brookstead). And because of this, if used, these curves will probably under-predict the true soil water variations occurring in the paddock.

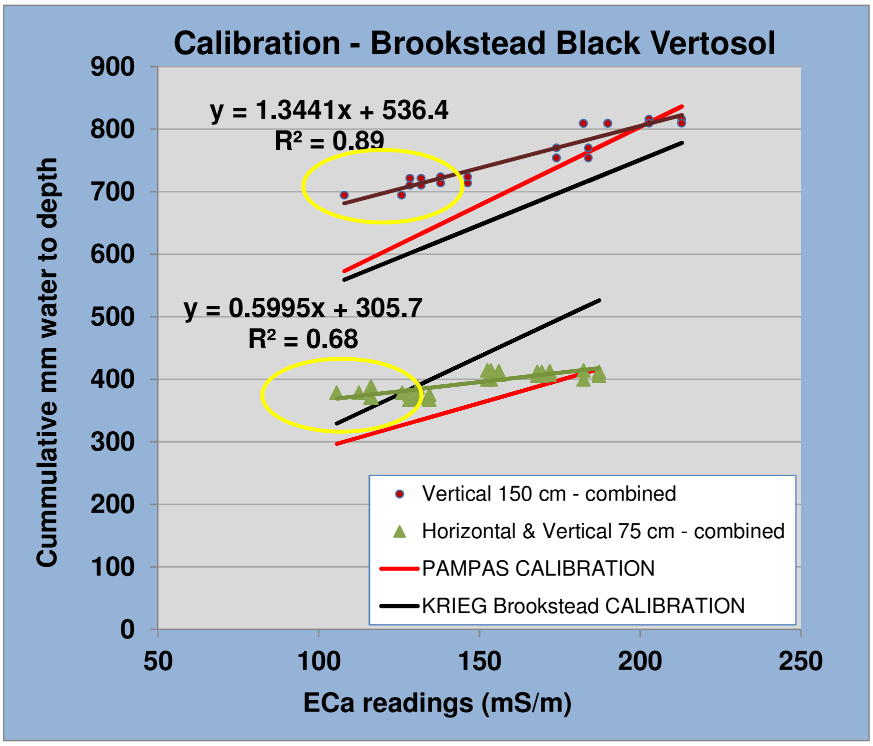


Figure 8 Combined calibration equations for both EM38's (temperature adjusted) Also showing EM38 soil calibrations for two nearby Black Vertosol soils. Yellow circles indicate the points collected at the chickpea site

This slope 'flatness' is because a suitable range of wet to dry soils were not sampled. Note the yellow circles on the graph (Figure 8) around points in the drier range. These 'drier' readings were collected in the chickpea paddock where the surface soil gravimetric SWC's were drier than in the other paddocks. However BD was also much higher in the surface layers of the chickpea paddock and this tended to unify the calculated volumetric SWC's in the surface layers across all the paddocks (see Figure 1 and Figure 2). So no significant moisture variation was measured. The dry surface mostly affected the readings in the horizontal dipole (and to some extent the vertical dipole with 0.5 m coil spacing) because the EM38 is most sensitive to the surface soil in this dipole mode.

It is reasonable to assume that the 'true' calibration curves lie somewhere closer in slope to the Pampas and Krieg calibrations (red and black lines on the graph). And given how different the BD is for the chickpea paddock, these points on the line might ultimately be excluded.

More cores taken when the whole profile is drier (possibly after harvest) will considerably improve this dataset and provide a good soil calibration for this site.

An EM38 soil calibration collected by DNRM for a similar Black Vertosol soil at Pampas is also provided in Figure 9 for your use.

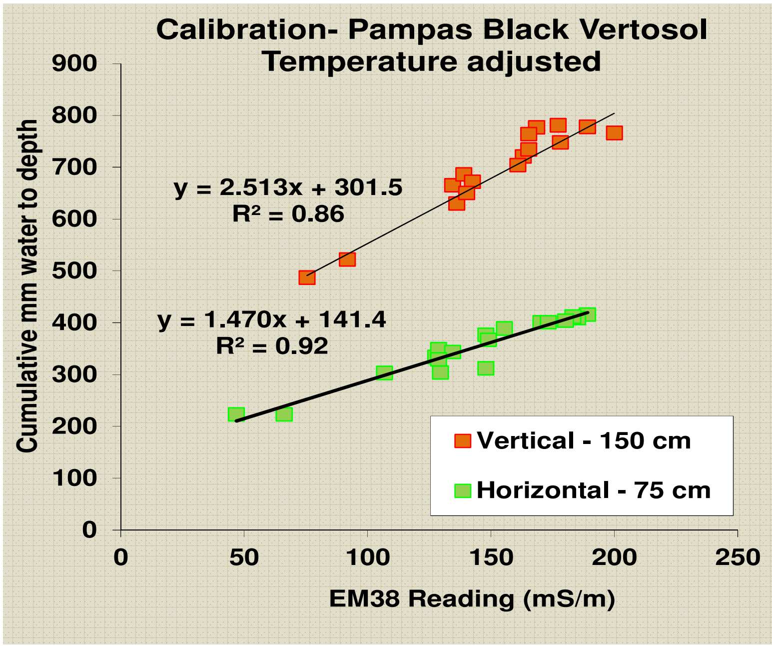


Figure 9 Temperature adjusted EM38 soil calibrations for a Pampas Black Vertosol

1.1.8 References

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