Calibrating and using a *Neutron Moisture Meter* to determine water use by urban trees

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Some background

Neutron moisture meters, NMMs, measure the amount of water in a given volume of soil. The volume of water divided by the total volume of soil is called the *volumetric water content*, VWC, which we express in various ways, such as *m^3 of water per m^3 of soil*, or *mm of water per m-depth of soil*. Measuring the VWC of the soil at different depths over time allows you to calculate how much water a tree uses during the growing season. You can also combine information about the VWC with other information to calculate the total amount of water a soil can store.

Some theory

Neutron moisture meters operate by sending out 'fast' neutrons, $^0\eta_1$, into the soil and then measuring the number of 'slow' neutrons that 'bounce back'. 'Fast' neutrons are slowed down only by large atoms such as H, and water of course is largely composed of this (i.e. H_2O).This means that the higher the count of slow neutrons, the more water there is in the soil.

The count of slow neutrons, called the *count rate*, needs to be normalised for each NMM because the radioactive source in each NMM produces a slightly different quantity of 'fast' neutrons depending upon the amount and age of the radioactive sources in each machine (eg. $^{95}Am_{243}$ & $^4Be_9$). Normalisation also needs to occur for different soils because soils contain different amounts of H and other large atoms that are not related to the amount of H_2O in the soil (e.g. H in organic matter, Cl from salt, B naturally occurring in some subsoils – these do not vary with the soil water content). The normalised count rate is obtained by dividing the *count rate* measured at each point in the soil by a standard *count rate* measured in a large body of water (such as an oil drum full of water) – the ratio of these two readings is called the *relative count rate*, RCR. There is a linear relationship between RCR and the amount of water in the soil, the VWC, according to:

$$VWC = a \times RCR + b$$

where 'a' and 'b' are different constants for each soil type and probe. If the values of 'a' and 'b' are determined carefully and precisely, this equation can produce very accurate estimates of the amount of water in a soil.

Some practicalities

To obtain good values of 'a' and 'b' for your soil and NMM, you need to collect soil samples when the soil is wet and when it is dry to measure the VWC at the same times and location as the measured *count rates*.

The *count rates* in the soil are easy to obtain (see demonstration) and the standard *count rate* in a large drum of water needs to be measured only once in a while to check the stability of the decaying radioactive source ($^{95}Am_{243}$ has a ½-life in the order of hundreds of years). I will provide you with an average standard *count rate* for the NMM used today.

Obtaining good soil samples to calibrate the probe is trickier than you might think, and requires that you collect undisturbed soil samples to measure how much water they contain. Collecting undisturbed soil samples takes some skill and patience because most methods for collecting soil can disturb it considerably and provide useless information.

Once you extract a ‘good’ soil sample you divide it into two parts:

- Weigh one part carefully to obtain its moist and dry weights (dry it in an oven at 105 C overnight) – this information is used to calculate the gravimetric water content, GWC (see table) and to correct the weight of the other part of the soil sample.
- Tie a piece of thread around the other part so that it can be suspended from the thread by hand. Weigh it accurately without losing any bits of soil. You now need to determine the volume of this piece of soil, and this is done by dipping it briefly in molten wax to seal it, then weighing it in air and **<u>again</u>** in water (Archimedes’ Principle) – see table and demonstration.

Location:		Gravimetric water content (g g^{-1})				Bulk density (g cm^{-3})		
Soil horizon	Depth (cm)	Pot #	Weight of pot (g)	Weight of pot + moist soil (g)	Weight of pot + OD soil (g)	Weight of soil in thread (g)	Weight of soil in thread in wax (g)	Weight of soil in thread in wax in water (g)

Calculate the bulk density, BD, of the sample as follows:

$$BD = \frac{D_{water} \text{ x } W_{soil}}{W''_{water} - W_{wax}\frac{D_{water}}{D_{wax}}}$$

W_{soil} = oven dry weight of soil sample = $\frac{W_{moist}}{1+GWC}$, g

GWC = $\frac{W_{moist} - W_{soil}}{W_{soil}}$

W_{moist} = moist weight of soil sample, g

W_{wax} = weight of wax coating the soil sample, g

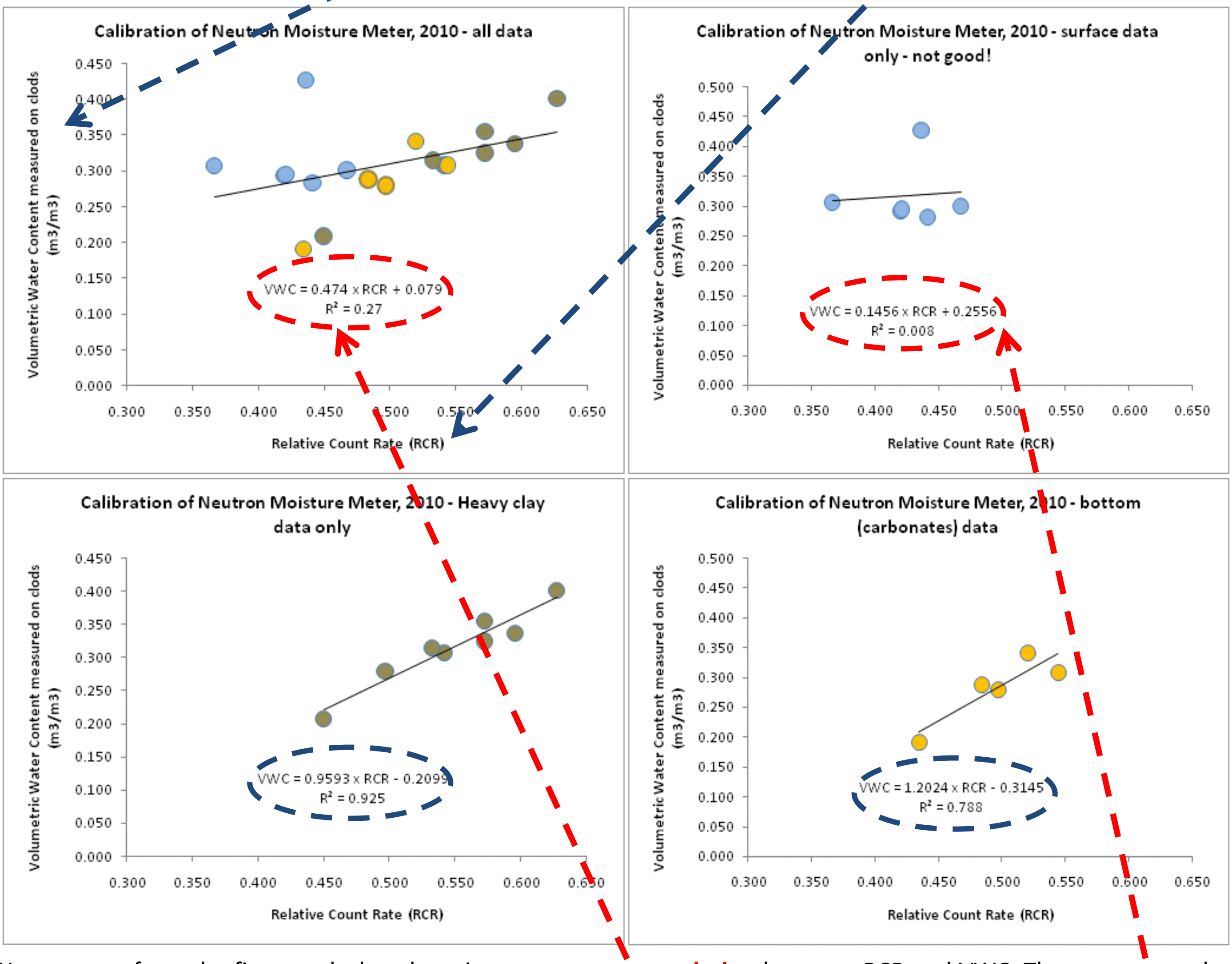
W''_{water} = the apparent increase in the weight of the water in the beaker experienced when the soil core + wax is immersed in it, g

D_{wax} = 0.84 g/cm^3 and D_{water} = 1 g/cm^3

Use the BD and the GWC of each sample to calculate its VWC as follows: VWC = GWC x $\frac{BD}{D_{water}}$

Repeat this procedure with several samples of soil at different water contents at different times of the year. This will allow you to produce a calibration for your probe and your soil as shown in the example in the following page…..

Soil horizon	Depth of your soil sample & Neutron moisture reading	Pot wt, g	Pot + wet soil, g	Pot + dry soil, g	GWC, g/g	Wt soil + thread	Wt soil + thread + wax, g	Apparent increase in wt of water with clod, g	BD of sample g/cm3	VWC, cm3/cm3 or m/m	Mean count rate, soil	Mean count rate, water	RCR
A-dry	20 cm	6.40	13.03	12.05	0.173	40.30	42.20	22.60	1.69	0.293	9569	22786	0.420
B-dry										0.209			0.450
B-moist										0.308			0.451
C-moist										0.308			0.544
A - moist										0.301			0.467
B-moist										0.315			0.533
B-sat										0.401			0.627
C-dry										0.191			0.434
A-moist										0.307			0.366
B-moist										0.355			0.572
C-sat										0.341			0.520
A - dry										0.283			0.441
A – sat'd										0.427			0.436
B-moist										0.337			0.595
B-dry										0.280			0.496
A-moist										0.295			0.421
B-moist										0.325			0.572
C-moist										0.288			0.484



You can see from the first graph that there is a pretty **poor correlation** between RCR and VWC. There are several reasons for this. Firstly, there are three different soil types involved (a shallow, sandy A-horizon in the top 10cm, a thick, clayey B-horizon from 10 to 60 cm, and a carbonate-rich subsoil below that. Secondly, NMM measurements taken within 10 cm of the soil surface tend to be rather inaccurate because the spherical cloud of fast neutrons goes above the ground surface and effectively measures the water content of the air! Hence there is **little correlation** between VWC and RCR! It is therefore better to separate the data for different soils and produce a separate calibration equation for each.

Some advantages and disadvantages of Neutron Moisture Meters

Advantages	Potential disadvantages
Based on solid principals of physics and therefore highly accurate once the neutron probe is calibrated. If something happens to your neutron probe (e.g. electronics breakdown) and you have to use a different probe, you can easily correct the calibration equations by taking a new reading in a barrel of water.	Not useful for detecting sharp wetting fronts because the NMM takes a reading from a large volume of soil, so any sharp changes in water content can be lost through averaging. However, if you are monitoring water use over long periods of time, you are probably not interested in detecting such things.
Neutron access tubes can be left in the ground for many years so you can come back to the exact same location to measure the water content without disturbing the soil.	Because the NMM contains a small (sealed) radioactive source, the EPS requires you to obtain a licence to own and operate NMMs, and special precautions are required when using and transporting the instrument; this requires some time and money, but it's worth it.
The measurements do not take much time – a few seconds.	Calibration is required in most soils, particularly if the soil contains a lot of organic matter, salt or boron.
The sample volume is relatively large (larger than for any other single instrument), and therefore more representative of the true soil water content than measurements taken by other instruments.	NMMs are relatively expensive but can be purchased second hand for < $10,000 and they last a long time (I'm still using a second hand instrument that is 25 years old, and I expect it will still produce neutron in 500 years time….).

Calculating how much water your soil can store

Once you know the bulk density, BD, of the soil down the profile of the soil your trees are growing in, you can estimate the maximum amount of water the soil can hold. Let's say, for example, that you measure the bulk density of the top 100 mm of the soil and find it to be 1.5 g/cm^3 (or 1500 kg/m^3). You can reasonably assume for most soils that the true density of the soil particles, PD, is ~2.6 g/cm^3 (or 2600 kg/m^3), which allows you to calculate the *pore space ratio*, which tells you how much of the total volume of your soil is made up of empty pore-space that can be filled with water:

Pore space ratio = $1-\frac{\text{BD}}{\text{PD}} = 1-\frac{1.5}{2.6} = 0.423$

This means, for this example, that 42.3% of the total soil volume in the top 100 mm is 'pore space', which means you can add 100 mm x 0.423 = 42.3 mm of water in the top 100 mm of soil. You can repeat this procedure for the whole soil profile and sum the amounts to estimate the absolute maximum amount of water your soil profile will hold. An example for a soil having 4 horizons and which contains tree roots down to 1 m depth is shown in the table below.

Soil Horizon	Depth (mm)	BD (g/cm^3) (measured)	PD (g/cm^3) (assumed)	PSR (cm^3/cm^3) (calculated)	Maximum amount of water (mm)
A1 (sandy)	0 to 100	1.45	2.65	0.453	45.3
A2 (loamy)	100 to 500	1.58	2.65	0.404	161.5
B (heavy clay)	500 to 750	1.82	2.65	0.313	78.3
C (carbonates)	750 to 1000	1.63	2.65	0.385	96.2
				Total	381.3

This depth of water can be converted to a total volume of water simply by multiplying the total amount of water (381.3mm or 0.3813 m) by the area in which you wish to store water (e.g. the area between street trees). For example, if the distance between the bitumen road and the concrete footpath in front of a house is 3 m and the distance between the trees (or the distance between driveways) is 20 m, the soil profile should be able to take in approximately 0.3813 m x 3 m x 20 m = 22.9 m^3.

If, for example, you assume 25 mm rain falls during a typical summer thunderstorm in Adelaide and that all the water from a house of say 500 m^2 roof-area is diverted onto the street, this amounts to 12.5 m^3 of water in front of every house on the street. If all this water were somehow re-directed onto the verge around each street tree, it would take only two storms like this to completely saturate the soil profile down to 1m.

Considerations

Diverting all runoff/street water onto tree verges is a good idea if 1) all the water can infiltrate the soil surface and re-distribute itself down the soil profile quickly, and 2) the water is used by actively transpiring trees during summer. Good soil management on the verges could achieve this.

During winter, however, the soil would quickly become saturated under the scenario outlined above because the area of the verge on which we divert the runoff water is considerably smaller than the area of the roofs from which the water is collected. Once the soil is saturated, the rate of water infiltration will decline and all additional water would run off the verges back onto the street again. Furthermore, most street trees are not well suited to saturated soil conditions, so any technology designed to divert street water onto verges would need to be flexible so that saturated conditions do not last very long.

Other instruments for measuring soil water content

There are many instruments on the market for measuring water content of soils, and the ones based on variations in the apparent dielectric constant of the soil with variations in water content are increasingly popular. However, ALL of them need to be calibrated equally as much as the neutron probe. If you have questions about any of these instruments feel free to contact me any time. Alternatively, there are some good local suppliers of water-monitoring technologies, and plenty of reliable advice; two of these are listed below:

Sentek Sensor Technologies: http://www.sentek.com.au/home/default.asp
77 Magill Rd, Stepney SA 5069
Contact: Peter Buss
Ph. (08) 8366 1900
Email: pbuss@sentek.com.au

Irricrop Technologies: http://www.ictinternational.com.au/
P.O Box 503 Armidale, NSW 2350 or 23 McCarthy Cres, Armidale, NSW 2350
Contact: Peter Cull
Ph. (02) 6772 6770
Email: sales@ictinternational.com.au

Soil Water Solutions: http://www.soilwater.com.au/index.html
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