BUREAU OF SUGAR EXPERIMENT STATIONS

QUEENSLAND, AUSTRALIA

TECHNICAL REPORT

EVALUATION OF A ROVING CAPACITANCE PROBE FOR MEASURING SOIL MOISTURE

by

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In the Proserpine area of central Queensland, Australia, trials were conducted to evaluate the performance of a roving capacitance probe for determining soil moisture. Soil moisture was monitored using both a neutron moisture meter (NMM) and a roving capacitance probe on seven different soil types at depths between 0.20 and 1 m. Volumetric soil moisture was also determined from core analysis. While the capacitance probe was more accurate when used with specific site or soil type calibrations, a general calibration was believed to be acceptable for most purposes. The calibration supplied with the sensor produced considerable error. The capacitance probe was quick, cheap and simple to use with a similar level of accuracy to that of the neutron probe. Difficulties with the capacitance probe resulted from poor installation of access tubes, and development of cracks around the access tube in cracking clay soils.

1.0 INTRODUCTION

1.1 Background

A number of non-destructive devices exist for measuring soil moisture, these include time domain reflectrometery, neutron thermalisation, gamma ray attenuation, electrical conductivity and capacitance (Gardner 1994). The neutron moisture meter (NMM) developed in the late 1940's has become the most widely accepted non-destructive device for measuring soil moisture (Ayars *et al,* 1995). The NMM measures soil moisture by counting the number of neutrons reflected from hydrogen atoms in the soil, back to a detector located within an aluminum access tube. Despite their wide acceptance, neutron devices have a number of limitations including:

- poor depth resolution, due to the large scale of influence;
- radioactive source, resulting in difficult license agreements, and costly training of personnel;
- inability to leave the device unattended for automatic recording;
- inaccurate measurements near the soil surface due to 'escaped' neutrons;
- high cost $16,000 (Aug 1997, including software);
- difficulty disposing of used devices. (Ould Mohamed 1997)

Time Domain Reflectrometry and capacitance devices such as the enviroSCAN have been developed as an alternative to the neutron probe. The *in situ* design of these devices limits their mobility so they cannot be used in a similar manner to the neutron probe. Development of roving capacitance probes has been slow considering the limitations of existing technology. The 'Gopher' roving capacitance probe evaluated in this study consisted of a handpad with LCD display and a single three element sensor mounted on a 100 cm staff. The device allowed for soil moisture determination at 0.1 m intervals to 1.0 cm or *in situ* logging of soil moisture at a single depth over time. The handpad allows for direct measurement or logging of soil moisture, calculation of waterbalance and direct entry of calibration information for up to 54 sites.

1.2 Capacitance theory

Capacitance devices measure the dielectric constant of the soil. The dielectric constant is a ratio between the density of an electric flux through a medium and that through air. Given the large difference in dialectic constant between water (ε_{water} = 80) and dry soil (ε_{soil} =2-7), the dialectic constant can be measured to accurately determine soil moisture (Ould Mohamet *et al,* 1997, Soil Moisture Technology 1997). Measuring soil moisture by capacitance is however complicated by soil temperature and the presence of salts in the soil water (Mead *et al,* 1995, Ayers *et al,* 1995). Capacitance devices have additional limitations when operated in the field. These include:

- the small sphere of influence, which varies with soil moisture;
- uncontrolled climate inside the PVC access tube;
- sensor orientation within the pipe;
- non-uniformity of the access tube and wall thickness;
- poor installation in the field resulting in air gaps or changes in density along the pipe. (Paltineanu and Starr 1997, Ayars *et al,* 1995)

2.0 METHODOLOGY

Seven field sites were located in the Proserpine district of the central Queensland coast Sites were established in commercial sugarcane on trash blanketed, first ratoon fields of the variety Q124 (Table 1). At each site, two 1.20 m neutron access tubes and two 1.00 m PVC capacitance tubes were installed over a 3 m length of row, 30 m into the cane. Aluminium access tubes were installed using a mechanically driven 0.45 m pushtube. PVC capacitance tubes were installed using a slightly oversized 0.65 m hand auger. Contact between the tubes and soil was ensured by backfilling with a soil slurry. Neutron Moisture Meter readings were taken every 2-3 days at depths of 0.20, 0.30, 0.40, 0.50, 0.60, 0.80 and 1.00 m. Soil moisture was also recorded using the capacitance probe every 0.1 m to a depth of 1.0 m. Gravimetric soil moisture and bulk density were determined according to Culley (1993) from three 0.50 x 0.73 m diameter cores taken every 0.10 m to a depth of 1.00 m at each site. A number of gravimetric samples were also obtained at different times by auguring samples every 0.10 m to a depth of 1.00 m. The gravimetric moisture content of all samples was determined by drying at 105^0C, for 24 hours and converted to a volumetric basis by multiplication with the bulk density.

Field Site	Soil type	Australian Soil Classification	Irrigation Type	Green/ Burnt	Variety
Orr	Sodic Duplex on Tertiary Sandstone	Grey Sodosol	Furrow	Green	Q124
Hinschen	Gradational Sodic Alluvial Plains	Yellow Sodosol	Furrow	Green	Q124
Telford	Non-Sodic Duplex - Tertiary Sandstone	Yellow Kandosol	Overhead	Green	Q124
Muller	Sodic Duplex on Tertiary Sandstone	Grey Sodosol	Furrow	Green	Q124
Moranino	Cracking Clay - Broad Alluvial Plains	Black Vertosol	Overhead	Green	Q124
Cantamessa	Cracking Clay - Broad Alluvial Plains	Grey Vertosol	Furrow	Burnt	Q124
Prosvegus	Alluvial levees and Terraces – Recent Streams	Leptic Rudosol	Furrow	Green	Q124

Table 1 Field Site Characteristics (Hardy 1998, Isbell 1996)

Measurements with the (NMM) were based on four second counts and calibrated using texture coefficients (McDougall *et al,* 1996). The Gopher probe was calibrated using a linear equation (Eq 1), supplied with the sensor, as texture based calibrations were not available at the time of the trial.

Eq 1: Soil Moisture (%vol) = (69 x counts) + 1582

3.0 RESULTS AND DISCUSSION

3.1 Comparison between capacitance and NMM readings

NMM and capacitance raw data (counts), were divided by the standard count (counts in water) to produce a count ratio for each device. The correlation between capacitance and NMM count ratios is presented for each field site in figure 1. Outlying data at the Prosvegus site occurred at depths below 50 cm as a likely result of stones causing air gaps around the access tubes. Ayars *et al* 1995 report similar findings from a poorly installed access tube, in which the neutron probe measured sizeable changes in soil moisture, while the capacitance probe registered little change. The Cantamessa cracking clay site observed a very poor relationship between the count ratios of the two devices. This may have resulted from shrinkage and the creation of air gaps as the soil dried. Ayars *et al,* 1995 suggests 'that capacitance probes should not be used in cracking soils unless extraordinary measures are taken to correct for cracking'.

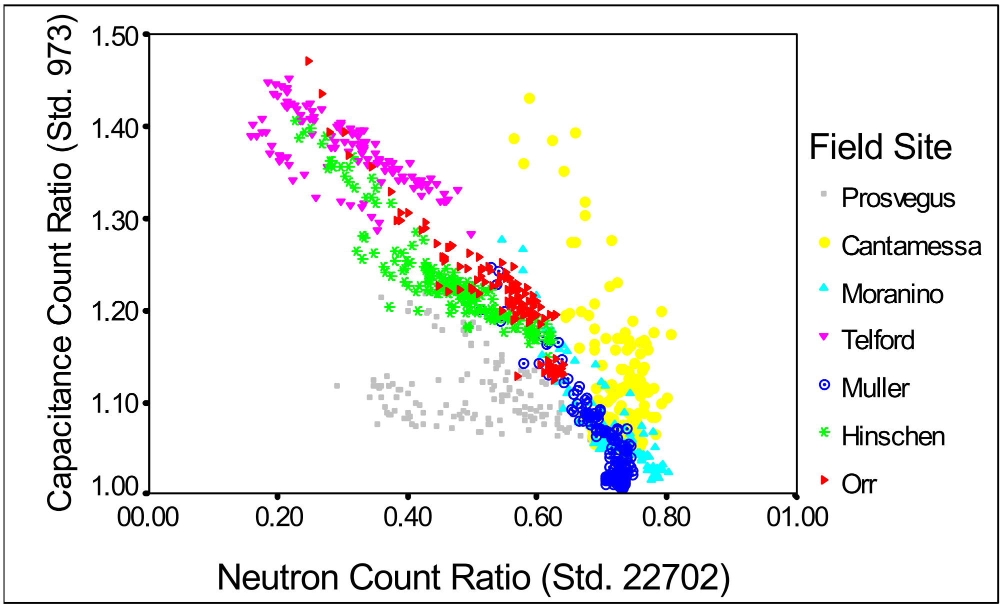

Figure 1 Comparison of neutron and capacitance count ratios by field site

Excluding outlying data from the Cantamessa and Prosvegus sites, the relationship between neutron and capacitance count ratios for the two devices was best described by linear regression (Eq2, Eq3).

Eq 2: Capacitance count ratio = - (0.656 NMM count ratio) + 1.522
Eq 3: NMM count ratio = - (1.247 Capacitance Count Ratio) + 1.995
R2 = 0.82 SE 0.05 Sig. 0.001

3.2 Texture based calibration of the capacitance probe

Analysis indicates similar relationships exist for heavy, light and sandy clay soils, while the sandy clay loams, sandy loams, and sands have a unique relationship between capacitance count ratio and soil moisture (figure 2). Mead *et al,* (1995) states that differences in soil texture and densities necessitate that site specific calibrations be developed for precise calibration of capacitance devices. However our data indicates that use of a single calibration equation for all soil types except sands may be sufficient for applications where specific soil moisture is not required. Calibration coefficients for the capacitance probe are provided on a count ratio basis for each texture class in Table 2.

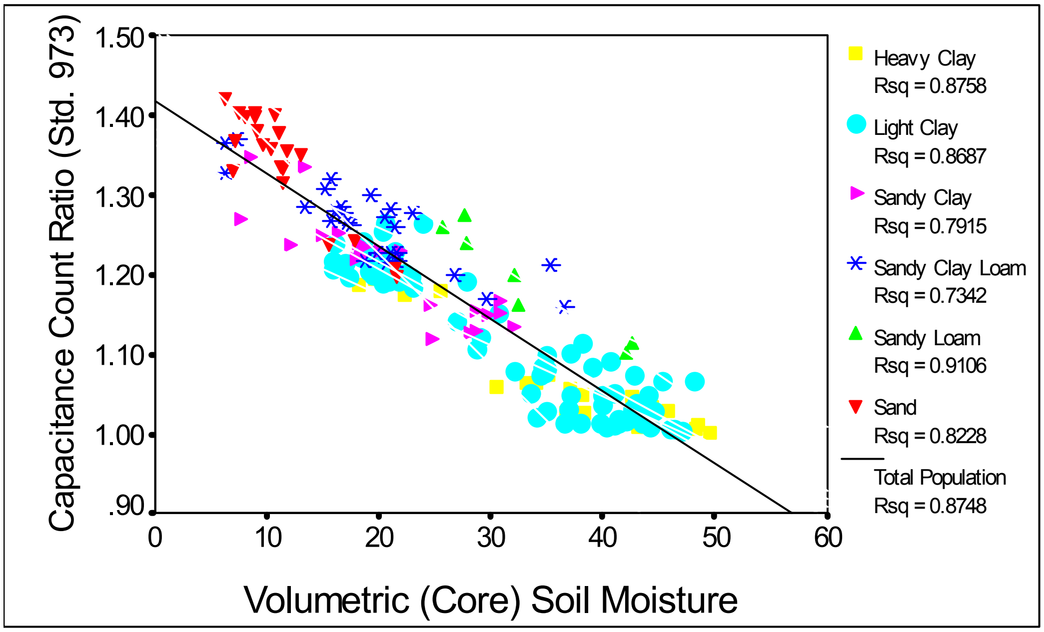

Figure 2 Relationship between capacitance count ratio and soil moisture

	Slope	Intercept	Sample Size	R^2 value	Significance	Moisture Range (%vol)
General						
Supplied Calibration	-44.95	73.208	?	?	?	?
Derived Calibration	-96.33	139.853	174	0.87	0.001	6-50
Texture						
Sand	-58.94	90.715	21	0.82	0.001	6-22
Sandy Loam	-93.86	144.761	6	0.91	0.001	25-43
Sandy Clay Loam	-117.99	168.343	26	0.73	0.001	6-37
Sandy Clay	-102.34	144.795	20	0.79	0.001	7-32
Light Clay	-110.79	155.260	74	0.87	0.001	7-48
Heavy Clay	-136.50	182.549	22	0.88	0.001	18-50

Table 2 Calibration coefficients for the ‘Gopher’ capacitance probe

3.3 Comparison of neutron and capacitance

Regression of NMM count ratio with volumetric soil moisture produced similar or slightly lower R squared values than the capacitance probe (Table 3). Within the limited moisture range of the trial, this analysis indicates the capacitance probe to have similar or slightly greater accuracy than the neutron probe. A small number of studies have compared the performance of *in situ* capacitance and NMM devices. Ould Mohamed *et al,* (1997) concluded that although capacitance calibration is highly sensitive to change in soil structure and texture, the technique proved more accurate for determining soil moisture than the NMM. This was believed to be due to the smaller sphere of influence and higher depth resolution of the capacitance device. Ayers *et al,* (1995) also concluded that a well installed capacitance system can measure changes in soil water as well as the neutron device in non-swelling/shrinking or non-cracking soils.

Soil type	R^2 neutron probe	R^2 capacitance probe
Sand	0.84	0.88
Sandy Loam	0.93	0.87
Sandy Clay Loam	0.66	0.79
Sandy Clay	0.70	0.73
Light Clay	0.85	0.91
Heavy Clay	0.79	0.82
General	0.86	0.87

Table 3 Comparison of the count to soil moisture relationship for the neutron and capacitance probes

3.4 Comparison between the supplied and derived calibrations

The calibration supplied with the capacitance sensor was found to produce considerable error. The supplied calibration tended to overestimate soil moisture at the ‘wet end’ and underestimate soil moisture at the ‘dry end’. (Figure 3)

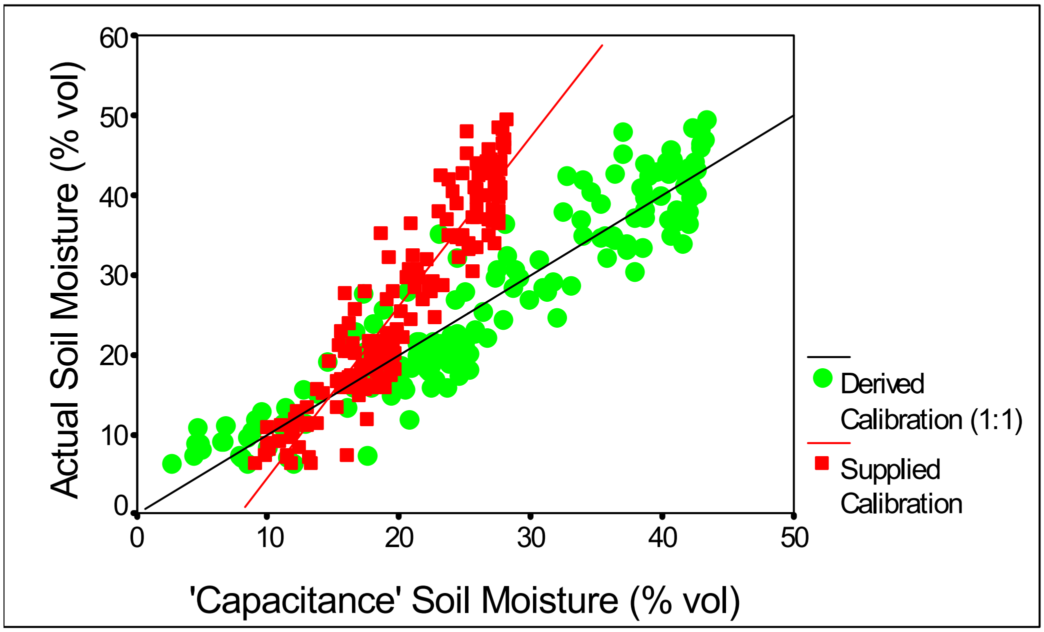

Figure 3 Comparison between the actual volumetric soil moisture determined from core analysis and soil moisture determined from the supplied and derived calibrations

3.5 Installation and operation of the capacitance probe

Capacitance tubes were constructed in accordance with the 'Gopher' Technical Handbook (Soil Moisture Technology 1998) from 50 mm Class 6 James Hardie pressure pipe and a 40 mm PVC Class 18 end cap. The 'Gopher' Technical Handbook suggests that tubes should be installed by augering an oversized hole and repacking the soil around the tube using a small diameter dowel. This approach was not tested as repacked soil is likely to be of different density to the surrounding soil, potentially resulting in erroneous readings. Instead a very slightly oversized hole was hand augered and a soil slurry was poured around the tube to remove air gaps. However tube malformation caused the sensor head to jam inside the access tube at a number of sites. A new internal auger system that removes soil from inside the access tube has been developed to overcome some of these difficulties.

The handpad was found to be suitable for use in the field and not overly affected by rain or rough treatment. Soil moisture was displayed instantaneously, and could be viewed for any depth down the profile or logged every 10 cm for down loading. Data could also be displayed graphically for each profile and for each depth over time. A soil water balance could be calculated from predetermined values of field capacity and saturation. Logging of data with the gopher probe was also found to be considerably quicker than the NMM. Comparison between the operation and cost of the NMM and 'Gopher' capacitance probe is presented in Table 4.

	Capacitance 'Gopher'	NMM
Access tubes	40mm Class 6 PVC $6-8 ea	Aluminium $20-30 ea
Installation	Special hand auger required ~ Air spaces must be excluded from around the tube.	Mounted push rig, or motorised auger
Recording time 0-100cm	45-60 sec (10 readings)	95-120 sec (7 readings, 4 sec count) 175 to 200 sec (7 readings, 16 sec count)
Software	Free with 'Gopher' probe. Windows based	$3,000 - Dos
Training and Licensing	No licensing requirements	Radiation Health and Safety Course Cost $300 - $700 Approval for Storage, Transport and Operation of a Radioactive Device
Manufacture and Service	Victoria, Australia	USA (limited service Sydney)
Approximate Cost	$1,800	$15,000 -$16,000 with software (Aug 1998)

Table 4 Comparison of the 'Gopher' capacitance probe operation and cost with a Neutron Probe (NMM).

4.0 APPLICATION TO THE SUGAR INDUSTRY

Given the cost and difficulties associated with the use of NMM, roving capacitance probes offer a cheap, quick and safe means of determining soil moisture. At present, capacitance probes are viewed with scepticism by the scientific community. This is in part due to the reliability of existing equipment, lack of calibration data and limited comparative studies with other soil moisture devices. The limited results presented in this study indicate the 'Gopher' capacitance probe has similar accuracy to the NMM (using 4 second counts). Assuming the difficulties associated with tube installation can be overcome with new auguring technology, and provided that sound calibrations are available, roving capacitance probes appear to be a suitable alternative to the NMM for research and extension purposes. Given their lower cost and simple operation, capacitance devices also offer growers a simple but accurate tool for determining soil moisture to assist with the scheduling of irrigations.

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Soil Moisture Technology (1998) ‘Gopher’ Technical Handbook. Soil Moisture Technology, Noosaville Qld.

APPENDIX I

CONTACT DETAILS FOR THE GOPHER PROBE

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