NEUTRON MOISTURE METER CALIBRATION EQUATIONS FOR SOIL WATER ASSESSMENT IN THE SUGAR INDUSTRY

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Abstract

Calibration equations to determine volumetric soil moisture using a neutron moisture meter were developed for a range of soils cropped by the sugar industry. Both linear and non-linear calibration equations were developed from a pooled data set of 1128 observations along with individual site calibrations and linear calibrations obtained for six soil textural classes. The accuracy of these equations in determining soil moisture were compared to the general calibration equations supplied with the neutron moisture meter. Both the pooled data set calibration equations and the supplied calibration equations were found to overestimate the relative differences in volumetric soil moisture on light textured soils by up to 11.3% and to underestimate the differences on heavy clays by up to 7.1%. Errors of up to 11.5% volumetric moisture were also found in absolute soil moisture determination using these equations. The calibration equations developed for individual sites were found to produce an average deviation in absolute soil moisture of 1.6% while equations developed using data grouped according to soil texture produced an average deviation from the measured soil moisture of 0.58%. Relative differences in volumetric soil moisture of 0.1-3.0% were found using the individual site calibrations while relative differences of 0.4-1.9% were found using the textural class equations. These results indicate that textural class calibrations may be used instead of individual site calibrations for some NMM applications in the sugar industry.

Keywords: Neutron moisture meter, soil moisture, water, irrigation, calibration

Introduction

The neutron moisture meter (NMM) has been widely used since the early 1950's for the measurement of soil moisture in both research and commercial applications. It has been extensively used as a research tool within the sugar industry over the last ten years and is one of the techniques that is currently being investigated for routine irrigation scheduling applications. It is a rapid and non-destructive technique of monitoring the soil water regime with a high degree of repeatability. However, the necessity of calibrating the NMM for the measurement of soil moisture in individual soils has been widely debated. While factory calibration equations for the NMM are supplied by the Australian distributors (Irricrop Pty Ltd, Narrabri), results from many workers (Rawls and Asmussen, 1973; Lal, 1974; Williams et al, 1981; Chanasyk and McKenzie 1986) suggest that universal linear calibration equations may not be appropriate for many applications and soils. On the other hand, the need for individual calibration equations at each site where the technique is used solely for irrigation scheduling purposes is questionable. This paper reports the results of a study undertaken to identify the necessity for individual site calibration of the NMM and the applicability of universal calibration equations.

Materials and Methods

Data was collected from 26 commercial canegrowing farms located in the Bundaberg, Mackay and Burdekin areas. Sites were selected as representative of the wide range of soils irrigated within the sugar industry and were monitored over the range of soil moistures (4-49%) normally encountered with commercial management. Access tube holes were obtained at each site by hydraulically driving a hollow 49 mm diameter coring tube to a maximum depth of 140 cm. In each case, an aluminium access tube (50 mm diameter) was installed into the sample hole and a sixteen second NMM reading taken using a CPN503 hydroprobe. The NMM count data was converted to a count ratio using the standard count obtained in a water drum. The cores from the access tube holes and up to two additional cores located within 150 mm of the access tube were sampled by cutting into short lengths (either 100 or 200 mm) at depths corresponding to the NMM measuring depths. The moisture content of these samples was then determined gravimetrically by oven-drying at 105°C for three days with the volumetric soil moisture (VSM) calculated from the gravimetric moisture content and the volume of the soil core. In each case, the soil texture of each sample was obtained using the field procedure and textural classes described by McDonald et al. (1990).

Calibration equations relating the count ratio to the VSM were obtained using a non-weighted, least squares regression technique. Linear calibration equations relating count ratio to VSM were obtained for each site, the pooled data set (1128 observations), and for sites grouped according to six soil textural classes (sands, sandy loams, sandy clay loams, sandy clays, light clays and heavy clays). Non-linear regressions were also obtained for the pooled data set. Two sites, containing high levels of gravel, were found to exhibit an outlier character and, in accordance with similar studies (McHenry 1963; Babalola 1978), were excluded from the pooled data analysis. A comparison of regression lines test (Smedecor and Cochran, 1967) was conducted to identify significant differences between textural class regressions and data sets. To compare the accuracy of the various calibration equations in predicting both absolute and relative differences in VSM, the moisture content was obtained using each of the calibration equations (including the equations supplied by the Australian distributor) for three soil classes and a range of field moistures.

Results and Discussion

Significant ($P<0.05$) linear, exponential and logarithmic functions relating count ratio to VSM were found for the pooled data set (Figure 1). The non-linear functions provided slightly better correlations with the standard errors of the count ratio estimates being 0.052, 0.051 and 0.049 for the linear, power and logarithmic regressions, respectively. The error in the predicted VSM calculated using the 95% confidence-limit regressions for these equations and the measured count ratio was approximately 7% for the linear regression. However, for the non-linear functions, the confidence range varies with volumetric moisture. For these functions, the errors in absolute moisture determination ranged from 3% to 10% for the power function and from 2% to 12% for the logarithmic function.

(Insert Figure 1 near here)

The fitted linear regressions for each of the soil textural classes are shown in Figure 2 with the equation parameters given in Table I. Significant ($P<0.05$) linear regressions were identified for each of the textural classes with coefficients of determination ranging from 0.63 to 0.88 and standard errors of the count ratio estimates ranging from 0.037 to 0.066. The standard errors of the count ratio estimates derived using the individual site calibrations ranged from 0.037 to 0.039.

There was no significant ($P<0.05$) difference in the regression functions calculated for the sandy loam, sandy clay loam and the sandy clay textural classes (Table I). However, a significantly ($P<0.05$) larger gradient and smaller intercept was found for the sands compared to the above textural classes while smaller slopes and larger intercepts were found for both the light and heavy clay soils. These differences suggest that substantial errors would occur in the measurement of both absolute and relative differences in VSM where a single universal calibration equation is used. This is confirmed by the results of the investigation into the effect of calibration equation and soil texture on the predicted volumetric soil moisture (Table II). In this analysis, the soil textural class calibrations produced an average deviation in absolute VSM from the measured field value of 0.58% with a maximum deviation of 1.2% while the individual site calibrations produced an average deviation of 1.6% (maximum 4.1%). However, the supplied calibration equations produced an average deviation of 5.4% (maximum 11.5%) while the pooled linear and logarithmic equations produced average deviations of 2.7% (maximum 8.8%) and 1.4% (maximum 2.5%) respectively.

(Insert Tables I and II, and Figure 2 near here)

Substantial differences were also found in the relative soil moisture determined using the supplied calibration equations. The supplied calibration equation overestimated the relative soil moisture difference between the highest and lowest moisture content investigated (Table II) by 6.5% for the sand and underestimated a similar difference by 3.4% and 7.1% for the sandy clay loam and heavy clay soils, respectively. The linear and logarithmic calibration equations derived from the pooled data were found to overestimate the relative difference for the sand and sandy clay loam soils by up to 11.3% and to underestimate the difference for the heavy clay by up to 3.6%. The individual textural class calibration equations overestimated the relative difference in VSM for each soil by between 0.04% and 2.0% while the individual site calibrations underestimated the difference in all cases by between 0.1 and 3.0%.

These results show that substantial errors in both absolute soil moisture and relative differences in soil moisture determination can occur through the use of either the supplied calibrations or generalised universal calibration equations developed from a wide range of soils. If the 6.5% error in determining the relative difference between soil moisture in sandy soils using the supplied calibration was consistent throughout the full 120 cm of a crop's rooting zone, this would represent an error of 78 mm in calculating the depth of water present in the root zone. However, if the soil moisture was determined using the soil textural class calibration, the error would be 9.6 mm and if determined using an individual site calibration would be 1.2 mm. However, where a similar calculation is conducted for the sandy clay loam soil, the error in VSM derived using the textural group calibration would be 4.8 mm compared to an error of 36 mm where an individual site calibration is used. Thus, in some cases, the textural class calibrations may be more accurate at determining VSM than individual site calibrations.

Where the NMM is used for research purposes within the sugar industry, it is suggested that individual calibration equations are developed for each site. This is especially important where the NMM measurements are used to determine the volume of water stored in the crop root zone for either irrigation efficiency or crop water extraction purposes. However, in some cases where a high level of accuracy is not required, the soil textural class calibrations could be considered as a reasonable alternative. For irrigation scheduling under commercial conditions, it is difficult to justify the additional time and cost involved in determining individual site calibrations and a calibration based on the soil's field texture should be used instead of the calibration equations supplied with the instrument.

Conclusions

The supplied calibration equations and single universal calibration equations developed from the pooled data set did not accurately determine either absolute or relative differences in volumetric soil moisture for a wide range of soils within the sugar industry. In general, these equations over-predicted relative differences in soil moisture for light textured soils and under-predicted relative soil moisture differences in heavy clays. Differences of up to 11.5%

were also found in absolute soil moisture determination using these equations. However, the use of either individual site calibrations or calibrations based on the soil textural classes significantly reduced the error in both absolute and relative NMM soil moisture determinations. In general, the slope of these calibration equations were found to decrease, and the intercept to increase, with increasing clay content confirming that a single linear calibration equation is inappropriate for a wide range of soils. However, the use of individual site calibrations did not improve the accuracy of VSM determinations compared to the textural class calibrations for all soils. Hence, for many applications in the sugar industry, the development of individual site calibrations may not be warranted and the determination of soil moisture using the NMM should be undertaken using the soil textural class calibration equations.

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Table I. Calibration equation[A] parameters for the soil textural groups.

Textural group	Slope[B]	Intercept[B]	Std error of estimate	r^2	n	T grouping ($P<0.05$)	Volumetric moisture range
sand	0.0368 (0.0031)	-0.0946 (0.0338)	0.038	0.87	22	a	6.0-15.5
sandy loam	0.0141 (0.0009)	0.1855 (0.0172)	0.066	0.63	155	b	4.1-33.6
sandy clay loam	0.0140 (0.0004)	0.1798 (0.0104)	0.037	0.87	188	b	6.7-39.4
sandy clay	0.0149 (0.0003)	0.1582 (0.0096)	0.043	0.88	168	b	4.5-39.4
light clay	0.0106 (0.0003)	0.2958 (0.0097)	0.046	0.78	337	c	6.8-44.8
heavy clay	0.0092 (0.0004)	0.3630 (0.0148)	0.039	0.71	184	d	19.8-49.9

[A] Count ratio = slope * volumetric moisture (%) + intercept

[B] Standard error of the predicted value given in brackets

Table II. A comparison of the volumetric moisture estimates obtained using a range of calibration equations for selected field moistures and three soil textural classes.

Calibration equation	Volumetric soil moisture (%)								
	sand			sandy clay loam			heavy clay		
Field measured	7.7	10.1	12.9	18.3	25.2	32.6	27.6	32.4	43.9
Supplied with instrument	12.7	17.6	24.4	25	31.6	35.9	34.6	37.5	43.8
Pooled (linear)	-1.1	5.9	15.4	16.6	25.9	32.0	30.2	34.3	42.8
Pooled (natural log)	7.2	9.8	15	15.8	23.8	31.2	28.9	34.6	42.6
Textural class	7.7	10.3	13.7	17.5	26.4	32.2	26.5	34.4	44.7
Individual sites	8.1	10.2	13.2	19.9	23.9	31.2	31.7	34.5	47.2

Figure titles

Figure 1. Calibration equations relating count ratio measured with a CPN503 hydroprobe and volumetric soil moisture for a range of soils cropped in the sugar industry.

Figure 2. Linear calibration equations for each of the soil textural classes (1=sand; 2= sandy loam; 3=sandy clay loam; 4=sandy clay; 5=light clay; 6=heavy clay)