3.1 The Determination of Soil Moisture Content and Field Bulk Density Using Neutron and Gamma Probes

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INTRODUCTION

Neutron probes are extensively used for determining soil moisture content in the field (Haverkamp et al. 1984; Chanasyk and Naeth 1988). The principle behind this method is the relationship between soil water content and the themalization of fast neutrons. Thermalization of neutrons occurs as the energy of the fast neutrons is slowed by collisions with atomic nuclei to the level of the thermal energy of atoms in a substance at room temperature (Gardner 1976). The thermalization of the neutrons is most efficient when the colliding particles are of equal mass as in the case of hydrogen, so that fast neutrons become thermal neutrons after only 18 collisions with hydrogen nuclei (Long and French 1967). When a source of fast neutrons is lowered into a moist soil, it becomes surrounded by a cloud of thermal neutrons, as a result of numerous collisions with hydrogen in water molecules. If the source is lowered into a dry soil, the neutrons must travel farther in order to become thermalized, causing the cloud of thermal neutrons to be of lower density. Thermal neutron density is measured with a detector which is insensitive to fast neutrons (Gardner 1976). The absence of charge and the small energy of thermal neutrons enables easy penetration of and absorption by suitable atomic nuclei, and the consequent nuclear reactions produce ionization that can be measured with detector tubes, such as Boron-Trifluoride (Long and French 1967). The density of the thermal neutrons can be calibrated against water concentration on a volume basis. Usually a source of high energy neutrons and a detector are lowered into the soil using aluminum access tubes, which allow for in-situ soil moisture determination on a regular basis.

Gamma radiation through soil has been used to measure the field density of a soil. The degree to which a beam of gamma rays is attenuated in passing through a soil depends on the density of the soil. The use of gamma probes for measuring soil density includes transmission apparatus and scattering apparatus. The density measurement by the backscattering method uses a cesium source and a detector tube. Gamma rays are radiated into the soil from a ^{137}Cs source contained in the lower end of the probe, and a detector, placed in the upper end of the probe, detects the scattered gamma rays from the material near the probe. The detection rate is a function of the reciprocal of the wet density of the material. The backscattering of the gamma rays can be calibrated against the wet (field) density of the soil measured by gravimetric analysis. For the determination of dry bulk density, soil moisture content (v/v) must be measured separately and be subtracted from the field bulk density obtained with the gamma probe.

This report deals with the calibration of the neutron probes and of the gamma probe that are being used to determine field soil moisture and density conditions by staff of the Saskatchewan Institute of Pedology.

MATERIALS AND METHODS

The neutron probes for measuring soil moisture content include five Troxler probes and one CPN probe. The source of fast neutrons is ^{241}Am/Be and the measurement of thermal neutrons is done with a BF_3 detector tube. Calibration of the neutron probes involved gravimetric sampling, inserting the probe into the previously sampled soil (access tube lowered into the corer hole), and recording the thermal neutron count at the corresponding depth increments. The counts are divided by the standard counts (count of thermal neutrons when the probes are shielded inside their containers), resulting in a ratio count. The ratio counts are calibrated against the corresponding volumetric soil moisture contents from gravimetric analysis.

The gamma probe for measuring field bulk density is a CPN probe. The source of the gamma radiation is ^{137}Cs and the backscattering of radiation is detected with a Geiger-Mueller detector tube. The calibration of the gamma probe for measuring field bulk density is done using ratio counts (count in the soil/count in shielded container) and the corresponding calculated field bulk density values from gravimetric analysis.

RESULTS AND DISCUSSION

The general operation of the newer Troxler probes is simple and convenient. However, the durability of this equipment in the field is very poor, as indicated by considerable "down time" of these units in the past five years. The main problem with these Troxler units (as indicated by technicians that have repaired these units) is that they are not dust or shock proof. Rough handling by field crews has resulted in a variety of problems, including damage to the electrical connections in the main cable for lowering the source and detector into the soil. Another problem that results in probe malfunction is when the source becomes wet (i.e. water in the access tube). The older Troxler probe "Old blue" (Troxler #389) has excellent durability in the field, but is less convenient to use because it is heavier and bulkier than the newer units. The CPN probe so far has shown good durability in the field. However, the CPN probe is quite heavy because it includes shielding material for gamma radiation, as it measures both soil moisture and field density.

The neutron probes require very little warm-up time. However, it is always a good practice to take 6 to 10 standard counts before a series of readings are taken. The standard counts should stabilize to within 5% of the mean before soil reading are taken. The CPN probe, however, does need considerable warm-up time. An unexperienced operator of this unit may not be aware of this problem and record differences in soil moisture content and density that are not real. The operator should be aware of a "ball-park" standard count for either moisture or density readings, and proceed only when this count has been reached.

The calibration of the neutron probes and the CPN probe in 1990 showed good relationships between volumetric soil moisture contents and the ratio counts (Tables 3.1.1 and 3.1.2; Figs. 3.1.1, 3.1.2 and 3.1.3).The slopes of the regression equations in Table 3.1.1 appear similar from year-to-year. However, for some of the probes there are

Table 3.1.1 Calibration of neutron probes for measuring volumetric soil moisture content

Probe	Date	Regression equation	R^2 value
		Soil moisture content	
Troxler #389	Spring 1982	Y= -0.040 + 0.411 R	
	Fall 1989	Y= 0.036 + 0.404 R	0.93
	Spring 1990	Y= -0.012 + 0.400 R	0.86
Troxler # 1086	Fall 1987	Y= -0.020 + 0.488 R	
	Spring 1988	Y= -0.023 + 0.547 R	0.87
	Spring 1990	Y= 0.006 + 0.538 R	0.91
Troxler # 4701	Spring 1982	Y= -0.049 + 0.596 R	
	Fall 1982	Y= -0.044 + 0.572 R	
	Spring 1990	Y= 0.017 + 0.559 R	0.95
Troxler # 4703	Spring 1982	Y= -0.044 + 0.587 R	
	Fall 1982	Y= -0.043 + 0.584 R	
	Spring 1988	Y= -0.017 + 0.618 R	0.77
	Fall 1989	Y= -0.011 + 0.496 R	0.80
	Spring 1990	Y= 0.012 + 0.534 R	0.93
Troxler # 4922	Spring 1982	Y= -0.044 + 0.587 R	
	Fall 1982	Y= -0.034 + 0.559 R	
	Fall 1989	Y= 0.012 + 0.527 R	0.89
	Spring 1990	Y= 0.024 + 0.531 R	0.91
Chicago/Matador #349	Fall 1986	Y= 0.003 + 0.190 R	0.82
	Spring 1988	Y= -0.013 + 0.206 R	0.93
CPN 501	Fall 1987	Y= -0.504 + 1.105 R	0.81
	Spring 1988	Y= -0.459 + 0.948 R	0.82
	Spring 1990	Y= -0.747 + 1.214 R	0.78

Y = volumetric soil moisture content , R = ratio count

Table 3.1.2 Calibration of gamma probes for measuring field bulk density

Probe	Date	Regression equation	R^2 value
		Field bulk density	
Chicago/Matador #349	Fall 1986	Y= 2.418 - 0.741 R	0.42
	Spring 1988	Y= 2.648 - 1.034 R	0.51
CPN 501	Fall 1987	Y= 3.092 - 0.550 R	0.69
	Spring 1988	Y= 3.151 - 0.594 R	0.67
	Spring 1990	Y= 3.206 - 0.567 R	0.72

Y = field bulk density, R = ratio count

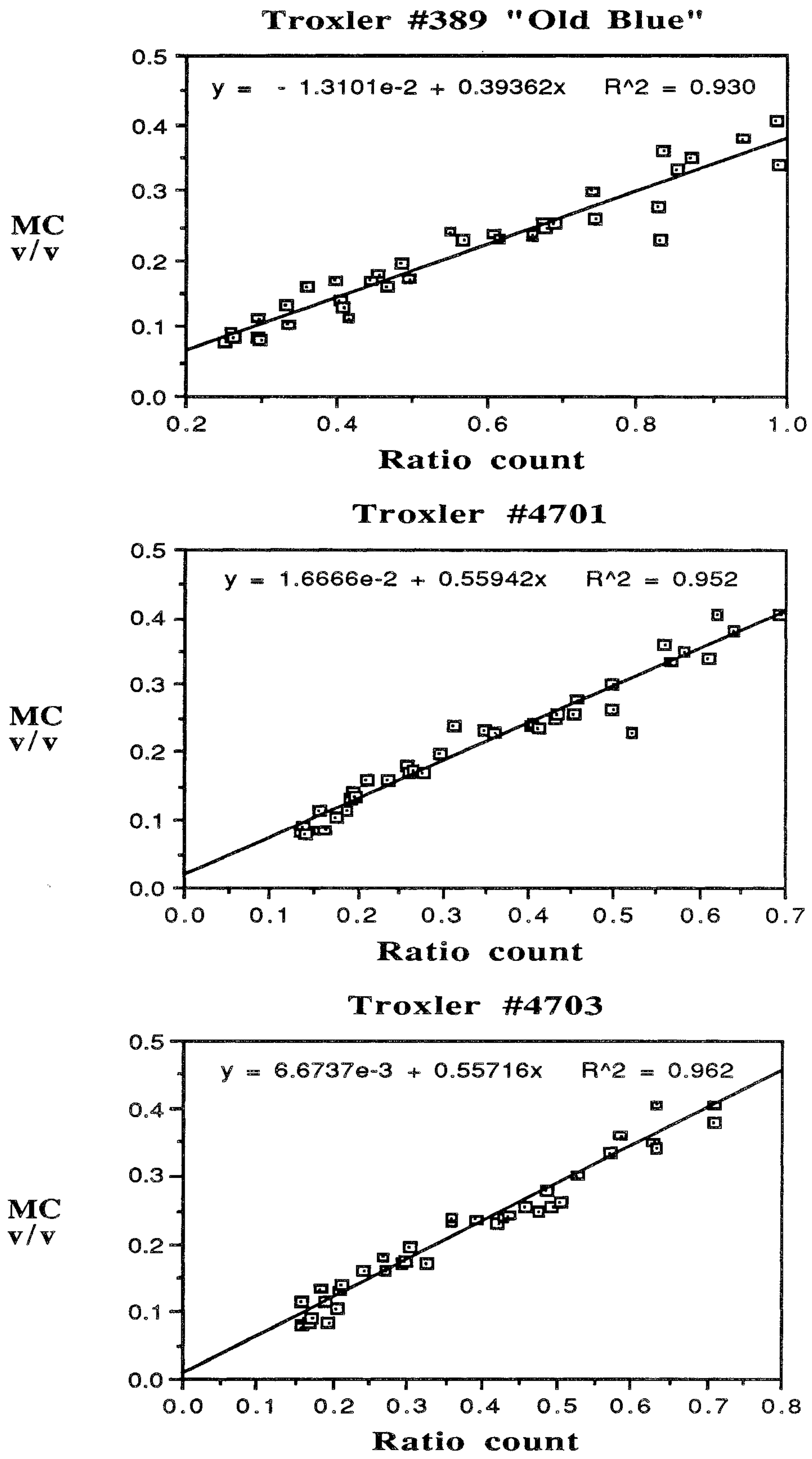
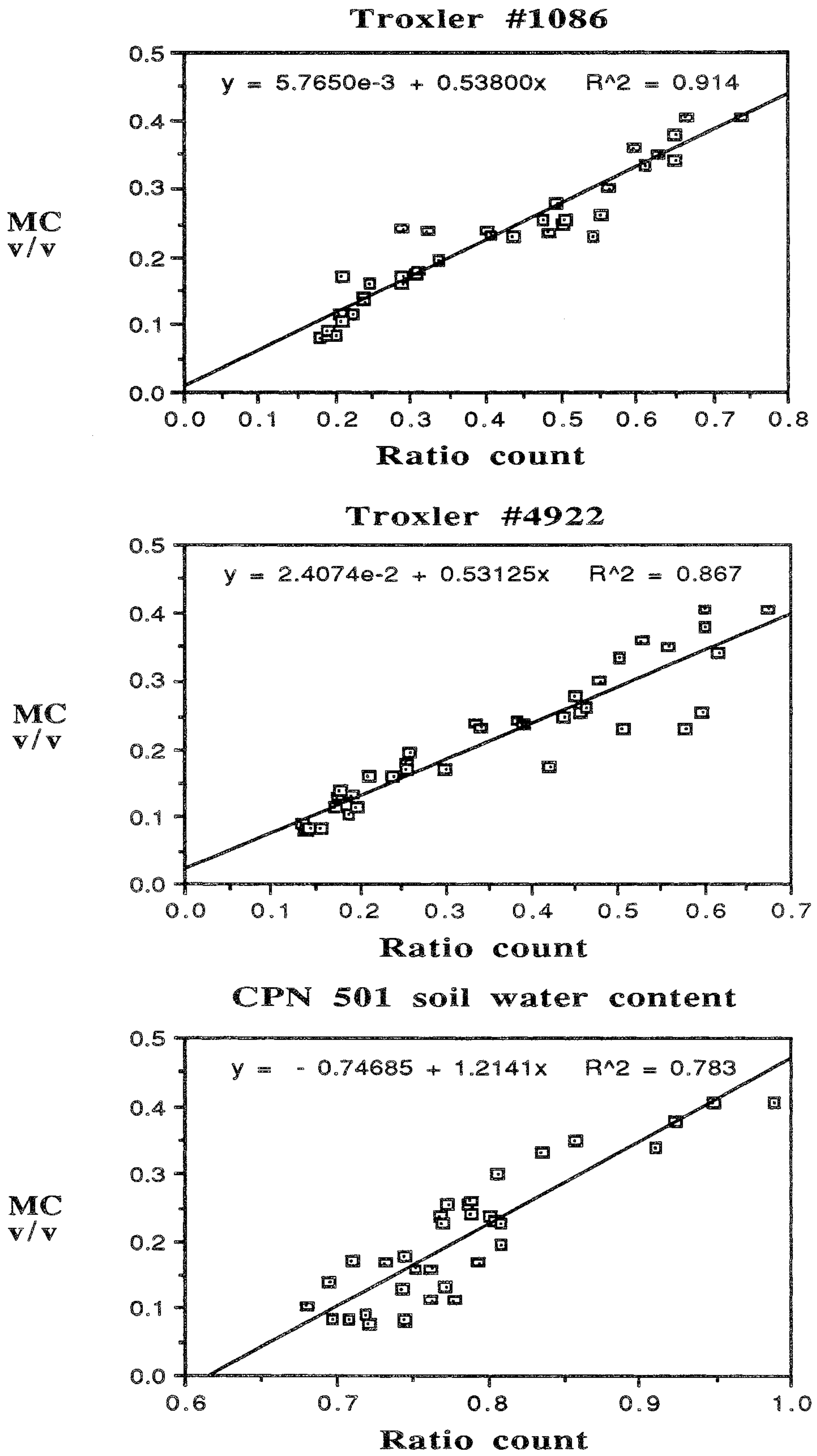


Fig. 3.1.1 1990 Calibration curves for neutron probes: Troxler units #389, #4701 and #4703



Troxler #1086

Troxler #4922

CPN 501 soil water content

Figure 3.1.2 1990 Calibration curves for neutron probes: #1086, #4922 and #501

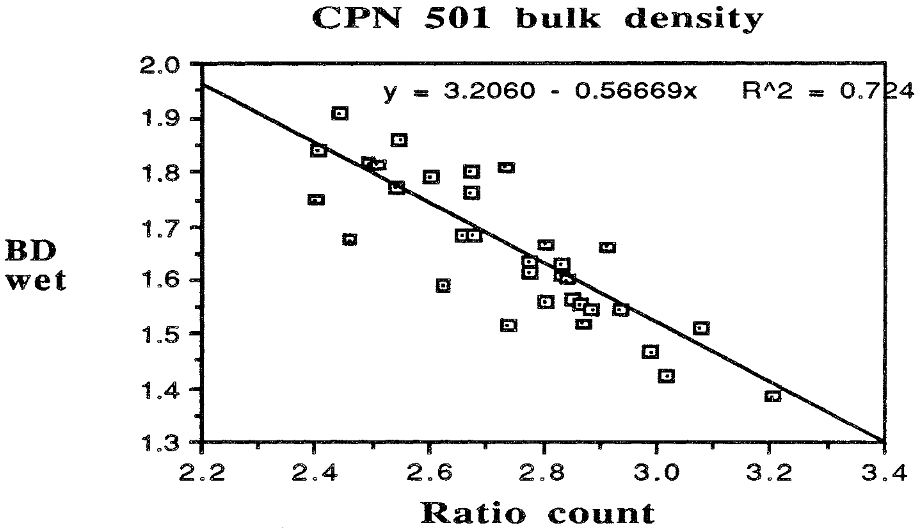


Figure 3.1.3 1990 Calibration curve for the gamma probe: CPN unit #501

some significant changes. The sources for fast neutrons and gamma radiation decay over time, which may result in a shift of the calibration curve. Furthermore, as repairs are made to the probes, the performance of the units may be effected. Consequently, these probes should be calibrated on an annual basis.

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