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A COMBINDED HORIZONTAL PENETROMETER FOR TRANSIENT DETECTION OF SOIL WATER CONTENT AND MECHANICAL RESISTANCE

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Abstract: Important factors for regulating soil tillage and for performing soil variability maps in precision farming are soil strength and water content. In this study, a combined horizontal penetrometer was designed for the on-the-go and simultaneous measurement of soil water content and mechanical resistance. The maximum sampling rate for both sensors was 10 Hz and the maximum operating depth was 20 cm. For the water content sensor, its measurement principle depends on the field effect of the fringe capacitance.

Key words: *soil water content, soil compaction, resistant force, penetrometer.*

INTRODUCTION

Soil strength and water content are important factors for regulating soil tillage and for performing soil variability maps in precision farming. Moreover the effects of soil compaction on plant growth, yield depression, water infiltration and drainage requires an advanced tool to provide soil physical information as precise as possible (*Schafer* et al., 1992). It has been recognized for a long time that soil compaction is significantly related to water content, bulk density, texture, and organic matter (*Ayers* and *Perumpral*, 1982).

Therefore, soil compaction is a reduction in the volume of a given mass of soil. Since bulk density is defined as the mass of soil occupying a unit volume, it can act as an indicator of soil compaction. Soil penetrometers, as popular tools to investigate soil mechanical impedance, and cone index, as a meaningful measure of the penetration resistance, have been employed to characterize soil compaction for many years (*Perumpral*, 1987).

Over the past decade, several studies for the simultaneous measurement of soil penetration resistance and water content using dual sensor technique have been approached. *Topp* et al. (1996) as well as *Young* et al. (2001) integrated a TDR (Time Domain Reflectrometer) sensor into the rod of a penetrometer and carried out preliminary field experiments. Thereafter, *Topp* et al. (2003) investigated how to calibrate this combined penetrometer in laboratory and use in field. *Vaz* and *Hopmans* (2001) designed a coiled TDR-penetrometer probe for an impact penetrometer, and an experiment to determine the relation among soil penetration resistance, water content and bulk density was also carried out (*Vaz* et al., 2001). According to their report, it is relatively time-consuming to measure the water content with a coiled TDR-penetrometer probe between impacts (≈1 min). *Newman* and *Hummel* (1999) modified a penetrometer cone with an infrared water content sensor to characterize soil physical properties. *Sun* et al. (2003) developed and tested a new type of water content sensing penetrometer based on the capacitance principle under laboratory conditions.

This innovated penetrometer has the advantages of rapid response for continuous measurement and low cost with adequate accuracy in comparison with the penetrometers combined with TDR and the infrared sensor.

In this study, a combined horizontal penetrometer was designed for the on-the-go and simultaneous measurement of soil water content and mechanical resistance. The maximum sampling rate for both sensors was 10 Hz and the maximum operating depth was 20 cm. For the water content sensor, its measurement principle depends on the field effect of the fringe capacitance.

MATERIAL AND METHOD

Soil mechanical resistance measurement

A detailed diagram of the measurement system for the soil water content and mechanical resistance is given in Figure 1. Like the most of conventional horizontal penetrometers, this prototype consisted of four components: a cone penetration rod, a blade, a force lever and a force sensor with strain gage load cell. The blade incooprerates two functions: At first, it ensured that the measurement results of the force sensor are independent of the depth. Secondly, it could protect the force sensor from impact by stone. In order to facilitate the blade penetrating in the soil, the part of the blade was designed with a wedge angle of 60°. The nominal sensitivity for the force sensor was 2 mV/V and the nominal measurement force was 104 N. The cone was designed to approximate ASAE penetrometer standard (ASAE Standard: ASAE S313.3, 1998), using the large standard cone size of 20 mm diameter with a 16 mm shaft diameter. For the purpose of enhancing the cone's wearing ability, the material of the tip of the cone and of the two metallic rings in Fig. 1 were made from chromium-nickel steel.

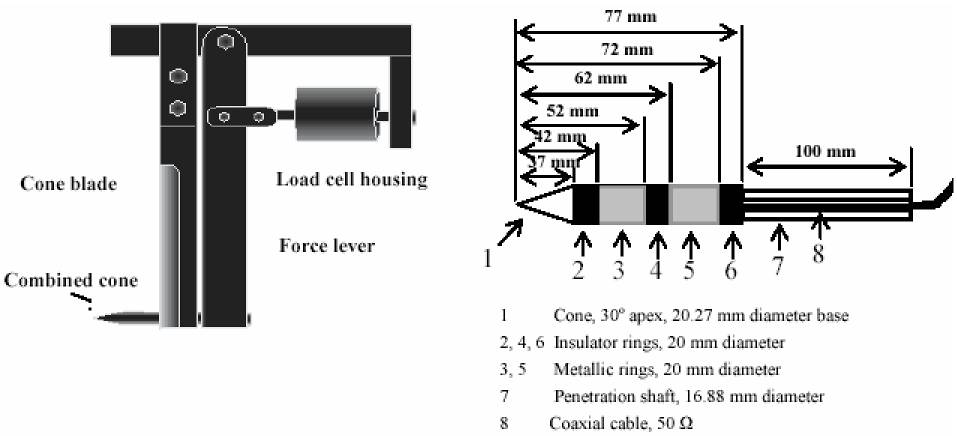

Figure 1: Diagram of the horizontal combined penetrometer

Soil water content measurement

The soil water content was determined by a fringe capacitance sensor that was integrated into the penetration cone. From Figure 1, it can be noted that two metallic rings were separated by three insulation rings. Both metallic rings acted as two electrodes of the fringe capacitance sensor and the moisture sensibility of the sensor relies on the fringe field between electrodes. There are two common methods for continuously measuring the capacitance of soil probes. A conventional method is based on the frequency measurement technique (Dean et al., 1987) since the oscillation frequency varies with the value of the capacitor and, thus mainly relies on the dielectric properties of the medium around the soil probe. Another is to determine the electrical impedance of the soil probe at a given frequency of excitation (Gaskin and Miller, 1996). For both methods, the operating frequency should be higher enough to reduce the influence of soil salinity. So far several previous studies have discussed the influence of soil salinity on the measurement accuracy. Three researchers pointed out that uncertainties caused by soil conductance and faulty contact are largely avoided by using a high frequency of 30 MHz (Thomas, 1996). In this fringe capacitance sensor, the measurement technique of electric impedance was used and the operating frequency was chosen at 100 MHz.

Experimental environment and procedures

The field experiments were conducted in September, 2004 at the Endenich experimental field of the Department of Agricultural Engineering, Bonn University, where the soil texture was the same as that of the silt-loam used in the laboratory for calibration. The electric conductivity of the field was 0.253 mS cm^{-1}.

Two experiments were carried out in four adjacent plots in the field. 1: soil water content profiles test. 2: soil strength compaction strength measurement test.

Before experiment 1, three rectangle pits (length: 3m, width: 0.35m, depth: 0.35m) with an interval of 5 m in the plot were out and the soil from each pit was dried in an oven at a temperature of 105 °C. In order to get the soil samples with different water contents, the heating time was set to with 6, 12, 18 hours for each sample, and finally the soil samples with gravimetric water contents of 6 %, 9 %, and 12 % were obtained, respectively. Then each soil sample was brought back to each corresponding pit with the same density as it before digging out.

Before experiment 2, the surface of the field was deliberately compressed by four pathes of a tractor tire. Light, moderate and heavy compression was performed a tractor crossed the measurement path with 5, 10 and 20-times, respectively. This experiment consisted of two steps. At first, the horizontal combined penetrometer measured through a path. Then, an ASAE standard cone vertical penetrometer was employed to measure soil compaction along the path again. The vertical penetration depth was 500 mm and the operating velocity was 30 mm s^{-1}.

RESULTS AND DISCUSSION

Soil water content profile test

Figure 2 presents the output signals of the capacitance sensor from the water content profile test. The operating speed of the tractor in this test was 1m s^{-1} and the measurement depth was at 15 cm. In Figure 2 there are three concaves corresponding to different depths along the curve. The first concave within the distances of 5-8 m refers to the values of the soil sample with a gravimetric water content of 6 %; the second concave within the distances of 14-17 m refers to that of 9 % and the third within the distances of 21-24 m to that of 12 %, respectively. Besides, other higher values of the output signals refer to that of the undisturbed soil. By core method, the gravimetric water content of the undisturbed soil was 20.3 %. From Fig. 2, it is also noted that the amplitudes of these concaves are sensibly different. This fact means that the dynamic resolution of the capacitance sensor for gravimetric water content was within ±3 %.

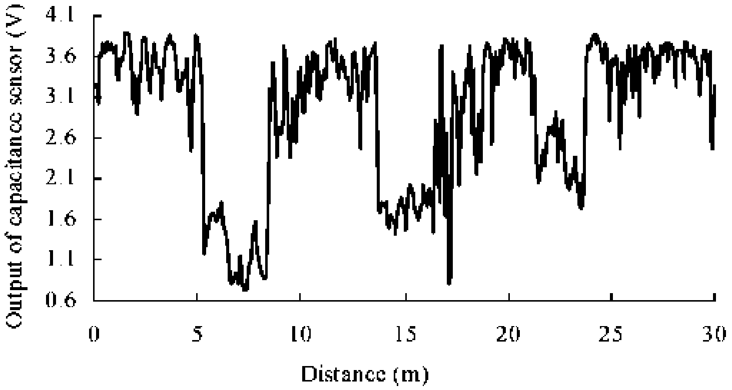

Figure 2: Response of the water content sensor through the moisture profile

Soil compaction measurement test

Figure 3 shows the measurement results both from combined horizontal penetrometer and the ASAE standard vertical penetrometer. It is evident that seven peak values concerning the readouts of the force sensor of the horizontal penetrometer can be clearly observed. Except for a peak value corresponding to the distance of 22 m, other six peak values were due to the tractor's compression. In particular, the amplitudes of the pair of peak values between the distances of 4-6 m are greater than others since this area was just heavily compressed.

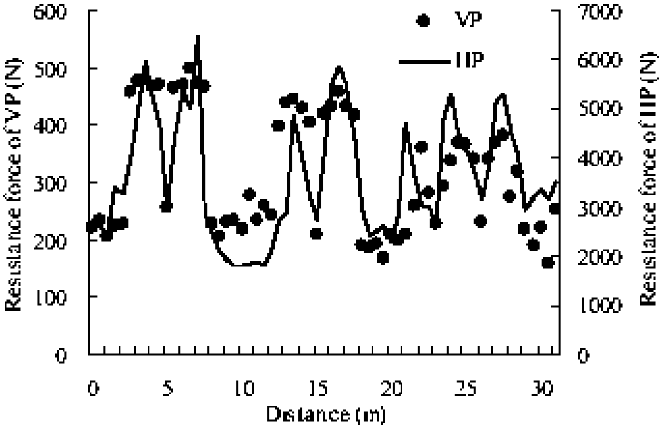

Figure 3: Measurement results from the vertical and the horizontal penetrometers VP: Vertical penetrometer; HP: Horizontal penetrometer

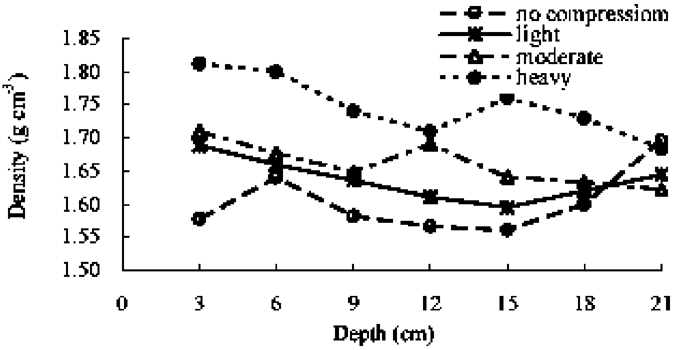

Figure 4: Density distributions at the depths of 0-20 cm

Figure 4 gives a comparison for the bulk density related to the heavy, moderate, light and none compression case. The data concerning the bulk density were collected by core method. The reason for the peak value corresponding to the distance 22 m is that there was a boundary zone passing through this area. Evidently, the measurement results from the vertical penetrometer also demonstrated that the penetration resistance of this area was significantly greater than that of its vicinity.

CONCLUSIONS

The tests conducted with the combined penetrometer outlined an adequate dynamic resolution in on-the-go measurement of soil water content. The penetrometer reflected the compaction zones as detected by the vertical penetrometer. The effect of depth was investigated and the conclusion was that there no significant influence on the force measurement.

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KOMBINOVANI HORIZONTALNI PENETROMETAR ZA ODREĐIVANJE MEHANIČKOG OTPORA I SADRŽAJA VODE U ZEMLJIŠTU

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Sadržaj: Veoma važni faktori za regulisanje obrade zemljišta i izrade zemljišnih mapa u konceptu Precizne poljoprivrede, su otpor i vlažnost zemljišta. U ovom radu je prikazan kombinovani horizontalni penetrometar za istovremeno merenje, u hodu, optpora i vlažnosti zemljišta, i urađena simulacija. Maksimalna učestalost uzimanja uzoraka oba senzora bila je 10 Hz a maksimalna dubina rada 20 cm. Merni princip senzora vlažnosti zemljišta zavisi od granične vrednosti poljskog vodnog kapaciteta zamljišta.

Ključne reči: *vlažnost zemljišta, sabijenost zemljišta, sila otpora, pentrometar.*