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Application note

Improvement of a dual-sensor horizontal penetrometer by incorporating an EC sensor

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ABSTRACT

Following the development of a dual-sensor horizontal penetrometer for the simultaneous measurements of soil water content and strength, an electrical conductivity (EC) sensor with a 4-ring Wenner-array was incorporated into the cone of the horizontal penetrometer. In order to overcome the cross-modulation of signals from water content and EC sensors, two filters with specific pass-bands were connected in each circuitry. Both laboratory calibration and field test were conducted, and the experimental results showed that the improved technique could provide more informative data to interpret soil physical conditions at field-scale.

1. Introduction

For map-based approaches in precision agriculture (PA), diverse sensor techniques are utilized to rapidly collect information at field-scale. As a mobilized operation, on-the-go measurement has drawn increasing attention in investigating soil properties. The earlier instruments designed for on-the-go soil measurements were mostly realized with single sensors that could only measure one physical parameter (Glancey et al., 1989; Alihamsyah et al., 1990; Dollite and Collins, 1995; Adsett et al., 1999; Erhardt et al., 2001). Apparently, the single-parameter measurement is theoretically insufficient to predict several soil properties at the same time, and thus it is required to explore the possibility of multi-sensor techniques (Adamchuk et al., 2004). For instance, regarding soil strength measurement, even though horizontal penetrometer is an effective tool to evaluate the distribution of soil strength at field-scale, either higher soil compaction or lower water content can result in higher soil strength, so the strength measurement does not provide certain information of soil bulk density (Ayers and Perumpral, 1982; Topp et al., 2003; Hummel et al., 2004). In order to separate the interdependency among various soil attributes, two types of dual-sensor techniques for simultaneous, on-the-go measurement of soil penetration force and water content have been developed recently. One was reported by Mouazen and Ramon (2006). In their study, a subsoiler chisel equipped with a NIR sensor and a load cell was devised. Another type of prototypes combined a dielec-

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tric sensor with a conventional horizontal penetrometer in our early study (Sun et al., 2006). However, soil strength not only depends on bulk density and water content, but also on other factors such as textural compositions and organic matter. Thus, it is still limited to interpret the information archived from these dual-sensor techniques. Similarly, EC is also viewed as a resultant indictor related to soil salinity, water content, porosity, texture and organic matter (Rhoades and Ingvalson, 1971; Rhoades and van Schilfgaarde, 1976; Corwin and Lesch, 2005; Friedman, 2005). As a continual development of the dual-sensor technique based on our early study (Sun et al., 2006), the objective of this study was to incorporate an EC sensor into the dual-sensor horizontal penetrometer so that triple-fold information with respect to soil conditions could be obtained during on-the-go measurement.

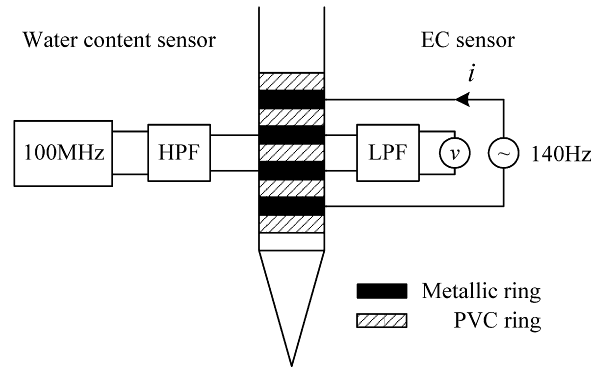

Fig. 2 – Combined design of 4-ring for water content and EC sensors. HPF: high pass filter, LPF: low pass filter.

2. Material and methods

2.1. Sensor design

Fig. 1 shows the sensor prototype consisting of a sensing cone, a blade, a force lever and a force sensor (strain-gage load cell). This mechanical structure was originally designed by Alihamsyah et al. (1990). The function of the blade had twofold. Firstly it facilitated cutting soil, and secondly it got rid of the impact on the force lever. Thus, during on-the-go measurement, the penetration resistance was simply transmitted to the force sensor via the force lever. Thereafter, Sun et al. (2006) embedded a fringe field sensor with two rings into the cone to determine water content. This study embedded four rings into the cone to simultaneously measure water content and EC value. Fig. 2 illustrates the electrodes configuration of the sensing cone together with each measurement circuitry. The left side of the cone in Fig. 2 referred to the water content sensor as early designed, and the right side referred to EC sensor, of which four rings are arranged with Wenner-array. Especially, the inner pair of electrodes was shared for both sensors. According to dielectric theory and previous studies (Gaskin and Miller, 1996; Paltineanu and Starr, 1997; Singh et al., 1997), the operating frequency to determine soil water content should be considerably higher (a fraction of 100 MHz or higher), whereas the frequency to measure EC is quite lower (a fraction of 1 KHz). Therefore, by choosing appropriate band-pass filter for each sensor, the cross-modulation between both sensors may be eliminated so that it is possible for them to conjoin the inner rings. In this design, the water content and EC sensors operated at 100 MHz and 140 Hz, respectively. As far as the detail descriptions of water content sensor and Wenner-array method are concerned, they have been well addressed in a number of references (Rhoades and Ingvalson, 1971; Gaskin and Miller, 1996; Robinson et al., 2003; Corwin and Lesch, 2005; Sun et al., 2005).

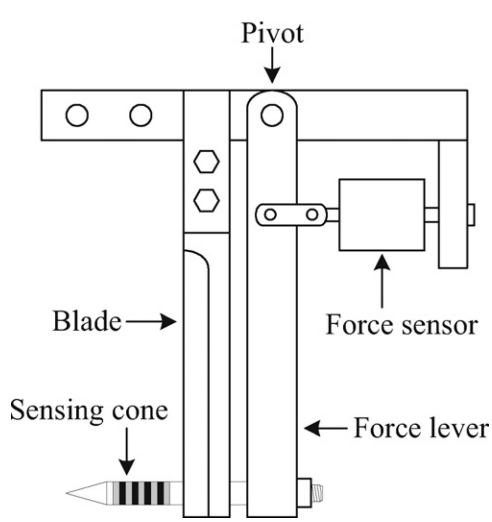

Fig. 1 – Schematic diagram of the prototype.

2.2. Calibration of water content and EC sensors

The intentions of calibration are not only to establish the relationship between each sensor's output and measured soil attribute, but also to check if there is unwanted effect of cross-modulation in the sensing cone. According to USDA Standard of soil texture classification, the used soil sample for calibrating water content was silt–loam and its textural compositions (mg mg^{-1}) were: sand 0.17, silt 0.67, and clay 0.16. These samples were oven-dried for 24 h at 105 °C and then passed through a 2-mm sieve. After sifting, they were rewetted and filled into plastic cans (diameter: 100 mm, height: 165 mm). To ensure the samples sufficient time to reach equilibrium, the calibration was conducted 2 days after adding the water. For the EC sensor calibration, similar to the methodology recommended by several researchers (Gaskin and Miller, 1996; Bristow et al., 2001; Muñoz and Berga, 2005), NaCl solutions with different concentrations or molarities whose EC values arranged from 0 to 20 mS cm^{-1} were tested. During calibrating the EC sensor with known conductivity solutions, the effect of EC values on the water content sensor was also tested. Additionally, as a reference of the calibration, a commercial EC instrument (DDS-307, Shanghai Precision & Scientific Instrument Co., Ltd., measurement accuracy of ±1%) was used.

2.3. Test site and conditions

Shortly after harvesting potato in the August of 2007, the field trial was conducted in a plot (length: 240 m, width: 30 m) at the Dikopshof Experimental Farm of Bonn University, Germany.

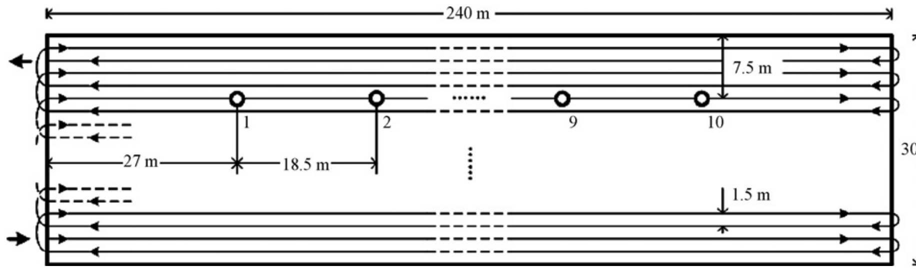

Fig. 3 – Field experimental schema, "○" denotes core samples located within the field.

The soil textural composition of this plot is identical to that used for calibrating the water sensor in the laboratory. Fig. 3 illustrates the traveled path of on-the-go measurement, the interval between two paths, and the location where each core sample (diameter: 56 mm, height: 40 mm) was taken. The operating depth and velocity were fixed at 20 cm and 5 km h^{-1}, respectively. Based on the experimental results at three different depths (10, 15 and 20 cm) in our previous study (Sun et al., 2006), the force measurement of this horizontal penetrometer was independent of operating depths. Therefore, here we only tested an operating depth of 20 cm, and thus the depth of core sampling was 20 cm accordingly. During the test, a PDA (iPAQ 3850, HP) was used to log data with a sampling rate of 10 Hz and a GPS receiver (SCA-12S, Ashtech Inc., USA, accuracy: 1 m) was equipped to provide positioning information.

3. Results and discussion

3.1. Calibration results

Figs. 4 and 5 show the calibration results of water content and EC sensors, respectively. Moreover, Fig. 5 provides additional information about the effect of EC on the output of water content sensor. In brevity, two observations can be made: (i) for each sensor, there exists a linear approximation with $R^2 > 0.97$ and (ii) the output of the water content sensor is nearly independent of EC values in the case of EC < 5 mS cm^{-1}; otherwise it slightly decreases as EC value increases from 5 to 20 mS cm^{-1} (see the dotted-line in Fig. 5). Comparing to the results obtained by Gaskin and Miller (1996), whose water content sensor was insensitive to EC up to 1.5 mS cm^{-1}. However, an appropriate correction for this triple-sensor may be required when EC value is above 5 mS cm^{-1}.

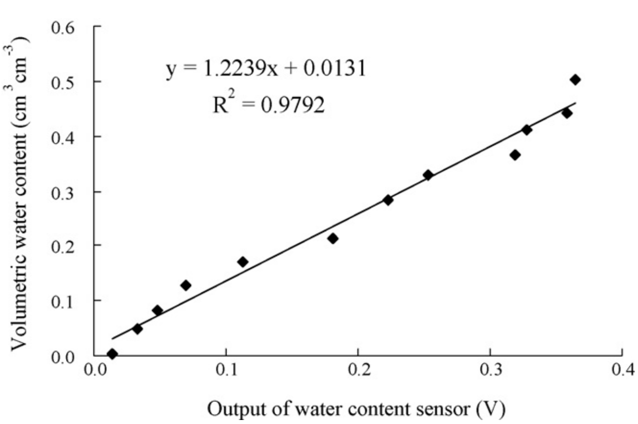

Fig. 4 – Calibration result of water content sensor.

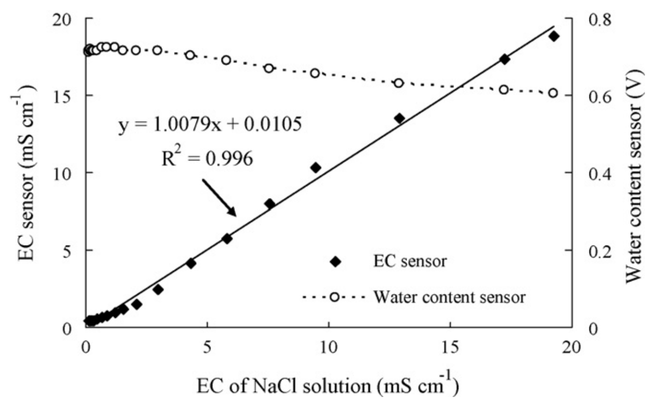

Fig. 5 – Calibration results of EC sensor with NaCl solution and dependency on water content sensor.

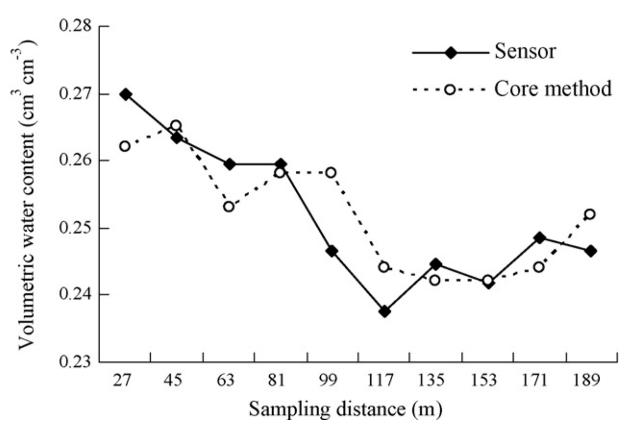

Fig. 6 – Straightforward comparison of water content sensor to core samples.

3.2. Validating water content sensor

Figs. 6 and 7 exhibit the performance of water content sensor in the field. Here the raw data acquired from the sensor measurement were averaged in 3 m distance. The core samples were taken out from the same depth along a measurement path shown in Fig. 3. Comparing to the data obtained by core

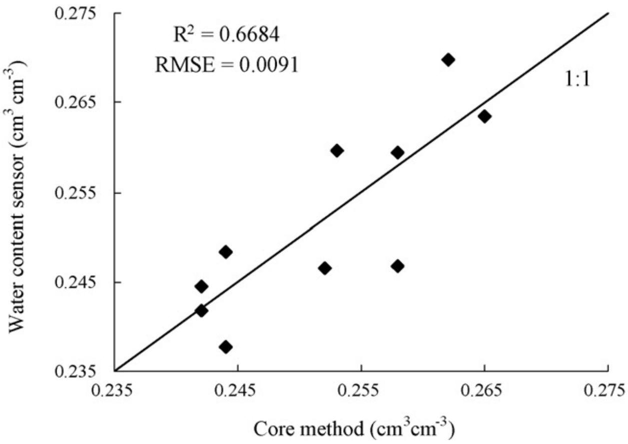

Fig. 7 – Statistical assessment of water content sensor with core samples, in which the line denotes a bisector (1:1).

as well as oven-dried method, it fit a bisector (1:1) with R^2 of 0.6684 and RMSE of 0.0091 $cm^3\,cm^{-3}$.

3.3. *Comparisons of EC_a, water content and penetration force mappings*

There are various EC measures in terms of different application environments. Soil apparent electrical conductivity (EC_a) is a measure sensor-based quantifying EC values at the field (Sudduth et al., 2003; Corwin and Lesch, 2005). Fig. 8 presents three mappings generated from these sensors. At first, the EC_a mapping (Fig. 8a) revealed that the measured EC_a varied within a range of 0.2994–0.3266 mS cm^{-1}. This demonstrates that the experiment field belonged to non-saline soils. Thus, the influence of salinity can be ignored, whereas other soil physical or chemical attributes, such as water content, texture, bulk density, organic matter and caption exchange capacity, may become a major factor dominating the EC_a values. Secondly, comparing the EC_a mapping to that of water content (Fig. 8b), a significant correlation between them is evident. In the area that has higher water content in Fig. 8b, the same area in Fig. 8a also the higher EC_a values. Thirdly, comparing the penetration force mapping (Fig. 8c) to that of water content, it can also see a tendency that higher soil penetration force is attributed to lower water content and vice versa.

However, some conflicting results are observed in the local area marking with a circle. The circled area in Fig. 8b, the water content remains relatively consistent at a middle level, despite EC_a in Fig. 8a and the penetration force in Fig. 8c varies significantly. Comparing Fig. 8a through c within the same local area, higher soil penetration force corresponds to lower EC_a and vice versa. For the purpose of interpretation, the effect of soil bulk density should be excluded because both EC_a and the penetration force are directly proportional to its values. Likewise, it is not due to the effect of clay content since higher clay content causes higher EC_a and higher penetration force. Although seeking a rational inference among the miscellaneous interdependency of soil attributes is beyond the scope of this study, there is an "on-the-go" effort to develop forward more advanced multi-sensor systems for PA application.

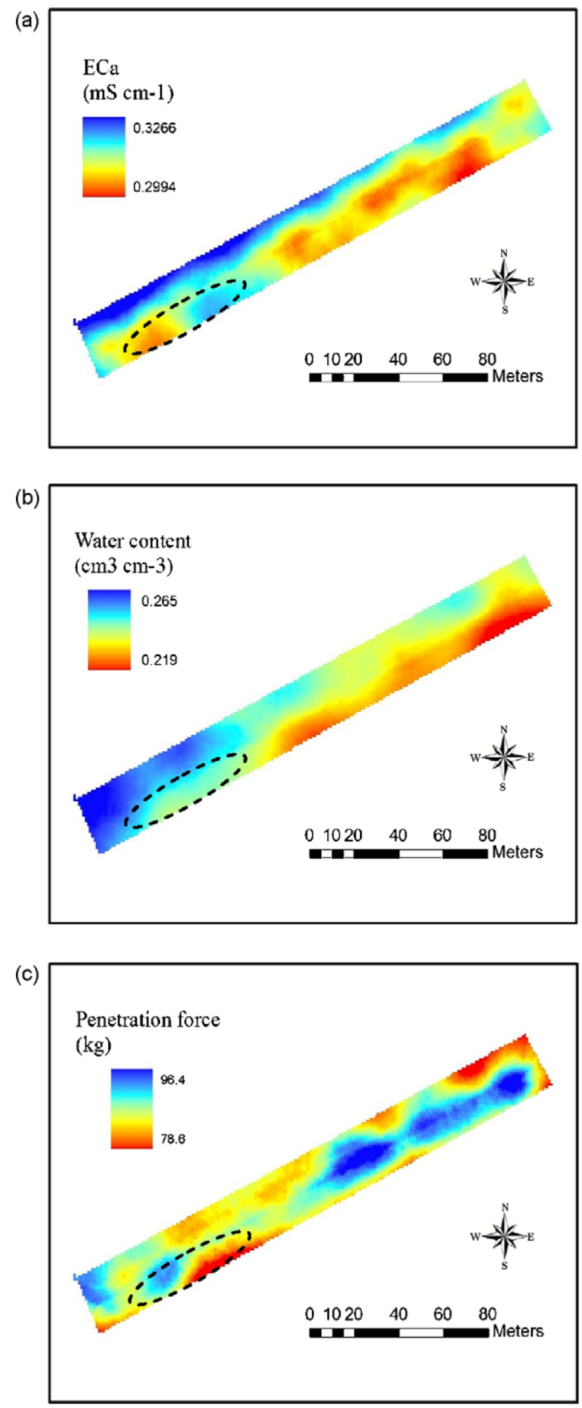

Fig. 8 – Comparison of EC_a, water content and penetration force mappings.

4. Conclusions

As a further advancement to on-the-go measurements an existing dual-sensor horizontal penetrometer has been expanded successfully. The sensor can measure soil water content, EC and penetration force simultaneously. Results from the laboratory calibration and the field test indicate that the performance of the prototype sensor appears satisfactory.

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