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# Towards development of on-line soil moisture content sensor using a fibre-type NIR spectrophotometer

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**Abstract**

As the soil moisture content ($w$) is a deterministic factor for site-specific irrigation, seeding, transplanting and compaction detection, an on-line measurement system will bring these applications into practice. A fibre-type visible (VIS) and near-infrared (NIR) spectrophotometer, with a light reflectance measurement range of 306.5–1710.9 nm was used to measure $w$ during field operation. The spectrophotometer optical unit was attached to the subsoiler chisel backside to perform the light reflectance measurement from the soil surface on the bottom of the trench opened by the proceeded chisel. The spectrophotometer–optical unit system was calibrated for $w$ under stationary laboratory conditions on samples collected from an Arenic Cambisol field with different soil textures. A partial least square analysis was carried out in order to establish a statistical model relating soil light spectra with the gravimetric $w$ of the 0.005–0.26 kg kg$^{-1}$ range. This model was validated with the full cross validation method resulting in a small root mean square error of cross validation (RMSECV) of 0.0175 kg kg$^{-1}$ and a high validation correlation of 0.978. Further validation of the model developed in the laboratory under stationary state showed also a small root mean square error of prediction (RMSEP) of 0.0165 kg kg$^{-1}$ and a prediction correlation of 0.982. When the NIR sensor-model system was used to determine $w$, based on on-line field measurement, a relatively larger RMSEP of 0.025 kg kg$^{-1}$ and lower prediction correlation of 0.75 were found. However, a reasonably similar spatial distribution of $w$ was found between the on-line NIR measurement and oven drying methods. Therefore, the on-line NIR $w$ sensor developed is recommended to provide valuable information towards the site-specific applications in soils.
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*Keywords:* Moisture content; On-line measurement; Sensor; Spectrophotometer

## 1. Introduction

Soil moisture content ($w$) is one of the most critical soil components for successful plant growth and land management, particularly in drylands. It is determined by a conventional method based on oven drying of samples collected from fields. In spite of the fact that the oven drying method is a difficult, costly and time consuming procedure, it provides discontinuous information about $w$. An alternative on-line measurement system of $w$ is still an attractive and difficult challenge for researches and engineers involved in the development of precision farming research, particularly

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in large-scale fields under arid and semiarid zones. Site-specific irrigation, transplanting, seed drilling and compaction detection in such fields might be brought into practice if a successful on-line measurement system of $w$ is incorporated into farm machines.

Stafford (1988) divided the sensors to monitor $w$ from mobile machinery into two categories of contact and non-contact non-destructive sensing systems. While the former systems include the electrical conductivity (Bowers and Bowen, 1975), microwave (Whalley, 1991), capacitance (Bobert et al., 2001) and nuclear magnetic resonance (Paetzold et al., 1987) techniques, the latter include microwave reflectance (Whalley and Bull, 1991) and ground-penetrating radar (Shih et al., 1986) techniques. The near-infrared reflectance (NIR) spectroscopy is a promising non-contact measurement method available to provide rapid information about some soil physical and chemical properties, namely organic matter content, nitrogen, potassium, phosphorous, pH, $w$, particle size and mineral composition of the soil. It is based on the understanding of the interaction between the incident light and properties of soil surface such that the reflected light characteristics vary due to the surface physical and chemical properties. When light is illuminated towards the soil surface, the radiant energy is distributed through three different processes: reflection, absorbance and transmission. As transmission in soil equals zero, the balance between reflection and absorbance is governed by the influence of the soil physical and chemical properties. These properties determine the colour and roughness of the soil surface, influencing the amount of light reflection and/or absorbance. Bowers and Hanks (1964) found that the intensity of reflected light from the soil surface decreased with increasing $w$, particle size and organic matter. The $w$ was measured with stationary-state NIR spectroscopy by several researchers (Bowers and Hanks, 1964; Kano et al., 1985; Dalal and Henry, 1986; Slaughter et al., 2001). In comparison with several studies reported about the stationary-state NIR spectroscopy measurement of soil properties, only very few researchers were able to report the development of real-time NIR spectrophotometer measurement systems. This is attributed to the difficulties of building up a real-time spectroscopic measurement system. Moreover, inserting the spectrophotometer illuminating and reflecting units within the soil leads to delicate and breakable instrumentation, particularly when working in fields with gravels and stones. A portable infrared reflectance method based on light emitting diodes was used by Stafford et al. (1989) to measure $w$. However, the instrument showed limited use because the emitting diodes at 1950 nm were not available commercially. Shonk et al. (1991) introduced a real-time fibre-type NIR spectroscopy measurement system, which utilised a single wavelength light reflectance to measure the percentage of soil organic matter. They declared that the sensor is promising to be useful for prescription applications of soil applied chemicals. Sudduth and Hummel (1993) developed a portable-type NIR spectrophotometer to measure soil organic matter, cation exchange capacity and $w$ to depths from 0.35 to 0.50 m. They found good correlation between soil measured properties and light reflectance under stationary laboratory conditions. However, when measurement was done on-line in the field, they reported inaccurate estimation of soil properties, which was attributed to the variations in soil-to-sensor height during wavelength scanning.

The only research involving the development of a real-time NIR spectroscopy measurement system of $w$ among other soil properties is reported in Shibusawa et al. (1999). The light illumination and reflection fibres are attached to a spectrophotometer of 300–1700 nm VISNIR light source. The optical unit stands above the soil surface at a distance of 0.075 m (Shibusawa et al., 2003). This gap between the soil and optical-sensing unit could lead to a possible soil-to-sensor height variation due to changes in both the soil topography and/or vertical forces acting on the chisel. Furthermore, the several sensing units in the housing make the system complicated and rather expensive. A useful spectrophotometer sensor to measure soil properties should be simple, cheap and properly designed to have continuous touch with soil to avoid the distance variation problem of the soil-to-sensor optical unit that limited the few real-time spectroscopy measurement systems so far.

This study describes the development of a simple and reliable, fibre-type NIR spectrophotometer sensor for the on-line measurement of $w$. A comparison between maps of the on-line NIR spectrophotometer and oven drying methods is presented.

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