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Development of on-line measurement system of bulk density based on on-line measured draught, depth and soil moisture content

Abdul Mounem Mouazen[a,b,*], Herman Ramon[a]

[a] Department of Agro-Engineering and -Economics, Faculty of Agricultural and Applied Biological Sciences,
Kasteelpark Arenberg 30, B-3001 Heverlee, Belgium
[b] Department of Rural Engineering, Faculty of Agriculture, University of Aleppo, P.O. Box 12214, Aleppo, Syria

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Abstract

On-line measurement of soil compaction is needed for site specific tillage management. The soil bulk density (ρ) indicating soil compaction was measured on-line by means of a developed compaction sensor system that comprised several sensors for on-line measurement of the draught (D) of a soil cutting tool (subsoiler), the soil cutting depth (d) and the soil moisture content (w). The subsoiler D was measured with a single shear beam load cell, whereas d was measured with a wheel gauge that consisted of a swinging arm metal wheel and a linear variable differential transducer (LVDT). The soil w was measured with a near infrared fibre-type spectrophotometer sensor. These on-line three measured parameters were used to calculate ρ, by utilising a hybrid numerical–statistical mathematical model developed in a previous study. Punctual kriging was performed using the variogram estimation and spatial prediction with error (VESPER) 1.6 software to develop the field maps of ρ, soil w, subsoiler d and D, based on 10 m × 10 m grid. To verify the on-line measured ρ map, this map was compared with the map measured by the conventional core sampling method.

The spherical semivariogram models, providing the best fit for all properties was used for kriging of different maps. Maps developed showed that no clear correlation could be detected between different parameters measured and subsoiler D. However, the D value was smaller at shallow penetration d, whereas large D coincided with large ρ values at few positions in the field. Maps of ρ measured with the core sampling and on-line methods were similar, with correlation coefficient (r) and the standard error values of 0.75 and 0.054 Mg m^{-3}, respectively. On-line measured ρ exhibited larger errors at very dry zones. The normal distribution of the ρ error between the two different measurement methods showed that about 72% of the errors were less than 0.05 Mg m^{-3} in absolute values. However, the overall mean error of on-line measured ρ was of a small value of 2.3%, which ensures the method accuracy for on-line measurement of ρ. Measurement under very dry conditions should be minimised, because it can lead to a relatively large error, and hence, compacted zones at dry zones cannot be detected correctly.

Keywords: Bulk density; On-line measurement; Sensor; Moisture content; Draught; Depth

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* Corresponding author. Tel.: +32 163 285 92; fax: +32 163 285 90.
E-mail addresses: abdul.mouazen@agr.kuleuven.ac.be, amouazen@net.sy (A.M. Mouazen).

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1. Introduction

Soil compaction is one of the main factors limiting plant growth and crop yield. It is well-known that soil compaction is a natural or human created problem that results in increase of bulk density (ρ) and root penetration resistance, while decrease in void ratio and available nutrients, water and oxygen for plant can very frequently take place. Moreover, it was found by Fleige and Horn (2000) that anthropogenic compaction in traffic rut and plough pan caused a reduction of coarse pores and saturated water conductivity, leading to surface runoff and soil erosion. Alleviation of the negative effect of soil compaction on plant growth, along with the reduction of tillage energy input and increasing the surface plant residue relay on successfully managed site specific tillage operations. With the recent development in precision agricultural technologies, researchers have focused on development of on-line sensors to measure different properties in agricultural soils (Adamchuk et al., 2004). Since on-line measurement of soil compaction demands simultaneous measurement of different influencing parameters and a proper mathematical modelling technique, development of an on-line soil compaction sensor is still a challenging issue for researchers involved in new technologies and engineering sections of precision agriculture.

The most common techniques to determine the degree of soil compaction is the field measurement of ρ and penetration resistance. Both parameters are measured with traditional methods under static conditions, using core sampling methods and penetrometers, respectively. Under dry soil conditions, these measurements are very difficult and time costly procedures, in addition to the discontinuous data output provided based on fine or coarse measurement grids. Soil compaction was referred to indirectly as on-line measured soil mechanical resistance or draught (D) of different cutting or penetration tools using different load cells (Sprinkle et al., 1970; Upadhyaya et al., 1984; Glancey et al., 1996; Sirjacobs et al., 2002; Verschoore et al., 2003) or strain gauges (Glancey et al., 1989; Adamchuk et al., 2001). Godwin and Miller (2003) stated that there is now, from commercial sources, evidence that the electromagnetic induction (EMI) will distinguish between different levels of soil compaction (Smith, 2001). However, EMI is mainly dependent on the clay content, salinity, organic matter, moisture content (w) and ρ (Schmidhalter et al., 2001), which introduce problems of discrimination of different factors. In a recently published study, Besson et al. (2004) related the soil electrical resistivity to soil ρ, showing successful discrimination between loose and compacted layers. In addition to the sensitivity of the electrical resistivity to salinity and ambient temperature, the developed electrical resistivity–bulk density relationship depended on the soil type and w.

When ρ is selected for on-line, tractor-based measurement of soil compaction with a soil cutting tool or penetration device, all influencing parameters should be measured simultaneously during measurement, namely D, depth (d) and w. Liu et al. (1996) developed a real-time texture/compaction sensor. They stated that if d and the speed of a soil cutting tine are kept constant, D will be a function of texture, ρ and w. Based on a combination of the finite element method and multiple linear regression analysis, Mouazen et al. (2003) developed the following model for the calculation of soil compaction indicated as bulk density:

$$\rho = \left(\sqrt[3]{\frac{D + 21.36\,w - 73.9313\,d^2}{1.6734}} \right) \times 1.14 \qquad (1)$$

where D is the draught in kN, w the soil moisture content in kg kg^{-1}, d the subsoiler depth in m and ρ is the bulk density in Mg m^{-3}.

The mathematical model of Eq. (1) stablishes a basis of carrying out an indirect measurement of ρ, when the independent parameters (D, d and w) can be measured simultaneously on-line. So far, Mouazen et al. (2003) produced ρ maps by using Eq. (1) and measured D of the subsoiler (cutting tool) with an extended octagonal load cell, similar to the load cell developed by Godwin (1975). However, soil w and subsoiler d were measured using traditional techniques, so that w was measured with oven drying methods and d was measured manually. But, the on-line measurement of ρ will only be satisfied, if all the independent parameters (D, d and w) are measured on-line simultaneously, with values to be substituted into Eq. (1) to obtain ρ.