Soil & Tillage Research 162 (2016) 78–86

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Application of an on-line sensor to map soil packing density for site specific cultivation

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ARTICLE INFO

Article history:
Received 14 December 2015
Received in revised form 20 April 2016
Accepted 24 April 2016
Available online 8 May 2016

Keywords:
Packing density
Soil compaction
Site specific tillage

ABSTRACT

Tillage is the most energy consuming operation in the primary production in agriculture. The majority of farmers worldwide adopt homogeneous tillage operations to optimise crop establishment, reduce weeds and compaction, where soil disturbance took place across the entire field including areas where no soil preparation is needed. This practice consumes high energy and leads to decrease soil resistance to water and air erosion. This paper investigates the potential of a previously developed on-line soil bulk density (BD) sensor to map packing density for the delineation of management zones for site specific tillage. The on-line sensor consisting of a multi-sensor platform pulled by a tractor was used to measure soil BD in two experimental fields with potato in East Anglia, UK. It consisted of a load cell to measure subsoiler draught, a wheel gauge to measure depth and a visible and near infrared (vis-NIR) spectrophotometer for the measurement of moisture content (MC). Based on these three on-line measured parameters, BD was calculated using a previously developed model with a hybrid numerical and multivariate statistical analysis. The packing density (PD) was then calculated for all on-line measured points as a function of BD and clay content (CC). Maps of soil BD and PD were produced, and both fields were divided into management zones with different tillage recommendations.

Results, in the studied fields, showed that the on-line BD sensor can map not only the spatial distribution in BD but enable estimation of PD too. Classifying the PD into three compaction classes revealed that only 4.8% of the field needs aggressive tillage (primary and secondary tillage) and about 34.8% of the field requires harrowing or surface loosening with a cultivator (reduced tillage), while the remaining area of the field do not need any sort of tillage. Virtual calculations of fuel consumption and CO_2 emission in one field based on the three PD classes confirmed that site specific tillage would significantly reduce energy consumption and CO_2 emission, as compared to reduced and conventional tillage practices. By this it can be concluded that the on-line multi sensor platform for the assessment of PD holds a great potential for mapping and managing soil compaction site specifically. A future study is needed to relate soil compaction to actual plant growth and yield, and evaluate cost of production and practical limitations of this approach.

1. Introduction

The increasing world population, changing diet and climate change are the main challenges facing modern agriculture to produce sufficient food, feed and fuel. As a result, there is a growing consensus within our global community that the protection of natural resources and implementation of environmentally and economically sound agriculture practices is of the utmost priority. Under the Thematic Strategy for Soil Protection, a soil framework directive prepared by the European Commission (EU Framework Directive 232, 2006) has considered soil compaction as one of soil threats. Together with erosion, organic matter decline, contamination, salinisation, soil biodiversity loss, sealing, landslides and flooding, compaction occurs in specific risk areas, which must be identified and treated according to the framework directive.

Soil compaction is a major problem in the current food production system (Hamza and Anderson, 2005), as it hinders plant growth and reduces yield, increase soil erosion and water pollution. It increases production cost due to reduction in land

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http://dx.doi.org/10.1016/j.still.2016.04.016

productivity, input loss and increase in energy consumption by tillage to eliminate compaction and prepare the soil to a proper seedbed. Bulk Density (BD) is the most common parameter used as an indicator for soil compaction for all soils (Håkansson and Lipiec, 2000; Mouazen and Ramon, 2006; Quraishi and Mouazen, 2013a) and indeed several studies have shown relationship between BD and crop yield (Negi et al., 1981; Pabin et al., 1991; Czyz, 2004). Recently, Packing Density (PD) has gained attention as an advanced indicator for soil compaction (Jones et al., 2003; Tobias and Tietje, 2007), as it is defined as a composite index of BD and clay content (CC). It was originally developed by Renger (1970) to describe soil compaction for the German soil mapping manual. So far, PD was not explored as a parameter to indicate the need for tillage site specifically.

One of the major limitations that affect successful management of soil is the huge spatial variability of soil properties (including compaction) within a field. However, the current practice for conventional and reduced tillage is that famers and growers used to cultivate the whole field uniformly, as a way to manage the risk of soil compaction, reduce fuel consumption and improve soil quality. Variable cultivation approach will offer many economic and environmental benefits to farmers and growers though reductions in the volume of disturbed soil. Therefore, there is a need to map the spatial variation in soil compaction (Mouazen et al., 2003), at sufficient sampling resolution to allow tillage equipment to respond to this variation and treat compacted zones only. One of the promising technologies to overcome within field variability in soil compaction is on-line soil sensors (Hemmat and Adamchuk, 2008; Mouazen et al., 2005a), capable of collecting high number of samples (Kuang and Mouazen, 2013), which also allow for rapid and cost-effective analysis and enable simultaneous estimation of a variety of soil properties including BD and CC (Mouazen et al., 2014).

The majority of studies reported in the literature on mapping soil compaction with on-line sensors were based on measurement of draught (e.g., Godwin, 1975; Al-Janobi, 2000; Andrade-Sánchez et al., 2007) or penetration resistance (e.g., Tekin et al., 2008; Topakci et al., 2010). More advanced studies realised the importance of soil moisture on penetration resistance so that a multi-sensor approach was introduced to account for the influence of moisture content (MC) (Sun et al., 2006). Mouazen and Ramon (2002) proposed a methodology to map the spatial variation in soil compaction referred to as BD with high sampling resolution, based on on-line multi-sensor platform. This was based on a hybrid modelling approach of finite element analysis and multiple linear regression analyses to establish a model to predict BD as a function of draught of a soil cutting tool (subsoiler), depth and soil moisture content, which was later expanded to the majority of soil textures (Quraishi and Mouazen, 2013b). A recent study by Naderi-Boldaji et al. (2016) developed empirical models to predict soil relative density from measurements of horizontal penetrometer resistance and MC in a wide range of soil textures. Authors did not account for particle size distribution in their estimation, and their hypothesis was that the model coefficient would be texture dependent when soil compaction is expressed as BD. So far, no on-line measurement of PD was reported in the literature, to provide data to develop recommendations for variable tillage.

The aim of this study is to map with high sampling resolution the spatial variability in soil PD in two fields in the UK using the on-line multi-sensor platform of Mouazen and Ramon (2006). The scope was to divide these two fields into management zones with different crop limiting values for variable cultivation approach based on the degree of compaction within a field.

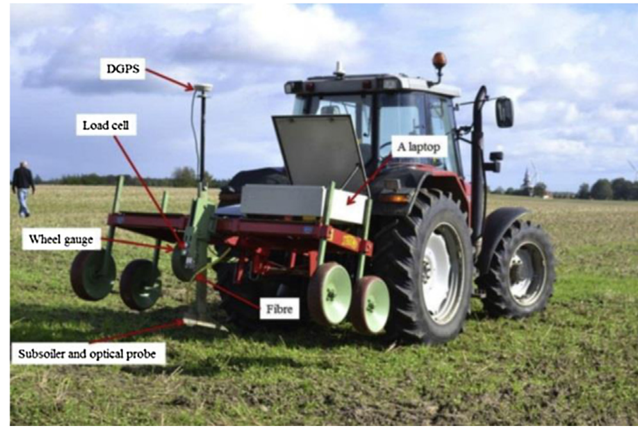

Fig. 1. Multi-sensor platform for the on-line measurement of soil properties (Mouazen et al., 2014).

2. Materials and methods

2.1. On-Line multi-sensor platform

In this study, the on-line multi-sensor platform designed and developed by Mouazen (2006) was used (Fig. 1). It consists of a subsoiler that penetrates the soil to the required depth, making a trench, whose bottom is smoothed due to the downwards forces acting on the subsoiler. An optical probe was attached to the backside of the subsoiler chisel to acquire soil spectra in diffuse reflectance mode from the smooth bottom of the trench (Mouazen et al., 2005b). The retrofitted subsoiler was attached to a frame, which was mounted onto the three point linkage of a tractor. An AgroSpec mobile, fibre type, vis–NIR spectrophotometer (tec5 Technology for Spectroscopy, Oberursel, Germany) with a measurement range of 305–2200 nm was used to measure soil spectra in diffuse reflectance mode. A single-ended shear beam load cell with a maximum capacity of 90 kN (Griffith Elder & Company Ltd., Suffolk, UK) for the measurement of draught and a draw wire linear sensor (Penny & Giles Controls Ltd., Dorset, UK) connected to a wheel gauge for the measurement of subsoiler depth were used in combination with the vis–NIR moisture sensor for the measurement of soil BD. More detailed information about data acquisition can be found in Quraishi and Mouazen (2013b).

2.2. Experimental sites and on-line measurement

Two test sites with potato crop production were measured in this work, namely, Thetford field (3.5 ha) with a clay loam soil texture (43.1% sand, 29.5% silt and 27.4% clay) and Wypemere field (peatland of 4 ha) with a silty clay soil texture (5.1% sand, 45.3% silt and 49.6% clay) in Cambridgeshire, UK. On-line measurement with the multi-sensor platform (Fig. 1) was performed in parallel transects to the tramlines. The length of transects depended on the dimension of the field. However, a constant gap of about 10 m was kept between neighbouring transects. Measurement was carried out at an average speed of 2 km h^{-1}.

In Wypemere field it was decided to carry out the on-line soil measurement after soil preparation with ordinary tillage, which included mouldboard ploughing followed by seedbed preparation. In Thetford field, the on-line measurement took place in compacted soil directly after crop harvest and before any tillage operation, where soils are supposed to have higher BD (compacted), compared to Wypemere field (cultivated). This *a prior* planned measurement was to show differences in soil compaction