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Assessing the effect of the seedbed cultivator leveling tines on soil surface properties using laser range scanners

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ABSTRACT

Poor seedbed preparation may cause low yields and poor resource utilization. Therefore, novel sensor technology for seedbed quality evaluation is strongly needed to make sure good growing conditions are achieved efficiently. The objective of this study was to quantify the effect of the front leveling tines and the tillage depth of a cultivator on soil surface roughness and aggregate size distribution. Field tests were performed with a seedbed cultivator, using 5 different leveling intensities and 2 cultivation depths. Using a laser range scanner, the soil surface was mapped before, during and after cultivation. These surface maps were analyzed using Granulometry to estimate aggregate size distribution in the seedbed. Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD) were calculated based on these aggregate size estimates. Additionally, roughness was calculated based on the surface profiles produced by the laser range scanner. The leveling intensity showed a statistically significant effect on the MWD, GMD and roughness, however, the cultivation depth showed no evidence to suggest a significant effect. Finally, roughness calculated during and after cultivation had a good correlation, which shows that it is possible to use the laser range scanner for roughness measurements during the tillage operation.

1. Introduction

In seedbed preparation and soil tillage it is relevant to assess key soil properties before and after tillage to make sure good growing conditions are achieved efficiently. Sensor technology can provide valuable feedback to optimize tillage and may even be used to evaluate the result during the farming operation with the possibility of performing on-line control of the machinery.

Information about soil properties such as soil surface roughness and aggregate size distribution can be used to describe the quality of the seedbed (Braunack and Dexter, 1989a, 1989b; Le Bissonnais et al., 2002; Håkansson et al., 2011, 2002). Recent research even indicates that 3D structure of the surface is a more sensitive parameter in tillage operations, than parameters such as bulk density or the saturated hydraulic conductivity (Arvidsson and Bölenius, 2006). The 3D structure of the surface can be used both to calculate the soil surface roughness and estimate the aggregate size distribution in the topsoil (Jensen et al., 2016).

Multiple different sensor technologies have previously been used to gather maps of the 3D structure of the soil surface in stationary setups in the laboratory or in the field. The sensor technologies used in the stationary setups include laser scanners (Darboux and Huang, 2003; Eltz and Norton, 1997; Huang and Bradford, 1992; Raper et al., 2004), photographic stereovision (Helming et al., 1992; Rieke-Zapp and Nearing, 2005; Scharstein and Szeliski, 2003; Zribi et al., 2000) and ultrasonic depth sensors (Robichaud and Molnau, 1990). Laser range scanners have also been used to map the soil surface in a dynamic setup with the sensor equipment mounted on an All-terrain vehicle (Jensen et al., 2014).

The objective of this study was for a seedbed cultivator to quantify the effect of the front leveling tines and the tillage depth on soil surface roughness and aggregate size distribution. The soil surface roughness and aggregate size distribution were calculated from maps of the soil surface gathered by a laser range scanner. The soil was scanned before and after cultivation with a stationary

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setup and during the cultivation operation with a dynamic setup where the scanner was mounted on the seedbed cultivator.

2. Materials and methods

In the experiment the soil was cultivated using a Kongskilde Germinator Pro, which utilizes a front leveling board consisting of a series of flat tines (Kongskilde, 2015). These leveling tines are the first soil treatment (not counting the tines that loosen the soil in the tractor tracks) and eliminate unevenness in the topsoil. The tips of the tines are flat with a width of 4.5 cm and with a 6 cm gap between each tine. In the experiment we analyzed the effect of the leveling tines at two cultivation depths using 3D scans of the soil surface. The experiment was a split-plot design with the intensity of the leveling tines as the whole plot factor and the depth as a sub plot factor. The cultivator leveling tines were adjusted to 5 different settings ranging from no interaction with the soil to maximum possible extension of the tines. The cultivator had two working sections, which were used to process the soil at 2 different cultivation depths in one pull. The cultivator was pulled at 10 km/h and the working sections were set to a depth of 5 and 8 cm. The experiment had 4 blocks/replications, within which the leveling tine settings were randomized. Each plot in the experiment was 3 by 20 m and the plots were laid out in a grid 4 plots wide and 5 long. The experiment was done in an area of the field with a homogeneous soil texture. Along the cultivation direction the plots were separated by enough space to ensure that the tractor could accelerate to the required speed (Table 1).

2.1. Study area

The experimental data used in this paper were recorded and gathered on April 7–10, 2015 at Flakkebjerg, Denmark (+55 19′ 20.1″, +11 23′ 19.6″) on a sandy loam soil. The soil was ploughed in November 2014 and had not been treated since. The top soil had a gravimetric water content of 10.5 g 100 g^{-1} which for the particular field corresponds to a water potential lower than −100 kPa. That is, the soil was relatively dry as compared to field capacity, which is assumed to be at c. −10 kPa for this soil type. The water content at −10 kPa for a neighboring field on a similar soil type was 18.7 g 100 g^{-1} in the topsoil (data not shown).

2.2. Data collection

To ensure that all data was recorded in high resolution a (semi-) stationary setup was used to scan the soil surface before and after cultivation. Additionally, the surface was scanned during the cultivation process with the scanner mounted on the cultivator.

The complete plot was scanned with the dynamic setup, but due to the limitations of the stationary setup, only the middle 2.5 by 3 m were scanned using this setup. The positions of the stationary scans were marked using GPS in order to scan the exact same surface both before and after cultivation.

Table 1
Leveling tine settings.

Leveling tine setting	Tine angle to ground	Intensity
1	N/A[a]	0%
2	57.8°	20%
3	67.2°	50%
4	73.3°	70%
5	82.1°	100%

[a] Raised out of the soil.

The middle 20 cm of the scans were discarded as there was a small gap between the working sections that caused small ridge to form with larger aggregates. Discarding this middle part also eliminated any interaction between the two cultivator sections. In the analysis of the data, a width of 1 m was used of the surface scans of each cultivator section.

2.2.1. Stationary data collection

In the stationary data collection, a setup of two tripods with an aluminum bar spanning between was used. A toothed rack was mounted on the bar allowing a train carrying the sensor equipment to ride along the bar. The sensor train is driven by a single stepper motor controlled with a Phidgets 1063 stepper controller. The sensor used was a SICK LMS511 Laser Measurement System mounted on the train facing down towards the soil surface. The laser measurement system is a line scanner recording the distance from sensor to surface along this line. The laser was mounted roughly 1 m above the soil surface and an angular resolution of 0.25° was used. With this distance to the surface, the scanner had a usable field of view of 2.5 m across the surface. The laser range scanner was configured not to use any internal digital filtering. Combining the data from the laser scanner with the position of the train as it rides along the bar results in a point cloud mapping the soil surface. The polar data from the laser scanner was converted to cartesian coordinates and interpolated creating a height map of the soil surface.

The stepper motor is set to continuously travel the whole distance across the aluminum bar, which means that with small delays and differences in processing time in the computer, the line scans will not be recorded with exactly the same distance between each line. Therefore, the motor position (number of steps since start) is recorded alongside the laser line scans.

Both the stepper controller and the sensor were controlled by a laptop, which also stored the collected data.

2.2.2. Dynamic data collection

In the dynamic data collection, the same laser range scanner was mounted to the transport trailer frame of the seedbed cultivator. This placed the scanner behind the machine, and when the frame was lifted during operation, the scanner was placed roughly 1.5 m above the soil surface. With this placement, the scanner had a usable field of view of over 3 m, which was enough to scan two working sections of the cultivator.

The cultivator was pulled at a speed of 10 km/h. This movement along the surface was much faster than in the stationary setup. Therefore, the scan speed was set to the laser range scanners maximum, 100 Hz. This, however, also resulted in a lower angular resolution of 0.67°.

A Dickey-John Radar II ground speed sensor was also mounted on the transport trailer frame to measure the vehicle speed.Again a laptop was used to store all the collected data.

2.2.3. Data preprocessing

The laser scanner returned the range from the scanner head to the surface. This means that the data from the laser scanner had to be converted from polar to cartesian coordinates in order to obtain a height profile that described the distance from the laser scanner plane to a given point along the surface profile.

The laser scanner only captured a single line of range information per scan, i.e. a single height profile of the surface. In order to build up a full height map of the soil surface, the system had to continuously capture lines of data while the sensor moved along the soil surface. The information about the position of the sensor (either from the stepper or the ground speed sensor) together with the laser range data created a discrete point cloud, which described the soil surface. The point cloud was a set of data