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Description of furrow shaping created by single standard tines

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ABSTRACT

Design: optimization and online evaluation of work quality of tillage tools help to find optimal balance between effort and result in tillage operation. Currently, usage of laser scanner has become widespread to examine the soil profile after tillage. However, the results are significantly affected by external circumstances in the field such as sunlight, weeds, residual of plant, etc. Therefore, a soil bin test was carried out by using a laser scanner to evaluate the width and the area of the furrow (shape of furrow) created by using four standard chisel plow tines heavy duty, double heart, double heart with wing and duck foot with widths of cut 0.065, 0.135, 0.450, and 0.400 m, respectively at different speeds and depths. MATLAB based computer program was used to estimate soil profile parameters. Lab results were verified in a field test. The field results were evaluated based on geometric shape of the furrow obtained from the soil bin and a model based on Willatt and Willis's approach in predicting the furrow shape. Results show that the width of the furrow increases linearly with depth while the area of the furrow increases quadratically with depth for all tines. An excellent geometric shape of the furrow was obtained from the soil bin for every tine. The furrow shape is triangle for heavy duty and double heart tines, while it is triangle plus trapezoidal shape for double heart with wings and duck foot tines. Willatt and Willis's equation related to the width of the furrow shows a good agreement for heavy duty and double heart tines at shallow depth.

1. Introduction

Tillage operations are always characterized by finding the best compromise between effort and result by balancing aggressiveness of mechanical interaction with the soil with power consumption and productivity determined by area per time. Since efficiency and greenhouse gas emissions become more important and machine dimensions in the highly developed markets start to reach the limits the optimum between effort and result needs to be established more intelligent.

The soil profile after tillage is a very important factor; it is indicating and showing the result of force applied by tillage tools, which will give knowledge about the soil movement and desired disturbance. Many analytical models (static or dynamic in two or three dimensional), empirical methods (linear regression, multi-linear regression, orthogonal regression and regression for reference tillage tools) and finite element method (FEM) were used in design of tillage tools and were focusing on how to reduce the forces without considering the resulting soil profile.

In (Dedousis and Bartzanas, 2010), it was revealed that the force per unit area is more useful than the force only to evaluate the efficiency of tillage tools in soil cultivation. It shows the soil-tool interactions, where the force is input value and the area is output value. This method was adopted by (McKyes and Desir, 1984; Hettiaratchi, 1993; Conte et al., 2011). Therefore, the area of soil disturbance created by the tillage tool needs to be quantified.

Recently, laser scanner has become a common device for soil profile measurement. Profile meter developed from passing through mechanical devices such as chain roller and pin meter to radar scanners and optical devices like laser and camera scanner (Willatt and Willis, 1965; Saleh, 1993; Mckyes and Maswaure, 1997; Oelze et al. 2001, 2003; Riegler et al., 2014; Martinez-Agirre et al., 2016). Generally, profile meters can be divided into two categories: two dimensional (2D) and three dimensional (3D), with contact (chain roller and pin meter) and without contact (laser and camera scanner). Jester and Klik (2005) compared different methods to measure soil surface roughness, including contact methods and methods using non-contact devices and they proved that the low cost and simple devices using contact methods like the pin meter required the highest measurement time compared to other methods while the laser scanner shows high resolution and precise measurements. However, the laser scanner is widely affected by other sources of light (Huang and Bradford, 1992; Darboux and Huang, 2003).

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Table 1
Physical properties of the soil bin soil ± standard error.

Parameters	Units and abbreviations	Values
Soil type		Sandy Loam
Clay content	[%]	9.0
Silt content	[%]	30.1
Sand content	[%]	60.9
dry bulk density	ρ_d [kg/m^3]	1370 ± 10
Moisture content dry base	Mc [%]	10.4 ± 0.88
Internal friction angle	?? [rad]	0.733
External friction angle	δ [rad]	0.393
Cohesion	C [kN/m^2]	5.6
Cone index	CI [N]	74.8 ± 9

Fig. 1. Tines used T1) heavy duty, T2) double heart, T3) double heart with wings and T4) duck foot.

The soil profile after tillage is actually affected by numerous factors. These factors can be related to the soil conditions (e.g. moisture, texture and soil bulk density); operation conditions (e.g. speed and working depth) and tools geometry. Liu and Kushwaha (2005) pointed out that studying the soil profile is very complex and progresses slowly because of many factors involved with it. Manuwa et al (2012) studied the effects of different tine width on soil profile parameters under soil bin conditions and they reported that the parameters of soil disturbance except the height of ridge increased in a wider tine. Solhjou et al. (2013) showed that different blade face geometry caused large differences in furrow size.

Some researchers focused on developing mathematical methods of the soil profile in order to predict its parameters. Willatt and Willis (1965) performed an equation to predict the width and area of the furrow for curved and plane tines by using a soil profile meter, the furrow disturbed by both tines were of a roughly trapezoidal shape. Rahman and Chen (2001) found that the furrow shape is trapezoidal created by two types of sweep tools, the bottom of a trapezoid is close to the sweep width and its height equals to the working depth. Where else, the furrow is a triangular shape created by two types of disc tools with the height equal to the working depth. Manuwa and Ogunlami (2010) proposed a prediction model for the soil profile parameters by using a regression based analysis.

As mentioned above the objective of this research is to evaluate the width and the area of the furrow created by four standard single chisel plow tines under various operating conditions by using a multi-linear regression analyses with a stepwise selection.

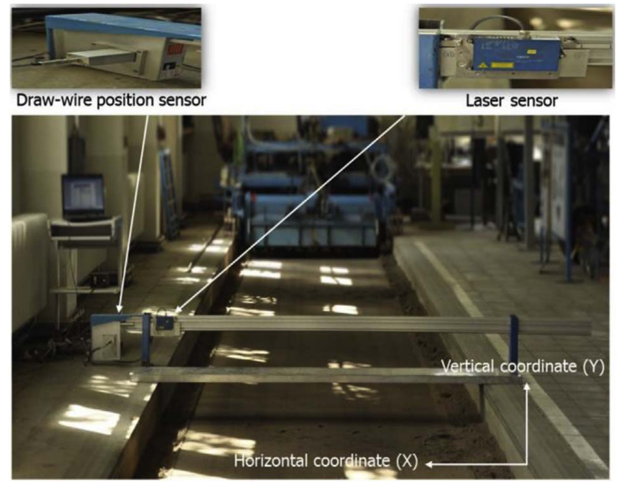

Fig. 2. Soil profile meter with optoNCDT 1700 from Micro-Epsilon (y-axis) and WS17KT from ASM (x-axis).

2. Materials and methods

2.1. Soil bin description and tine characterization

The experiment was carried out at the Chair of Agricultural Systems and Technology at Technische Universitaet Dresden, under controlled soil bin conditions. The soil bin was 28.6 m long, 2.5 m wide and 1.0 m deep. It was filled with a sandy loam soil which the physical properties are given in Table 1. The carriage was powered by an electric-hydraulic drive train with a maximum speed of 4.7 m/s delivering a maximum traction of 13 kN.

Four standard single chisel plow tines were used in the experiment: heavy duty T1, double heart T2, double heart with wings T3, and duck foot T4 (see Fig. 1) and Table 2 summarizes characteristic parameters of these tines.

2.2. Data measurements and calculation

2-D soil profile scanner was used a laser spot sensor for the vertical coordinate optoNCDT 1700 from Micro-Epsilon and a draw-wire position sensor for the horizontal coordinate WS17KT from ASM (see Fig. 2). After running the test, the soil loosening was removed manually and the scanner was placed over the soil bin.

A MATLAB based computer program was used in order to compute the width and the area of the furrow by using the following equations (1) and (2), respectively.

$$\mathrm{Wf} = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad (1)$$

where, Wf is the width of the furrow in m, X and Y are the point coordinates.

Table 2
Tine parameters.

Tines	Symbol	Length [m]	Width [m]	Thickness [m]	Radius [m]	angle [rad]	Weight [kg]
Heavy Duty	T1	0.47	0.065	0.02	0.30	1.05	3.4
Double Heart	T2	0.44	0.135	0.02	0.30	1.13	3.2
Double Heart with wings	T3	0.32	0.450	0.02	0.30	1.13	4.2[a]
Duck Foot	T4	0.30	0.400	0.01	0.30	1.48	2.9

[a] Wing only.