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Effect of tillage speed and straw length on soil and straw movement by a sweep

J. Liu [a,*], Y. Chen [b], R.L. Kushwaha [c]

[a] Department of Agricultural and Biological Engineering, Pennsylvania State University, 227 Agricultural Engineering Building, University Park, PA 16802, USA
[b] Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6
[c] Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 5A9

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ABSTRACT

Crop residue cover protects soil from erosion caused by water and wind. High amounts of residue are not needed and part of crop residue needs to be removed by bailing and part of the crop residue needs to be incorporated into soil. Since tillage operation impacts crop residue cover, cover residue management has been integrated into tillage operations. To provide mathematical relationships between tillage operation and residue coverage, thoroughly understanding the relationship between tillage tool, soil, and crop residue, and to develop mathematical models are important. Therefore, detailed data of soil, crop residue, and tillage tool interactions are needed. It is very difficult to acquire these data in field tests due to too many uncontrollable variables. Soil bin experiments were conducted to study soil and crop residue movement and crop residue incorporation by tillage with a sweep. Cereal straw was selected to represent surface crop residue, and there was no crop residues in the soil bin soil. The length of the straw ranged from 50 to 250 mm with an increment of 25 mm. A 325-mm-wide sweep was operated at speeds of 5, 7.5, and 10 km h^{-1} with a constant depth of 100 mm. Aluminum cubes of 1 cm^3 were used as point tracers to measure surface soil displacement; straw pieces with specific lengths were previously colored and used as point tracers to measure straw displacement. Straw tracers were oriented as parallel and perpendicular to the tool travel direction. Straw displacements measured with two different orientations of straw tracers were not significantly different. The straw mixtures of different lengths were spread over the soil surface to cover those tracers, and the straw mixtures worked well in studying straw movement and incorporation as two facts: (a) they reduced number of plots and then reduced experimental time and (b) they could represent single-sized straw in studying straw incorporation. Research results indicated that higher tillage speed resulted in larger soil and straw displacement that also buried more straw. Straw displacement increased with increasing straw length. The forward straw displacement increased by 20% when straw length increased from 50 to 250 mm although this increase was not statistical significant. The forward soil displacement was reduced by 70% and greater if tillage speed was reduced from 10 to 5 km h^{-1} independent of the straw length. The width of soil disturbance was increased by 40% if increasing tillage speed from 5 to 10 km h^{-1}. Results showed that longer straw were less buried than shorter straw at the same tillage speed. Compared to that of 50-mm-long straw, the unburied percent of 250-mm straw increased by 75% at 10 km h^{-1} speed, 85% at 7.5 km h^{-1}, and 90% at 5 km h^{-1}. For all nine lengths of the straw, the unburied straw percent in mass was ranged from 45 to 85% when tillage speed was 5 km h^{-1}; and it was reduced to 25–40% if tillage speed increased to 10 km h^{-1}.

1. Introduction

Traditionally, crop residues are used as animal feeding or bedding or trash. As an abundant resource of renewable energy, crop residues can reduce GHG emissions by 50% and reduce more than 80% of fossil energy demand (Cherubini and Ulgiati, 2009). However, a minimum amount of residue is still needed to protect soil from wind and water erosion. Increasing residue cover, even by a small amount, decreases soil erosion potential (Laflen and Colvin, 1981). When agricultural residues are used as feedstocks, the amount of crop residue available or can be removed from fields need to be determined in a sustainable manner (Graham et al., 2007). It is very important to be reminded that tillage operations greatly impact crop residue cover (Doughty et al., 1949). Therefore, crop residue management or management of tillage practices plays more important role in sustainable agriculture.

Too much crop residue can make seeding operations difficult. Reducing residue concentration to less than 2.3 t ha^{-1} by baling and removing residue resulted in significant increases in stand establishment and seedling dry weight as compared to treatments

* Corresponding author. Tel.: +1 814 863 6844; fax: +1 814 863 1031.
E-mail addresses: jliu@engr.psu.edu, jxl79@psu.edu (J. Liu).

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where the full quantity of residue was left on the soil surface (Siemens and Wilkins, 2006). Crop residue incorporation has been used as a means to maintain the level of soil carbon. That is, part of the crop residue needs to be incorporated into soil (Chen et al., 2004). The incorporation of crop residue into soil can be beneficial if the carbon–nitrogen ratio remains at an adequate level in the soil. We would be able to control the amount of residue cover to be incorporated or left on soil surface through different tillage practices if quantitative relationships among tillage tools, soil and residue conditions are known.

Each use of a soil-disturbing implement typically reduces residue cover (Colvin et al., 1986). Different soil-engaging tools have an implement effect on residue burial (Hanna et al., 1995). Previous research on crop residue incorporation was focused on the effect of tillage implements and their operations on the residue cover, and all experimental studies were conducted in fields. The benefits of field experiments are well known, but experimental conditions are difficult to control. The effects of tillage on residue cover depend on the speed and depth of tillage operation, type of implement, soil conditions, type and amount of residues, and the height of standing stubbles (e.g. Woodruff and Chepil, 1958; Wagner and Nelson, 1995; Chen et al., 2004). Hanna et al. (1995) studied the effects of operational factors on residue cover using a disk, a chisel, and a knife-type fertilize opener. They reported that shallower tillage depth and slower speed could reduce residue burial. One of the operational parameters that tend to have the largest effect on residue burial by tillage implements is the depth of tillage (Raper, 2004). Researchers quantified the effect of tillage on the crop residue cover by deriving a tillage equation that includes the initial fraction of surface cover, tool dimensions, and soil and tillage operational parameters (Gregory et al., 1982; Wilkins et al., 1983; Koohestani and Gregory, 1985). Unfortunately, these data could not be used for interpreting the physical process of soil, tillage tool, and crop residue interactions. As well, more detailed studies of soil and straw movement, and soil and straw interaction during tillage are required. By manipulating the conditions of the soil and crop residue, and by manipulating the operation of tillage, it is possible to enhance the sustainability of tillage and crop production. Soil movement affecting crop residue movement and burial was not considered in previous studies; no literature was found on studying crop residue movement by tillage. In addition, no sufficient data are currently available for more thorough understanding of soil, tillage tool, and crop residue interactions. Therefore, understanding the relationship between tillage tool, soil, and crop residue is important. Thus, a detailed study on tillage tool–soil–crop residue interaction under controlled conditions is needed, and this is most effectively carried out using a soil bin. Soil bin experiments were designed and conducted in this study. Experimental studies reported by Liu et al. (2007) indicated that a soil bin may not be suitable to simulate a field condition for soil displacement studies. However, a soil bin may be used to simulate field conditions for straw displacement studies. A soil bin may be also used to simulate a field condition for residue incorporation studies if the length of straw is shorter than 250 mm. Based on these findings, soil bin experiments were designed to discover relationships of straw cover, straw length, and tillage speed.

The goal of this study was to better understand the process of tillage tool–soil–crop residue interaction under controlled conditions. The hypothesis of this research was both straw length and tillage speed would significantly impact straw burial or percentage of residue cover at a confidence level of 90%. This confidence level was selected due to the purpose of this study was to explore above-mentioned interaction relationships and no similar data currently available.

The specific objectives were as follows.

(a) To study the effect of straw length and tillage speed on soil and straw movement, and straw burial in a soil bin condition.
(b) To examine the experimental methods of measuring soil and straw displacement and straw burial in a soil bin.

2. Materials and methods

Tracer methods were used to measure soil and straw movement. Tracer methods for measuring soil movement were developed in the study of tillage erosion (e.g. Lobb, 2002). Point tracers are individually labeled objects of various shapes and materials, which have the distinct advantage to characterize complex movement in three dimensions. Different lengths of surface straw in this study were to simulate combine harvesting situation. Many landowners in Canadian Prairies use combines with straw choppers to spread straw in field. The chopping length is adjustable. To determine an appropriate chopping length for a certain straw cover needed was also a purpose of this study.

2.1. Description of the soil bin

The soil bin was located at the Department of Biosystems Engineering, University of Manitoba, Canada. The dimensions of the bin were 15 m long and 1.75 m wide. The bin was 0.5 m deep, and was filled with loamy sand soil to a depth of 0.4 m. A tool carriage was supported by two rails, one on each side of the bin. The maximum travel speed of the carriage was 10 km h^{-1}. A full-width rotary tiller drawn by the carriage was used for tilling

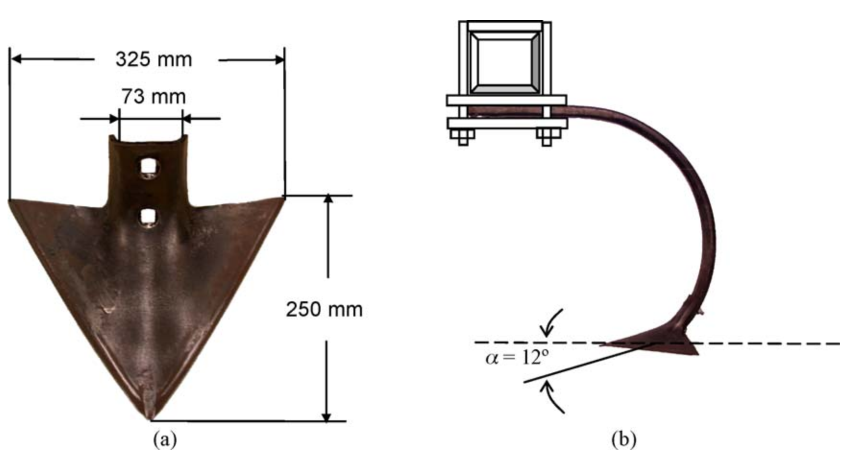

Fig. 1. Tool configuration: (a) the sweep (McKay 50-12K); (b) the sweep and shank.