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# Performance evaluation of fluted coulters and rippled discs for vertical tillage

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ABSTRACT

Vertical tillage (VT) is the latest form of conservation tillage dealing with excessive residue. Information on the performance of VT equipment is lacking in literature. In this study, five VT tools were tested in a corn stubble field to compare their performance. They were two coulters with 8 flutes (C8) and 13 flutes (C13), and three rippled discs with different diameters: 457-mm (D457), 508-mm (D508), and 559-mm (D559). All the five tools were tested at a working speed of 16 km/h and tillage depth of 100 mm. The results showed that increasing disc diameter from 457 to 559 mm resulted in significantly increased residue incorporation (44%), soil opening width (30%), soil disturbance area (127%), and lateral cutting force (79%), as well as decreased residue cover (5%). Increasing the number of flutes from 8 to 13 resulted in significantly lower soil sticking (39%) and soil opening width (29%), but a significantly higher residue cover (7%). Overall, the fluted coulters performed more aggressively than the rippled discs in disturbing soil and incorporating residue, and had a higher draft force and a higher soil sticking. Among all the tools, the D457 conserved the most amount of residue on the soil surface and disturbed the least amount of soil, whereas the C8 was the most intensive VT tool in these regards. The D559 had the highest soil loosening efficiency, defined as the soil loosening area divided by the draft force.

## 1. Introduction

Conservation tillage has received tremendous attention in most of the agricultural systems as it improves soil quality (Madejon et al., 2009; He et al., 2011), increases crop yields (de Vita et al., 2007; Naudin et al., 2010), controls soil erosion (Prasuhn, 2012), and reduces production cost (Tullberg et al., 2007). However, excessive residue in the conservation tillage systems is detrimental to seeding operation, seed germination, and early plant growth. Other than equipping planters with various coulters as leading tools to cut residues (Erbach, 1981; Raoufat and Mahmoodieh, 2005), agricultural producers have been seeking alternative conservation tillage systems to alleviate the problems of excessive residue. Vertical tillage (VT) was proposed as an alternative conservation tillage that cuts residue aggressively to improve seeding conditions while protecting soil and the environment. Although many agricultural machinery manufacturers, e.g., John Deere (Moline, Illinois, USA) and Great Plains (Salina, Kansas, USA), have released their VT machines, performance of those machines have not been well documented. Some studies on VT have been recently reported in the literature, and most of them concerned about the effects of VT equipment on agronomic and environmental aspects such as soil temperature and moisture content, crop emergence, plant stand, grain yield (Walther, 2017), and water quality in runoffs (Smith and Warnemuende-Pappas, 2015). In a recent study, the resultant soil and residue conditions of fluted coulters for VT were examined (Zeng and Chen, 2018). No other literature has been found on evaluations of VT tools in terms of engineering aspects, such as soil cutting forces and soil disturbance.

The common soil-engaging tools of VT equipment are various rotary tools, such as coulters and concave discs (Chen et al., 2016). Each rotary tool can be characterized by its diameter and edge shapes such as plain, notched, bubble, and rippled (ASABE Standard S477.1, 2013). The concave discs with different concavities and edge shapes are the major soil-engaging tools of disc tillage implements, such as disk harrow and disk plow (ASABE standard S414.2, 2009). The coulters with different edge shapes, such as bubble and fluted coulters, are typically found in seeding machines of conservation tillage systems as soil and residue cutting components (ASABE standard S477.1, 2013). The concave discs for tillage purposes are usually operated at a gang angle, while the coulters are set at a zero gang angle. Those rotary tools were widely adopted in VT equipment to size crop residue and shatter soil in the top layer. The intention is to create a field condition that facilitates seeding operation, residue decomposition, soil conservation, crop growth, and other field operations in a cost-effective manner.

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With the focus of dealing with excessive residue, several indicators including residue cover, incorporated residue, and size of residue have been suggested to assess the performance of VT soil-engaging tools (Chen et al., 2016). The residue cutting capacity of various rotary blades has been extensively studied. In general, use of rotary blades significantly decreased the residue cover (Raoufat and Mahmoodieh, 2005). Resultant residue conditions depend on the type and shape of the tool as well as the field conditions. The amount of residue cut by plain coulters was inversely proportional to residue density and proportional to working depth (Kushwaha et al., 1986). The coulter sharpness was an important parameter affecting cornstalk residue shearing, where the amount of sheared residue increased with the increases in coulter sharpness (Choi and Erbach., 1986). The smooth and rippled coulters worked superiorly to notched coulters in terms of cutting residue (Karll et al., 1978). Meanwhile, a comparative soil bin test between a toothed, notched, and smooth coulter on sugar cane residue found that the toothed coulter cut the most amount of residue with lowest energy requirements (Bianchini and Magalhaes, 2008). These existing studies were for traditional tillage and seeding, not for VT involving high speed operations.

The performance of rotary tools is affected by several geometrical and operational parameters of the tools, as well as soil and residue conditions. A comprehensive investigation on the performance of different coulters in a residue-free field indicated that coulter shape and style had no significant effect on draft and vertical forces, but influenced furrow formation and the level of soil disturbance (Schaaf et al., 1980). Soil dynamics of a single rotary blade is sensitive to blade diameter (Kushwaha et al., 1986), wedge tip curvature (Choi and Erbach, 1986), blade thickness (Tice and Hendrick, 1992), disc angle and rotational speed (Salokhe and Quang, 1995). Although an empirical power model explained the variation of coulter forces with the cutting depth (Tice and Hendrick, 1991), none of these soil and coulter geometrical parameters were considered in the model. An investigation of the interaction among discs in a gang found that the interaction had a stronger effect on the draft force than the vertical force (Chapman et al., 1988). Most of the existing studies focused on plain rotary blades working at low speeds in conventional tillage systems. However, the tillage performance of a fluted coulter was significantly affected by high working speeds ranging from 12 to 20 km $h^{-1}$ (Zeng and Chen, 2018).

In summary, the information on tillage performance and its affecting factors of VT soil-engaging tools are lacking in assessing this new conservation tillage practice. The objective was to evaluate the performance of five typical VT soil-engaging tools in terms of soil cutting forces, as well as soil and residue conditions.

## 2. Material and methods

### 2.1. Site description

A field experiment of fall tillage was conducted in November 2016 at a research farm in Portage la Prairie, Manitoba, Canada. A corn stubble field with corn stover being chopped and evenly spread over was used for the experiment. The field had a silty clay soil (43% clay, 48% silt, and 9% sand) within normal tillage depth. Soil moisture content and bulk density were measured using the core sampling method. Soil shear strength and penetration resistance were measured using a Vane Shear Meter (Geovane, New Zealand) and a Pocket Penetrometer (Geotester, Italy), respectively. Residue cover and density were measured using the image thresholding method and the quadrat sampling method, respectively. Details regarding those measurements can be found in Zeng and Chen (2018). Initial soil and residue conditions are summarised in Table 1.

### 2.2. Description of the VT tools

The VT soil-engaging tools tested were two fluted coulters and three rippled discs (Fig. 1a). The two fluted coulters had the same diameter (559 mm), but one had 8 flutes and the other had 13 flutes. The flutes of the coulters formed a wavy circumference that was designed to enhance lateral soil shattering. The rippled discs had different diameters, i.e., 559 mm (22 in., 508 mm (20 in., 457 mm (18 in., but they all had 25 ripples and 25 “saw teeth”. The saw tooth edge was designed to aggressively cut crop residue and self-sharpening. For the purpose of data interpretation, some common geometrical parameters were defined for the coulters and discs (Fig. 1b). The terms, flute and ripple were interchanged with wave. The working width of the coulters was the overall width of the waves along the circumference. The working width of the discs was the concavity. The wave radial length was the length of the wave along the tool radius. These geometrical parameters are independent of working conditions. The following parameters depend on the working depth. The cutting angle was the angle between the circular cutting edge of the tool and the soil surface. The number of engaging waves was the equivalent number of waves working in the soil at any moment. The pressure area was the surface area of the tool below the soil surface projected onto a vertical plane perpendicular to the travel direction. The soil trapping volume was the volume confined by soil surface, tool surface and an imaginary vertical plane parallel to the travel direction. Given a specific working depth of 100 mm, the values of these parameters were calculated and listed in Table 2.

In field tests, a single tool was mounted on a toolbar through a coiled shank (Fig. 1c). The shank was attached to a testing frame through a dynamometer. Two gauge wheels of the frame controlled the tillage depth. The frame was pulled by a tractor through a three-point hitch.

**Table 1**
Initial soil and residue conditions.

| Measurement | | Unit | Value |
|---|---|---|---|
| Soil | Moisture content | % | 35.7 ± 2.4 |
| | Dry bulk density | kg $m^{-3}$ | 1325.2 ± 62.8 |
| | Penetration resistance | kPa | 367.8 ± 114.6 |
| | Shear strength | kPa | 72.0 ± 23.1 |
| Residue | Cover percentage | % | 98.1 ± 0.8 |
| | Standing density | kg $ha^{-1}$ | 1853.8 ± 462.1 |
| | Flat density | kg $ha^{-1}$ | 7375.6 ± 3326.1 |

### 2.3. Experimental design

A completely randomized design was used for the experiment. Treatments were five different tools: the 8-flute coulter (C8), 13-flute coulter (C13), and 559-mm (D559), 508-mm (D508), 457-mm (D457) rippled discs. Each treatment was replicated five times. Thus, a total of 25 field plots were used in the experiment. The plots were 3 m wide to accommodate one pass of the tractor. The plots were 30 m long and laid out perpendicular to the previous crop rows. The working speed and the cutting depth of the tools were set at 16 km $h^{-1}$ and 100 mm respectively for all the treatments. There were buffer areas at two ends of the field for tractor acceleration and deceleration to ensure a constant working condition within the 30-m plots.

### 2.4. Measurements

All the measurements were conducted at three random locations in each plot, unless specified otherwise.

#### 2.4.1. Soil cutting forces

The force data was measured by the dynamometer shown in Fig. 1c. As the tillage tool travelled in the soil, force signals were recorded by a data acquisition system at 65 Hz. The data were then retrieved to calculate the soil cutting forces including draft ($F_D$), lateral ($F_L$), and