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The performance of a fluted coulter for vertical tillage as affected by working speed

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ABSTRACT

Vertical tillage is an efficient and effective tillage practice for conservation agriculture. However, the performance of vertical tillage tools has not been well documented. In this study, two vertical tillage tools: 8-wave and 13-wave coulters, were tested in a wheat stubble field at three different working speeds: 12, 16, and 20 km/h, to examine the effects of tool geometry and working speed on the tillage performance of the fluted coulters. Soil disturbance width, soil throw width, and soil sticking on the coulter as well as residue cover were measured. The results showed that the soil disturbance width was significantly different among the working speeds and between two coulters while the other measured variables were only affected by the working speed. The 13-wave coulter had a 17% lower soil disturbance width as compared with the 8-wave coulter. Increasing the working speed (from 12 to 16 km/h and from 12 to 20 km/h) increased the soil disturbance width by 7.0 and 13.1% and the soil throw width by 14.3 and 45.1% respectively, but decreased the soil sticking by 1.4 and 76.6% and the residue cover by 5.1 and 11.0% respectively. Generally speaking, the effect of working speed was more dominant than the coulter geometry on the tillage performance of the fluted coulters. For long-term no-tillage farmers with excessive residue concerns, the 8-wave coulter working at 20 km/h would be beneficial for sustainable farming practice.

1. Introduction

Conservation tillage, including no-tillage, aims to increase the profitability and sustainability of crop production, and its main advantage over traditional tillage is leaving at least 30% residue cover in the field to protect the soil and environment. In no-tillage systems, crop residue cover is often as high as 100%. A dilemma in conservation tillage systems is that the crop residue causes plugging of tillage and seeding equipment. Vertical tillage (VT) has been recently proposed to tackle the dilemma. In VT, crop residue is cut into small pieces, which avoids plugging seeding equipment in the subsequent seeding operation. The residue is partially mixed with soil for fast decomposition, while an essential amount of residue is maintained on the soil surface for soil protection. Thus, VT is a conservation tillage practice. In addition, VT has several other advantages over conventional tillage. An on-farm study of several commercially available VT machines showed that VT is more desirable in terms of soil and water conservation as compared with traditional tillage equipment on a site-specific basis (Klingberg and Weisenbeck, 2011). As for crop yields, the literature reported mixed results. A comparative study between VT and no-till found that VT significantly increased the plant population and yield with a marginally higher lodging resistance regardless of seeding rates (Watters and Douridas, 2013). Whitehair (2014) reported that VT did not yield more grain at any of nine site locations over a two-year period as compared with conventional, no-till, and reduced tillage systems. Vertical tillage successfully delayed runoff initiation in rainfall simulations; however, the steady-state rate and total amount of runoff were significantly higher in VT as compared with no-tillage (Smith and Warnemuende-Pappas, 2015). Vertical tillage is a recent concept, and little research has been done in this area.

In VT, soil-engaging tools interact with soil in a vertical plane perpendicular to the soil surface and along the travel direction (Chen et al., 2016). To date, vertical tillage equipment has been developed by many agricultural manufacturers, such as Great Plains (Salina, Kansas, USA), Salford Group (Salford, ON, Canada), and Kongskilde Industries (Soroe, Denmark) (Kanicki, 2014). The VT machines varied significantly in configuration, size, and functionality. For example, two different arrangement of VT implements were demonstrated in Chen et al. (2016) as disk-roller arrangement and disk-tine-roller arrangement. The leading and major working components of VT equipment are mostly coulters, but concave discs with small gang angles have also been used. Coulters are the least intrusive yet effective vertical tools that slice soil,

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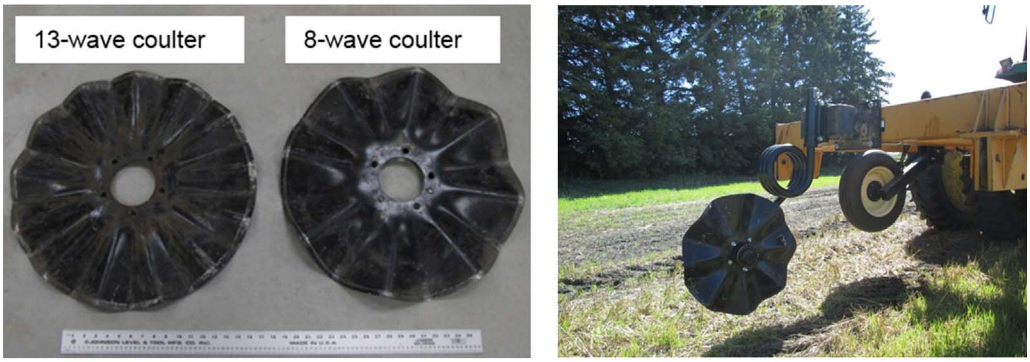

(a) (b)

Fig. 1. Coulters tested: (a) two different fluted coulters; (b) coulter and shank mounted on the toolbar.

cut residue, partially incorporate residue, and loosen soil. Coulters can be either configured on gangs or individually mounted using shanks. As compared with the gang configuration, the individual shank systems have several advantages: no interaction between coulters, more uniform tillage depth in an uneven condition, rock protection, less residue collection, and more accessible for maintenance. However, the individual shank configuration is usually more expensive to manufacture than the gang configuration. Traditionally, coulters were used on planters as seed openers and fertilizer banding openers (Fallahi and Raoufat, 2008). Coulters were also used on some conventional tillage equipment as auxiliary tools, for example, in the front of subsoiling tools (Zhang et al., 2007). Those coulters were typically straight coulters for the purpose of cutting residue and opening slots in the soil. The working speed of seeding and traditional tillage equipment typically ranges between 5.5 and 11 km/h (ASABE Standard D497.7, 2015). Coulters for VT are larger in diameters, and have more complex geometries as well as more aggressive residue cutting abilities. They are varied significantly in shape, dimension, and operating angles. These coulters are designed to travel at much higher speeds: 12 to 20 km/h (Chen et al., 2016).

The working speed is one of the most dominant operator-controlled variables that affect the performance of the soil-engaging tool (Stafford, 1979; Wheeler and Godwin, 1996). Tice and Hendrick (1992) inferred that a high speed may contribute to effective residue cutting by observing the kinematic behaviour of straight coulters in soil bin tests. Sarauskis et al. (2013) and Fiaz et al. (2015) experimentally confirmed that the coulter at increased speeds had an increasing residue cutting efficiency in wheat and rice fields respectively. However, coulters for VT that work at high speeds have not been well documented.

Soil and residue conditions resulting from a tillage operation is also affected by the geometry of the tillage tools. Experimental studies on the performance of different coulters in the residue-free condition indicated that furrow characteristics and soil disturbance varied with coulter geometry (Schaaf et al., 1980; Godbole, 1997). After a comprehensive study of four coulters with different shapes, Godbole (1997) concluded that the lateral soil displacement depended on the specific coulter surface area that contacted with soil, rather than the general geometrical characteristics of the coulters. Sarauskis et al. (2013) compared four different notched coulters on their residue cutting ability in a winter wheat field and found the one with the most notches and the deepest notches performed the best. Although Choi and Erbach (1986) reported that the coulter shape had no significant effect on cornstalk residue shearing, the coulter sharpness was the most important coulter geometrical characteristics influencing residue shearing. Similarly, a coulter with toothed geometry significantly improved the residue cutting efficiency (Magalhaes et al., 2007). As for the residue cover, several models and databases have been proposed by Stott et al. (1988) and Soil Conservation Service and the Equipment Manufacturers Institute (1992) regarding the effect of tillage tool geometry on the residue cover after field operations. There is a lack of information on the resultant soil and residue conditions from VT coulters. This information is crucial to guide the design of high-performance VT equipment.

In summary, previous coulter-related studies were carried out for small, straight coulters at low working speeds in traditional tillage. Little research has been done on large coulters at high working speeds in VT. This study focused on a specific type of VT tool, fluted coulters, rather than performing a comprehensive investigation of all VT tools. The objective of this study was to evaluate the tillage performance of two fluted coulters working at different speeds, in terms of soil disturbance and residue cover.

2. Material and methods

2.1. Site description

A field experiment was conducted in August 2016 at a research farm in Portage la Prairie, Manitoba, Canada. The soil type was silty clay with 46% clay, 49% silt, and 5% sand content. The field had winter wheat stubble with a row spacing of 0.25 m and a stubble height of approximately 0.15 m, and wheat straw was chopped by the combine straw chopper and evenly spread over the field in July 2016.

2.2. Equipment description

The VT tools tested were two fluted coulters with 8 and 13 waves, named as 8-wave and 13-wave coulters respectively (Fig. 1a). For each test, a single coulter was mounted to a toolbar through a coil shank (Fig. 1b). The toolbar had a three-point hitch and two gauge wheels for controlling the tillage depth. The original mounting of the shank allowed the coulter floating with a range of gang angle of 0–20°. In the tests, the gang angle of the coulters was fixed at zero degrees to avoid effects of the gang angle variation. The tilt angle of the coulter was also set as zero for the tests.

Both the fluted coulters had a diameter of 559-mm with formed flutes radiating from the outer periphery toward the centre. The fluted coulters consisted of equal-spaced waves along the thrust direction. Geometrical parameters of the coulters are listed in Table 1. These parameters are of importance in relation to the resultant soil and residue conditions. The working width is the maximum width measured at the periphery of the coulter. The coulter flutes can be characterized with wave gang angle and wave tilt angle. The wave gang angle was defined as the angle between the wave plane and the travel direction on the horizontal plane that was parallel to the soil surface. The wave tilt angle is defined as the angle that the wave plane makes with the vertical axis on the vertical plane that was perpendicular to the travel