Vertical Tillage and Vertical Seeding

Author#1
Ying Chen, Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6
Corresponding author Tel.: +1 204 474 6292; fax: +1 204 474 7512. E-mail address: ying.chen@umanitoba.ca

Author#2
Shêne Damphousse, Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6

Author#3
Hongwen Li, College of Engineering, China Agricultural University, Beijing 100083, China

Written for presentation at the
CSBE/SCGAB 2016 Annual Conference
Halifax World Trade and Convention Centre
3-6 July 2016

ABSTRACT In conservation agriculture, 30% to 100% of crop residue is left in the fields for soil erosion, soil fertility, and environment protection. However, excessive residue in the field causes plugging of traditional tillage and seeding equipment, which adversely affects crop emergence and yield. Vertical tillage (VT) and vertical seeding (VS) have been recently proposed as solutions to these problems. In this study, VT and VS were reviewed based on their history, definitions, functions, current field evaluation, and measurement methods. As an example of performance evaluation, a field study was conducted using a prototype planter for VS. The treatments were the combinations of three different planter travel speeds (2, 4, and 7.5 km/h) and four different residue levels (0, 2750, 5500, and 8250 kg/ha). Furrow cleanness and seeding depths were measured. Results showed that furrow cleanness was low as the initial residue level increased. Increasing the planter travel speed from 2 to 4 km/h resulted in a significant increase in furrow cleanness. However, there was no further increase in furrow cleanness at 7.5 km/h. Seeding depth did not vary with the residue level. The average seeding depth for all four residue levels was 41 mm. The planter seeded significantly deeper at 2 km/h than higher speeds (4 and 7.5 km/h).

Keywords: Vertical tillage, vertical seeding, residue, corn, planter, performance
INTRODUCTION  At a time when agriculture sustainability, cost of energy, and environmental impact are critical concerns, field operation is evolving from horizontal tillage to vertical tillage (VT), and from horizontal seeding to vertical seeding (VS). Vertical tillage originated from no-till corn systems in the Midwest, United States in 1990’s. No-till farmers in those regions faced seeding on heavy corn residue. To make seeding easier, they wanted to have tillage equipment that was able to cut residue into small pieces and mix them with soil for fast decomposition, while maintaining some residue on the soil surface for soil protection. The use of VT made these visions possible and changed the original no-till system to one pass of VT before seeding. Therefore, VT was loosely known as "tillage for no tillers" (Pearce, 2014). To date, vertical tillage equipment has been developed by many agricultural manufacturers, such as Great Plains, McFarlane Manufacturing, Salford Group, Summers Manufacturing, Thurston Manufacturing, Earth Master, Kuhn Krause, Environmental Tillage Systems, HCC Inc., Case IH, Landoll Corp., Kongskilde Industries, Maschio, and Sunflower (Kanicki, 2014).

Vertical tillage has many advantages over the traditional tillage practices, such as better cutting of soil and residue, management of residue without complete burial, helping planter/drill work through residue without plugging; providing uniform soil bulk density in the seedbed profile, and lower draft force requirement, and therefore faster travel speed. However, there has been mixed findings for the effect of VT on crop yield. A study comparing no-till and VT by Watters and Douridas (2013) found that VT increased the yield and plant stands, and also increased the profit by $12 per acre for soybean. In a study comparing different tillage practices for corn-soybean rotation, Kevin (2008) concluded that there was slightly higher yield for corn using VT, but no significant difference for soybean.

Over the years, various sources have described the definition of VT. However, it is still unclear. Dietz (2011) stated that VT is a combination of no disturbance to the residue and removal of any hardpan through soil penetration; Smith and Warnemuende-Pappas (2015) described that the concept of VT aimed to diminish the residue cover to minimally affect the crop in rotation; Whitehair (2010) defined VT as shallow tillage that resulted in no horizontal disturbance of the soil. Pearce (2014) describes it as a residue management technique that includes cutting up and anchoring the residue so that the wind and water does not take it farther from the field. Very recently, the use of different types of soil engaging tools has also become part of the definition of VT. In summary, further discussion is required to precisely define VT.

The concept of VT can be applied to seeding for VS, aiming to deal with heavy crop residue, while increasing field efficiency and lowering energy consumption. With the increase in popularity of no-till, VS will become necessary to manage crop residue while maintaining certain amount of surface residue for its benefits to the environment and reducing operating costs (Pollock and Reeder, 2010). Currently, the main challenge for VS is for openers to cut through heavy residue, such as corn stalks. In the past, several solutions have been proposed to seed in no-till fields, such as using a row cleaner (Gursoy, 2014). Residue removal by a row cleaner ranged from 40 to 63% as reported by Yang et al. (2015). Raoufat and Matbooei (2007) evaluated the performance of a conventional corn planter with a row-cleaner and found that the amount of residue cleared in the row area was 920 kg/ha as compared to 1350 kg/ha without the row cleaner. These results showed the limited effectiveness of row cleaners in heavy residue fields. Use of VS will be more effective for managing heavy residue.

Vertical tillage is a recent concept, and vertical seeding is a new term. To date, little research has been done on both these concepts. For better understanding of VT and VS, this study aimed to: 1) define VT and VS and review their functions, and 2) propose performance indicators of VT and VS and conduct a field experiment to evaluate a planter for VS.
DEFINITIONS OF VERTICAL TILLAGE AND VERTICAL SEEDING

Vertical soil engaging tools Soil engaging tool is a general term for any tillage and seeding tools. They can be classified as horizontal and vertical soil engaging tools, in terms of soil-tool interaction. Soil-tool interaction can occur on a horizontal plane or a vertical plane in the soil cross-section as illustrated in Fig. 1. For a horizontal soil engaging tool, the soil-tool interaction occurs in the horizontal plane parallel to the soil surface. Examples of horizontal tools include a moldboard plow and a sweep. For a vertical tool, the soil-tool interaction occurs on the vertical plane perpendicular to the soil surface. Examples of vertical tools include a coulter and a runner opener.

Soil can be subjected to shear, compression, and impact force, or a combination of these forces when interacting with a vertical tool. Figure 2 lists some examples of vertical tools. The most common vertical tool is a coulter. A coulter can be a plain coulter (Fig. 2a), a wavy coulter (Fig. 2b) or a notched coulter. Wavy coulters are designed for self-sharpening, and notched coulters are designed to improve soil penetration capacity. Coulters primarily subject shearing force when interacting with soil. As the vertical force of coulter distributes on a thin blade, the theoretical projected area of a plain coulter on the horizontal plane is nearly a “line” which is equivalent to the blade thickness. Therefore, the normal contact area between the coulter and soil is nearly zero, which will prevent the creation of plow pan in the soil. Another tool that uses shearing force is a runner opener (Rahman et al., 2001). A runner opener is not a rotary tool; therefore, soil penetration at high travel speed will be a challenge. Rollers (Fig. 2c) are typical vertical tools that compress soil to break large soil clods and level the soil surface. Packer wheels attached to a seeder also serve as vertical tools by compressing soil to ensure a firm seedbed. Rolling tines (Fig. 2d) interact with soil through compression and shear forces. It compresses soil as it penetrates the soil, and shears soil as it is retracted from the soil. Rolling tine has not been commonly used in VT due to its low operational speed. Rotary hoe (Fig. 2e) can also be classified as a vertical soil engaging tool. Besides compressing and shearing soil, rotary hoe impacts the soil due to its high rotational speed. Small concave discs (Fig. 2f) have been used for VT to enhance soil-residue mixing. Technically, concave discs move soil more horizontally as compared to coulters that have no concaves.

Vertical soil engaging tools can be further classified, in terms of their motion, as rotary and translational tools. Rotary vertical tools include coulters, rollers, packer wheels, and rotary hoes. Translational tools include runner openers and knives. Rotary tools have lower draft forces than
translational tools. Thus, vertical equipment with rotary tools can be built at a large-scale and can travel at twice the speed of traditional equipment.

![Image of vertical soil engaging tools](image)

(a) Plain coulter  
(b) Wavy coulter  
(c) Basket roller  
(d) Rolling tine  
(e) Rotary Hoe  
(f) Concave disc

Figure 2. Example of vertical soil engaging tools.

**Vertical tillage** In a broad term, VT is the tillage performed using vertical soil engaging tools. Technically, VT can be defined as the tillage in which soil-tool interaction takes place in a vertical plane. As an example, Fig. 3 illustrates the path of rotary tools arranged in ranks and gangs with a zero gang angle. As these tools rotate and move forward, they size residue into segments that do not plug the equipment in tillage and seeding operation and residue is mixed into the soil, which facilitates decomposition. Small tool spacing in VT creates a narrow range of soil aggregate sizes. Therefore, the resultant seedbed has more uniform soil bulk density and porosity, and appropriate aggregate sizes for seed germination and emergence.

![Diagram showing the concept of vertical tillage](image)

Figure 3. Diagram showing the concept of vertical tillage.
**Vertical seeding** In a broad category, VS is the seeding operation performed using vertical soil engaging tools. Similar to VT, VS can be defined as the operation in which the soil-tool interaction occurs in a vertical plane. As the vertical tools move forward, they cut residue and create soil furrows for placement of seed and fertilizer. Complete cutting of residue will avoid residue hair pinning and promote a good soil-seed contact. Common openers for VS are coulters, but they have been traditionally known as disc openers (with no concaves), such as double-disc and single-disc openers. As opposed to these vertical openers, horizontal openers, such as sweeps and hoes, shear soil or move soil more horizontally, and the resultant soil furrows are large in cross-section area. In heavy residue conditions, horizontal openers do not cut residues, but drag them, which causes plugging of the seeder.

**FUNCTIONS OF VERTICAL TILLAGE AND VERTICAL SEEDING**

**Functions of vertical tillage** Coulters are the most common tools used for VT implements, and wavy coulters are more often used (Fig. 4a). Coulters cause little lateral movement of soil, and plain coulters with a zero gang angle cause the least soil movement. Conical discs (Fig. 2f) have been also used as VT implements, and they contribute to horizontal shearing of soil due to their concaves, when compared to coulters. For better residue cutting and soil penetration, coulters and discs should have high down pressure and larger diameter (450 to 650 mm). Selection of down pressure and disc diameter depends on type of residue and amount of residue in the field. Following residue cutting and mixing, soil is typically conditioned using harrows. The conditioning process eliminates ridges and pulverises large soil clods. Choices of harrows include rollers and finger tines. Rolling basket has lugs with flat bars or round bars, which helps break large soil clods, and finger tines help to evenly spread the residue. Both equipment move soil around and level it.

A VT implement may have several ranks of same or different tools in a gang. Types of tools vary with implements. In general, people refer these tools as front and rear tools. In most cases, the front tools are discs or coulters, and the rear tools are rollers and tines. The implement shown in Fig. 4b can be referred as a disc-roller arrangement, featuring two ranks of discs and two ranks of rollers. The front row(s) of large discs with high down pressure will cut residue, dislodge roots, and mix residue into soil. The second rank of discs is mainly used for mixing of residue and soil. They are placed on the toolbar with a 200 to 300 mm spacing and gang angle ranging from 0 to 15°. Increased gang angles or using non-straight discs will result in increased lateral shearing of soil and residue mixing. Rollers at rear ranks provide good crumbling of soil. Although disc and roller angles are adjustable, those angles should be kept at a minimum for VT to avoid excessive horizontal shear. Another configuration is disc-tine-roller arrangement (Fig. 4c). It consisted of two ranks of plain discs and a rank of wavy discs, followed by three ranks of finger tines in the middle, and a rank of rolling baskets at rear end. More ranks of rear tools decrease the need for post-tillage soil preparation.

For producers who face considerable compaction and water infiltration issues, the machine may be configured with ranks of subsoiling tools. This eliminates the compaction layer created by field traffic, or plow pan at the operating depths of previous tillage (Gameda et al., 1985). However, most subsoilers are not vertical soil engaging tools. Vertical tillage can also be used for emergency tillage. When soil is too wet to seed, passing a VT implement at a higher speed will throw soil in the air and speed up the drying process. In cool regions, vertical tilling can warm the soil for quicker emergence and manage wet seedbeds.
Functions of vertical seeding A VS implement features vertical soil engaging tools, such as coulters, runner openers, and packer wheels. Coulters are required for openers that do not have a rolling or cutting action, such as runner opener that tends to float above the residue and can potentially clog from residue wrapping around the opener. In heavy residue conditions, the disc seed opener typically requires a coulter in the front. Those coulters cut residue and function as fertilizer banding openers as well. The implement shown in Fig. 5a had an additional rank of wavy coulters in the front of fertilizer banding openers for seedbed preparation. The fertilizer banding openers on the second rank were also wavy coulters. The seed openers were double disc openers, followed by packer wheels. The seeding unit shown in Fig. 5b consists of a wavy coulter for fertilizer banding, a disc opener, a gauge wheel, and a packer wheel. The packer wheel had an inclined angle, which would result in some lateral soil movement. Scrapers are a necessary part of disc openers (Fig. 5c).
FIELD EVALUATION OF PERFORMANCE

Performance indicators Traditionally, a soil engaging tool was designed with the objective that the tool requires minimum force/power and creates the optimal soil conditions for seeds and plants. However, for vertical soil engaging tools, residue-related performance should also be evaluated. The following describes the performance indicators and the measurements methods for VT and VS.

Figure 6a shows recently harvested corn stubble before tillage, which had 100% residue cover. After one pass of a disc-roller vertical tillage machine, residue cover was reduced to about 70% (Fig. 6b). Klingberg and Weisenbeck (2011) also reported that 75-80% of the corn residue from previous year was intact after one-pass of vertical tillage implement. Amount of surface residue change before and after field operation is an important performance indicator, as it reflects the extent of residue incorporation and soil disturbance. Thus, amount of residue on the surface should be measured before and after VT. Residue cover can be quantified in terms of mass per unit area using the quadrant method, or in terms of percentage of cover using the rope method. These methods are described later in the paper. Image analysis can also be used to measure residue cover (Chen et al. 2004a).

Incorporated residue is reflects the amount of residue mixed with soil, which affects residue decomposition. Therefore, this performance indicator should be evaluated for VT. It can be measured using the soil core method (Chen et al., 2004a). The minimum diameter of the core should be 100 mm, and the depth of the core should be the same as the tillage depth. Residue in the core is extracted by washing out the soil. The extracted residue is oven-dried at 60°C for 72 hours and weighed to determine the dry mass of the residue incorporated into the soil (kg/ha).

Size of residue is critical for VT implement, which has the purpose of sizing residue. The length of the resultant residue segments is affected by the spacing of coulter or disc blades. In general, size of corn residue can be reduced from about 80 to 150 mm. To examine the effectiveness of residue cutting, residue samples should be collected before and after tillage. The length of residue can be measured using a ruler (Fig. 6c).

Hairpinned residue is an important indicator for VS. It is defined as amount of crop residue pushed into the seed furrow by an opener. Hairpinned residue can be measured using the soil monolith method. Soil monoliths are procured from the soil surface along seed furrows immediately following seeding operations. Monoliths are also taken before seeding trial as a background reference. The width of monolith is selected to cover the soil disturbance width, and the depth of the monolith is the same as the seeding depth. Chen et al. (2004b) used a monolith size of 150 mm long, 50 mm wide,
and 50 mm deep. Soil in the monoliths is washed out using a plant root-washer to extract the hairpinned residue.

FIELD EVALUATION OF A PLANTER FOR VERTICAL SEEDING

Material and methods Field test of a planter was conducted in August 2015, on an Agriculture and Agri-Food Canada Research site in Portage la Prairie, Manitoba. The soil was Dugas silty clay (5% sand, 49% silt, and 46% clay). The previous crop residue was corn. The field was not tilled after harvest in the previous year, which made it an ideal condition to test the performance of the planter for residue cutting. The planter (Fig. 7a) was a prototype two-row planter designed for VS. It consisted of a notched coulter for fertilizer banding (Fig. 7b), followed by a double disc seed opener and a rubber gauge wheel (Fig. 7c). A vacuum precision meter was used to meter corn seeds down the shoot and into the soil.

![Figure 7](image)

Figure 7. The prototype planter for vertical seeding; (a) entire unit; (b) fertilizer banding opener; (c) double disc seed opener.

A randomized block design was used for the field test. The treatments were the combinations of four residue covers (R0, R1, R2, and R3) and three planter travel speeds (2, 4, and 7.5 km/h). Each treatment was replicated five times in five blocks; forming a total of 60 plots (4 residue covers x 3 travel speeds x 5 replications). Within each block, residue was rearranged to form four levels of residue cover. The residue in the R0 plot was completely removed, and the R1, R2, and R3 represented 1 time, 2 times, and 3 times the original residue cover of the field, respectively. The final residue conditions are shown in Fig. 8. The travel direction of seeding was across residue levels as illustrated in Fig. 9. Each plot was 6 m long, and the width allowed for two passes of the planter. Three travel speeds in each block were randomly chosen.

![Figure 8](image)

Figure 8. Four different residue cover conditions used in the field experiment.
Before tests, five cores (50 mm diameter by 100 mm height) were taken at random locations of the field. Soil cores were weighed, oven-dried for 24 hours at 105°C, and weighed again to determine the soil moisture content and dry bulk density. Mass of the surface residue of the field was measured before the rearrangement of residue treatments. Residue within a 1 m² quadrant (Fig. 8b) was collected at eight random locations of the field. The collected residue was oven-dried for 72 hours at 60°C (ASABE Standard, 2012), and weighed to obtain the dry mass (kg/ha). The dry mass obtained represented the residue cover for the R1 treatment, as the residue samples were taken before the rearrangement of residue treatments. The average value of the measured dry mass was used to determine the corresponding residue level for R2 and R3 by multiplying by 2 and 3, respectively.

After tests, furrow cleanness was measured to examine the effectiveness of opener in removing residue from the furrow area. This is a critical performance indicator for vertical seeding. Furrow cleanness was defined as the percentage of soil surface on the furrow which was not covered by residue. It was measured by the rope method. A 5-m rope with markers at each 0.3 m was placed along the furrow (Fig. 10a). A residue was counted when it coincided with the markers on the rope. The number of counts was divided by the number of marks on the rope to represent the fraction of residue cover on the furrow. The furrow cleanness was then determined by subtracting the fraction of the residue cover from 1.0 and was expressed in percentage. This measurement was performed for a total of 240 rows, with 4 rows per plot.

Amount of hairpinned residue should be measured for vertical seeding. However, in this case, hairpinning was not observed. Plant response is important in any seeding experiment, including vertical seeding. In this case, speed of emergence, plant growth, and yield were not measured as the seeding experiment was conducted later in the growing season and the data would not reflect the results of a normal farming practice. Therefore, only seeding depth was measured in this study. For measuring the seeding depth, the entire plant with seed and roots was dug out, and the length of the mesocotyl (distance between the seed and the sub-surface part of the stem) was measured, as illustrated in Fig. 10b. This measurement was performed for 300 plants, with 5 plants per plot.

Analysis of variance (ANOVA) was performed using SAS (version 9.3). The significance of the effects of the experimental factors was examined. Means were compared between treatments using Duncan’s multiple range tests at a probability level of 5%.

**Results and discussion** The field had a soil moisture content of 35.5% (d.b.) and a dry bulk density of 1,284 kg/m³ before seeding, which were typical for a silt clay soil. The initial corn residue dry mass measured for the treatments R0, R1, R2, and R3 were 0, 2750, 5500, and 8250 kg/ha, respectively.
Visual observation of the field showed that most of the furrows were cleared of residue and only few pieces of residue were seen on furrows, as shown in Fig. 10a. The furrow cleanness data showed that the planter performed well overall as it cleared at least 90% residue for all treatments. The plots without any initial residue (the treatment R0) showed the highest cleanness (near 100%) as expected (Fig. 11a). Statistically, the R2 and R3 treatments had significantly lower furrow cleanness, and the furrow cleanness of the R1 treatment was intermediate. Numerically, furrow cleanness decreased as the initial residue level increased. The planter cleared significantly more residue with the increase in speed from 2 to 4 km/h (Fig. 11b). Nejadi and Raoufat (2013) tested a corn planter with different speeds, and also found a higher residue removal rate at 8 km/h than at lower speeds. However, in this study there was no further increase in furrow cleanness when the speed was increased to 7.5 km/h.

There was no distinct difference in seeding depth for the varying residue levels, which means that the planter was able to seed at a reasonably similar depth in different residue conditions. The average seeding depth for all four residue levels was 41 mm, which was within the corn seeding depth (38 to 51 mm) recommended by MAFRD (2016). The travel speed of the planter had a significant effect on the seeding depth. Traveling at 2 km/h, the planter seeded at approximately 50
mm (Fig. 12b). At higher speeds (4 or 7.5 km/h), the seeding depth was reduced by approximately by 26%. This was a reasonable occurrence because lower speed gave the seed opener more time to penetrate the soil. The effect of travel speed observed in this study was consistent with the findings from Nejjadi and Raoufat (2013) who reported that lower planter speed (5 km/h) resulted in a deeper seeding depth as compared to 7 km/h.

CONCLUSION Vertical tillage and vertical seeding are performed using vertical soil engaging tools. The interaction of those soil engaging tools with soil occurs in a vertical plane. The soil is subjected to shear, compression, impact, or a combination of these forces. Most vertical tillage employs rotary soil engaging tools, which sizes residue and creates uniform soil bulk density in seedbed layer. Rotary vertical seeding tools cut residue and reduce hairpinning. Rotary vertical tools also require low draft force, and therefore, the equipment can travel at high speeds. As being promoted for residue management and energy saving, vertical tillage and vertical seeding are considered to be new forms of conservation practices. The results from the field test of the planter designed for vertical seeding showed good performance in terms of removing residue from seed rows. The resultant furrow cleanness was over 90% for all the residue levels. The faster speeds of 4 and 7.5 km/h cleared more residue than 2 km/h speed, and sowed shallower than the lower speed of 2 km/h. Thus, it is recommended to adjust target seeding depth based on the travel speed.

Acknowledgements. The authors thank Curtis Cavers from Agriculture Food Canada, Portage la Prairie and students (Sandeept Thakur, Zhiwei Zeng, Li Bo, Pieter Botha, Mukta Nandanwar, and Jamie Cheung) for their help with the field tests.

REFERENCES