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EXPERIMENTAL STUDY ANALYSIS OF DISC HARROWS FOR SURFACE TREATMENT OF ROW CROPS

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Abstract. Corn production generates a signifcant amount of residue and corn residue itself is slow in decomposition, which results in accumulated residue remaining in the feld. Tis can cause equipment plugging and poor soil-seed contact for seeding operations, which would negatively afect plant emergence and ultimately crop yield. Modern harvesters use adapters to chop and crush the residue. For situations where adapters are not available, it is necessary to employ tillage operation to break up the residue and mix it with soil for faster decomposition. Furthermore, feld studies have shown that incorporating corn residue into the soil increased the thousand-kernel weight, grain yields, and nitrogen efciency of the following crop as compared to tillage treatments without residue biomass return. Vertical tillage (VT), a newly coined form of tillage practice, can deal with high amount of crop residue in a sustainable manner.

Keywords: Vertical tillage (VT), soil, disc, result, parameters, effective, combination

Conservation agriculture maintains at least 30% residue cover on the soil surface to reduce soil erosion, conserve soil organic matter, and enhance biodiversity and productivity. Conservation tillage, including no-till, has been widely adopted in recent decades for many crops, but challenges in residue management remain, especially for corn. Te general consensus is that VT refers to the soil loosening in relatively vertical lines, although a precise defnition has yet to be established. Discs used in VT are designed to cut crop residue into small pieces and to incorporate them partially into the soil with minimal soil disturbance. Previous studies have shown promising results of the VT in terms of soil and water conservation and crop yield .

However, little research has been done on the mechanisms of soil dynamics and residue management of VT discs. Te majority of recent studies regarding the performance of disc tillage focused on soil cutting forces, soil disturbance, residue incorporation, residue spatial distribution, and fuel consumption efciency, but not on residue cutting efectiveness. Few earlier studies of residue cutting focused on disc openers for no-till planting and other seeding machines 15–18. Disc openers for seeding were mainly for slicing through the residue to reduce the possibilities of residue plugging and dragging; whereas discs for tillage involve intensive residue cutting as well as mixing with soil. Assessment of disc performance in the context of VT was much needed and this study was conducted to fll those gaps.

Te performance of a disc depends on the design and operational parameters of the disc. One of the disc design parameters is its shape and associated cutting edge. Previous studies have shown that the residue cutting efectiveness was signifcantly afected by disc shape, but there were also contrasting reports where four diferent disc shapes of smooth, futed, rippled, and notched had similar residue shearing performance. A toothed disc was developed for working on sugarcane residues, and the soil bin test results showed that the disc had a higher residue cutting efciency and lower soil cutting force as compared to smooth and notched discs. Field tests have shown that rippled discs were less aggressive in disturbing soil and incorporating residue than futed discs. As for the operational parameters, travel speed was of importance to the performance of concave powered discs and futed discs as well. However, little information on the efect of the working depth of VT discs was available. In conclusion, VT is a promising tillage practice to deal with high amount of corn residue, and its efectiveness is largely dependent on the design and operational parameters of the discs used. Tis more-than-tripled increase was signifcant and can be explained by the soil dynamics theory that draf force varies with the contact area between soil and tool.

Te rippled edge slightly increased the surface area as compared to the smooth edge, while the notched edge slightly decreased the contact area due to the notches. As for the depth efect, a deeper operation signifcantly increased the portion of the disc in contact with soil regardless of the disc type. Te plain disc had a medium vertical force, which was not diferent from the other two discs. Te lower vertical force of the notched disc may not necessarily afect its superior ability of soil penetration. Lower lateral forces are usually desired in terms of the frame stability of the implement. Te increase of the lateral force as the depth increased indicated a great deal of attention must be paid on the frame strength when designing the disc for deep tillage application. Te soil cutting forces were resultant forces of passive cutting reaction on the concave face and the scrubbing reaction on the convex face for a concave disc. Both the cutting force and scrubbing force acted at some angle between the horizontal and vertical directions. Te projected soil cutting force was against the travel direction in the horizontal direction and downward in the vertical direction; on the other hand, the projected scrubbing force is along the travel direction and upward. Te resultant draf force was against the travel direction and the resultant vertical force was downward, which was the same as that of the cutting force.

Tis agreed with the literature that the scrubbing force on the trailing convex side of the disc tends to be minor compared to the cutting force on the leading concave side of the disc. However, the soil cutting forces were smaller than those reported in Godwin et al. Te combination of shallow concavity and small disc angle used in this study possibly helped in reducing the soil cutting forces in all three directions. Te soil lateral displacement was the average displacement of all the tracers in the lateral direction and a positive value denoted the direction pointing toward the concave face of the disc. It was worth noting that soil tracers on the convex side tended to be pushed away in the opposite direction as compared to other tracers as observed in the experiment. Tis was related to the scrubbing action as described above. Similar to the lateral displacement, not all tracers were dislodged in the same direction. However, the majority of them were in an upward direction including the average value.

Te small upward displacements indicated moderate soil swelling and elevating movements and minimal soil overturning efect of the discs. Te primary cause of the diference was due to the diference in residue cutting mechanism between the angled tillage discs and relatively straight disc openers. Te concaved discs disturbed a fair amount of soil ahead of the disc and relied on the edge to “hook” lying residues in order to cut them. Terefore, the rippled and notched discs had numerically higher residue cutting rates than the plain disc thanks to their hooking edges. Te shallower the working depth, the less the soil disturbance and the higher the residue cutting efciency is.

On the other hand, a straight disc opener would ride over all possible residues on the path and penetrate the soil without causing signifcant disturbance to the seedbed. Te disc tended to cut or bend the residues at a smaller cutting angle, while the disc tended to push the residue ahead at a larger cutting angle.

Discussion In general, the efect of working depth was more pronounced than that of disc type in determining the resultant soil and residue conditions. Out of all eight measurements, the working depth signifcantly afected most of them except for the soil vertical displacement and residue cutting rate.

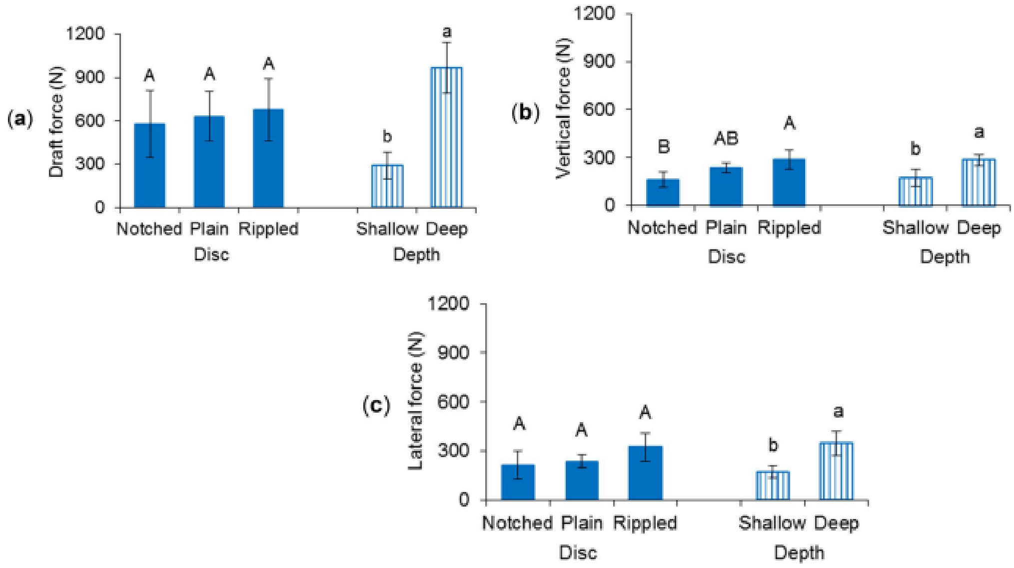

Figure 1. Soil cutting forces of diferent discs at diferent working depths: (a) draf force, (b) vertical force, and (c) lateral force; means followed by diferent lower case letters or upper case letters are signifcantly diferent according to Tukey's test at the signifcance level of 0.05; error bars are standard deviations

Te working speed was found to be more infuential than the geometrical parameters of similar VT discs in an earlier work of Zeng and Chen Terefore, it was fair to draw that the operational parameters were more dominated than the design parameters of VT discs in terms of soil dynamics and residue management performance. Te deep working depth was greater than the shallow one by a factor of two. As expected, the soil displacements were reversely correlated to the residue cover remaining. Te greater the soil displacements were, the more the residue being incorporated, and therefore, the less the residue cover would remain on the soil surface.

Te information gained in this study is important for the design and use of VT disc implements for corn residue management. Te results supported the general perception of the purpose of diferent discs and also quantifed the diferences in the performance of these new

VT discs. Te rippled disc was the most aggressive in terms of both disturbing soil and cutting residue, which resulted in the least amount of residue remaining on the surface. Te notched disc required the least amount of force to pull and was the second-best in residue cutting with a signifcant portion of the partially cut. Te plain disc was intermediate for the majority of measurements except for the residue cutting rate, where it was the least efective among the discs. Te results have many other implications.

For example, there is no diferent between the notched and rippled disc in terms of residue cutting. However, the rippled disc had a greater vertical force, which would indirectly afect the residue cutting ability of a VT implement.

Te insufcient downward force applied to disc-type implement would result in the surface residue being pushed into the bottom of the furrow instead of being cut. Despite the diference between discs, it would be more efective by varying working depth to alter tillage performance as compared to using diferent discs. Corn residue in the feld can be classifed into three diferent types including standing stubbles, lying stalks, and leaves, among which detached lying stalks presented the most difcult residue handling problem for seeding operations.

Te use of lying stalks in the experiment was justifed on this basis. Te discs were tested in a single-shank confguration, which would provide superior performance in uneven and rocky felds with the ability to handle high impact loads. However, one should expect to see an extra manufacturing cost associated with individual shanks as compared to gang confgurations. Conclusion Te performance of three diferent discs for vertical tillage was assessed at two working depths by measuring soil cutting forces, soil displacements, residue cutting, and residue mixing.

Dry corn stalk was used in the experiment. Te results showed that the working depth was more pronounced than the disc type in afecting tillage performance. Increasing the working depth resulted in increases in soil cutting forces, soil displacements, and residue mixing. Similarly, soil lateral displacement was maximized with the rippled disc and minimized with the notched disc. Te diference in residue cutting was not signifcant to the working depth nor the disc type. Te residue mixing rate varied from low to high as notched, plain, and rippled. Among the three discs tested, the rippled disc was the most efective tool in mixing them into the soil.

Te fndings would serve as references when designing and selecting tillage implement of conservation agriculture. Tree discs with diferent shapes including notched, rippled, and plain were tested in this study (Fig. 2). Te plain disc had a smooth and beveled cutting edge. Te notched disc had notches evenly distributed along the circumference; each notch had an opening of 50 mm at the periphery and a depth of 25 mm in the radial direction.

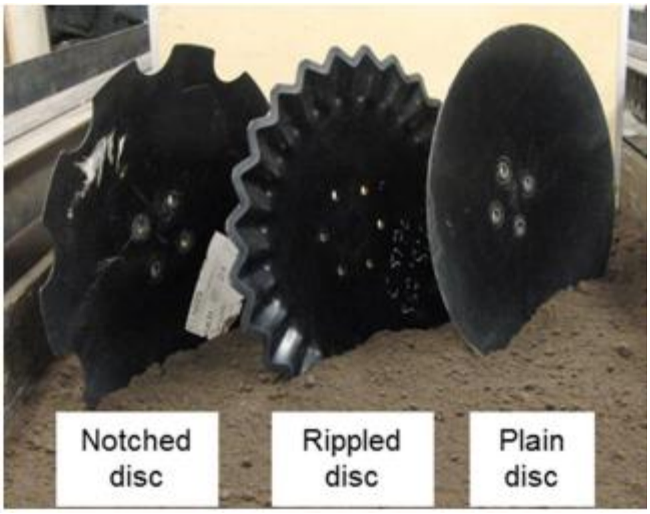

Figure 2. Tree discs tested with diferent shapes: notched, rippled, and plain.

Featured a continuous sawtooth wave design. Te edge of the rippled disc was composed of a total of 25 waved teeth; each tooth had a height of 13.5 mm and a peak and valley length of 25.0 and 50.0 mm in the radial direction. All disc blades had a sharpened circumference. Te notched disc was known for its soil penetration ability. Te rippled disc was designed to slice and size the crop residues while self-sharpening.

Te plain disc was the most versatile one and commonly used in general conditions. Te discs had the same thickness of 6.5 mm and the same diameter of 360 mm. Experimental design. Te experiment was conducted using a completely randomized factorial design. Two factors of the disc type and working depth were examined. Tree diferent discs (notched, rippled, and plain) were combined with two diferent depths w and deep tillage was 120 and 150 mm respectively. All discs were tested at a constant speed of 9 km/h. Measurements. Soil cutting forces. A plate dynamometer was mounted between the disc shank and the soil bin carriage to measure the soil cutting forces of the disc. Soil displacements. Soil displacement was measured using aluminum cubic tracers of 10 mm in side length. A total of 16 numbered tracers were arranged in two rows perpendicular to the travel direction and in the middle section of the soil bin .Te residue tracers were orientated along the soil bin width direction and were placed 100 mm apart in the travel direction. Two diferent residue cutting scenarios: completely and partially cut, were recorded. Te main efects of disc type and working depth were presented when the interaction efects were not signifcant.

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