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Effect of Combined Disc Angles on Soil Forces of Coulter Discs

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Abstract. *Furrow openers using single disc coulter operated at certain disc and tilt angles are becoming common for single pass seeding operation. Concerns have been expressed as to the efficiency of disc to place seed and fertilizer at a proper depth, and resulting compaction of the furrow wall. Tests were conducted in an indoor soil bin using 460 mm (18-in.), and 610 mm (24in.) diameter disc coulters to determine the effect of combined disc and tilt angles on soil forces, and resulting furrow wall strength. Experiments were carried out using various levels of combined disc angles, moisture content, soil compaction, and depth of operations. Measurements were taken for draft, vertical force, side force, soil strength of the furrow wall, and furrow profile. Results indicated that the most favorable condition in terms of the lowest values of draft, vertical force, side force, and soil strength of the furrow wall were obtained with 610 mm diameter disc at 5°&15° combined angle. However, for 460 mm diameter disc, the lowest values of draft and side forces were obtained with 5°&25° and 5°&25° combined angles, respectively.*

Keywords. Combined angle, Soil bin, Soil forces, Soil strength, Furrow wall.

Introduction

A disc is a major tillage tool for soil preparation and seeding operations. Single and double disc coulters have been used as furrow openers with conventional seeding equipment. However, single disc openers have been used to minimize soil disturbance with no-till planting. Although, discs are important equipment in conventional and no-till planting systems, their interactions with soil is not fully understood. The combined disc angles, which include disc and tilt angles, influence not only soil forces but also the soil strength of the furrow wall. Thus, a better understanding of combined disc angles is needed to ensure that discs can be implemented for their maximum effectiveness and efficiency. Therefore, the objective of this paper was to study the effect of combined disc angles on the soil forces, soil strength of the furrow wall, and furrow profile under various conditions of soil and disc operating parameters.

Literature Review

The relationship among soil conditions under no-tillage, residue on the soil surface, and coulter operation are not well understood. When the soil is wet and soft, the coulter tends to push the crop residue into the seed zone without shearing the residue (Chawla, 1972). Schaaf et al. (1980 and 1981) conducted an intensive study on performance of nine different coulters in a soil bin. The results indicated that penetration ability was inversely and vertical force was directly proportional to the diameter of the coulter. Coulter shape had not significant effect on draft or vertical force, but did influenced furrow formation and amount of soil disturbance. Large diameter (430 mm and 460 mm) coulters had significantly better performance at a given vertical load and good residue clearance ability.

Choi and Erbach (1986) evaluated four basic shapes of rolling coulters (smooth, rippled, fluted, and notched coulters). Draft and vertical forces on coulter increased with increase in operating depth, coulter diameter, and soil strength, and also with the presence of straw. A recommendation was that the most common planter's modification would be to mount some types of rolling coulter in the front of the furrow opener that would shear the crop residue and provide better seed-depth control. Coulter on no-tillage planters should be sharpened as needed. If the soil is dry and hard, coulters may not need to be sharpened as often as operating in wet and soft soil.

Kushwaha et al. (1986) studied the size of disc coulters in relation to the quantity of crop residue sheared. The 460 mm diameter coulter was found to shear nearly 100% of crop residue at all operating depths, and residue densities in the experiment. Tice and Hendrick (1992) studied the effect of the operating depth, thickness and wedge slope of flat coulters on the coulter forces and kinematics behavior. Results indicated that the coulter draft and vertical forces were smallest for thin coulters with small wedge slopes. The effect of coulter geometry on the force ratio depended on the soil type.

Materials and Methods

Tests were conducted in an indoor soil bin facility at the Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Canada. Since the 460 mm diameter disc coulter had proved to cut 100% crop residue (Kushwaha et al., 1986), this size of disc coulter was selected for an extensive testing with the following parameters:

- Two levels of soil moisture content (12% ± 1, and 17% ± 1).
- Three levels of soil compaction (low, medium, and high).
- Seven combined angles (7.5°&20.5°, 5°&15°, 10°&15°, 15°&15°, 5°&25°, 10°&25°, and 15°&25°). The 7.5°&20.5° combined angle was used as a base level of combinations.
- Three depths of operation (50, 75, and 88 mm).
- 8 km/h speed of operation.

Soil in the bin consisted of 47% sand, 24% silt, and 29% clay. Disc tested was supported on a movable carriage. A six load-cell force transducer installed on the carriage measured the soil reacting forces on the tillage tools. Three load cells measured the forces in the direction of travel (draft), two load cells measured the forces in the vertical direction, and one load cell measured the side force perpendicular to the direction of travel. A special mechanism was fabricated to fasten the disc for adjusting the tilt and the disc angles (Fig. 1). This assembly was attached under the force transducer. The travel speed of the carriage was controlled with a variable speed drive electric motor.

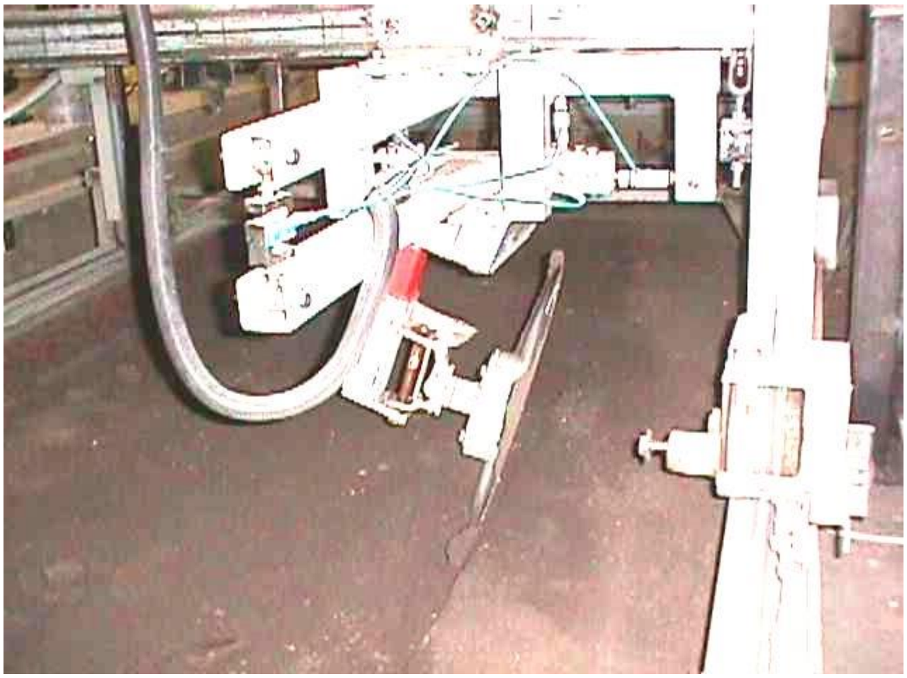

Figure 1. Disc coulter operating in the soil bin

Soil in the bin was prepared using the soil processing units. The soil was first rototilled and gradually brought to the desired moisture content by spraying water. Then, the soil was leveled and packed. A sheep-foot packer was used to pack subsoil followed by a smooth roller to pack the surface soil. Different compaction levels were obtained by varying the number of compacting passes. A low compaction level was obtained with one passes of both the sheep-foot roller and flat roller (back and forth). A medium compaction level was obtained with two passes of both the sheep-foot roller and flat roller (back and forth). A high compaction level was obtained with three passes of both the sheep-foot roller and flat roller (back and forth).

Moving the carriage at a mid-point, and then lowering the disc to the prepared soil surface adjusted the disc zero depth. The carriage was moved to starting position; the disc was then lowered to the desired working depth. The zero loads were recorded before starting the carriage. The forward movement of carriage activated a reed switch to record the soil forces at every second interval.

Immediately, after the disc operation, three replicates of the disturbed soil cross-section profile from each row were mapped using a moveable laser profile meter. A standard 30° cone penetrometer with a base area of 130 mm^2 (12.83 mm diameter) was used to determine soil strength of the furrow wall (Fig. 2). Three measurements of the soil strength of the furrow wall were taken along the length of the soil bin.

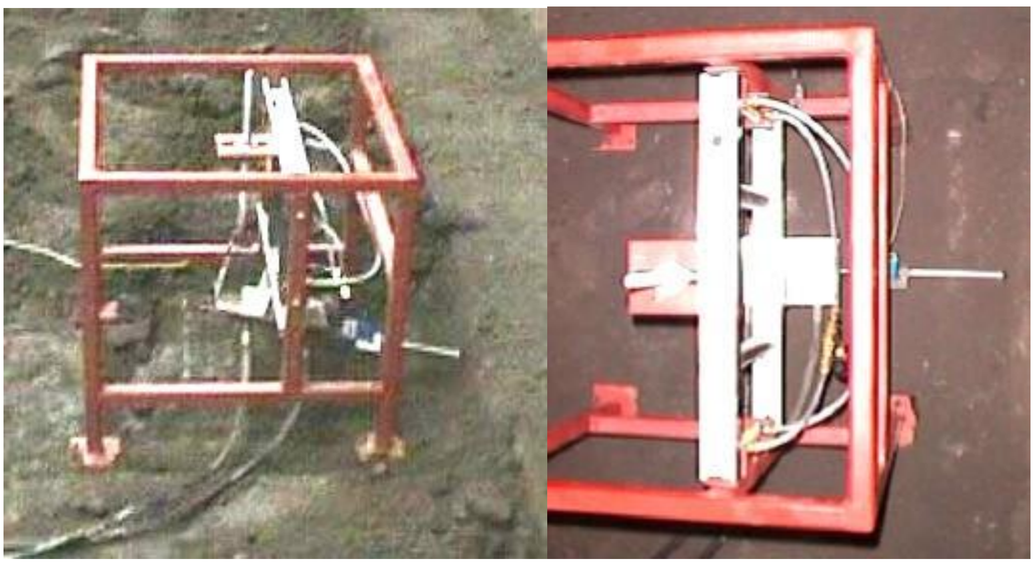

Figure 2. Apparatus supporting the cone penetrometer

After the data for the 460 mm diameter disc were analyzed, the 610 mm diameter disc was tested with the following parameters that were found significant:

- Two levels of soil moisture content (12% ± 1, and 17% ± 1).
- Low level of soil compaction.
- Three combined angles (7.5°&20.5°, 5°&15°, and 5°&25°).
- Two depths of operation (50 and 88 mm).
- 8 km/h speed of operation.

Results and Discussion

Part I: Results of 460 mm diameter coulter disc

Analyses of variance were performed for the draft, vertical force, side force, and strength of furrow wall in relation to two levels of soil moisture, three levels of soil compaction, three depths, and seven combined angles. Results showing significant variables and their interactions are given in Table 1.

Table 1. Results of analysis of variance for draft, vertical force, side force, and furrow wall strength (460 mm diameter disc).

Factor	Type	Levels
Moisture (M)	fixed	2
Compaction (C)	fixed	3
Angle (A)	fixed	7
Depth (D)	fixed	3

Source	DF	Draft	Vertical force	Side force	Furrow wall strength
M	1	0.000**	0.000**	0.000**	0.820-
C	2	0.000**	0.000**	0.000**	0.000**
A	6	0.000**	0.000**	0.000**	0.000**
D	2	0.000**	0.000**	0.000**	0.000**
M*C	2	0.365-	0.000**	0.061-	0.153-
M*A	6	0.000**	0.000**	0.000**	0.000**
M*D	2	0.000**	0.000**	0.000**	0.702-
C*A	12	0.004**	0.000**	0.000**	0.022*
C*D	4	0.000**	0.257-	0.003**	0.140-
A*D	12	0.000**	0.000**	0.000**	0.027*
M*C*A	12	0.445-	0.001**	0.010**	0.014*
M*C*D	4	0.378-	0.095-	0.192-	0.479-
M*A*D	12	0.001**	0.000**	0.000**	0.506-
C*A*D	24	0.487-	0.437-	0.222-	0.708-

****** Highly significant at 1% level of confidence.

***** Significant at 5% level of confidence.

- None significant.

Draft force

Figure 3 shows the draft for the 460 mm diameter coulter disc with the depth of operation at various levels of combined angles, soil compaction, 12% soil moisture, and at 8 km/h speed. Draft increased with an increase with the depth of operation for all combined angles.

The highest values of draft were obtained with 7.5°&20.5° combined angle. However, the 5°&25° combined angle resulted in the lowest values of draft at various levels of soil compaction. The increase in the soil compaction from low to high caused an increase of 21%, 28%, 40%, 24%, 29%, 37%, and 45% in the draft for 7.5°&20.5°, 5°&15°, 10°&15°, 15°&15°, 5°&25°, 10°&25°, and 15°&25° combined angles, respectively.

Results of draft at 17% soil moisture showed similar trends as that at 12% soil moisture except for the following differences:

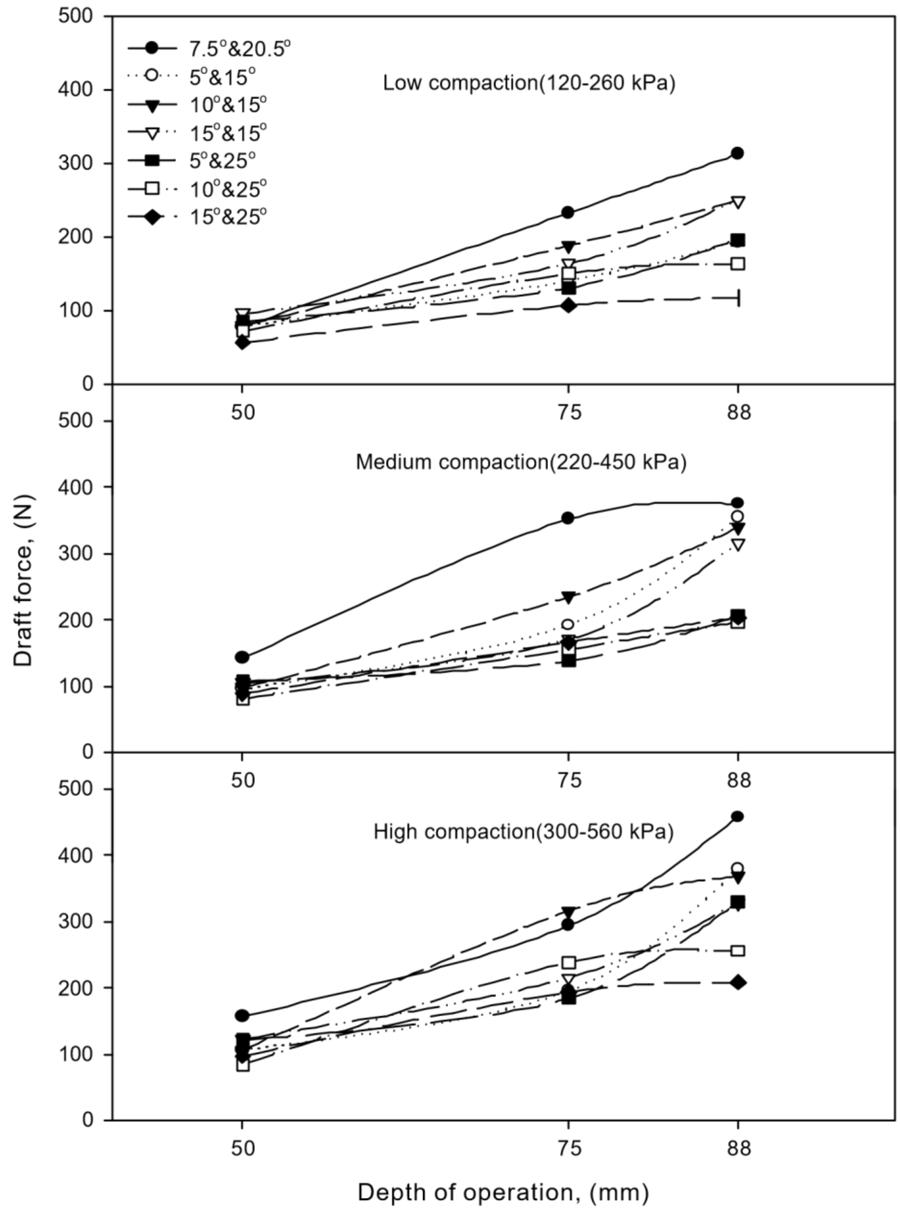

Figure 3. Draft of 460 mm coulter disc at various levels of combined angles, and soil compaction (12% soil moisture, and 8 km/h speed).

- The 7.5°&20.5° combined angle resulted in the highest values of draft at medium and high levels of soil compaction. However, at low level of soil compaction, the highest values of draft were obtained with 15°&15° combined angle at different depths.
- The 5°&25° and 10°&25° combined angles resulted in the lowest values of draft at medium and high levels of soil compaction. However, the 15°&25° combined angle resulted in the lowest values in draft at low level of soil compaction.
- Draft decreased by 58%, 10%, 19%, 9%, 13%, 15%, and 11% when the soil moisture increased from 12% to 17% for 7.5°&20.5°, 5°&15°, 10°&15°, 15°&15°, 5°&25°, 10°&25°, and 15°&25° combined angles, respectively.

Vertical force

Figure 4 shows the vertical force for the 460 mm diameter coulter disc with the depth of operation at various levels of combined angles, soil compaction, 12% soil moisture, and at 8 km/h speed. Vertical force increased with an increase in the depth of operation for all combined angles at various levels of soil compaction.

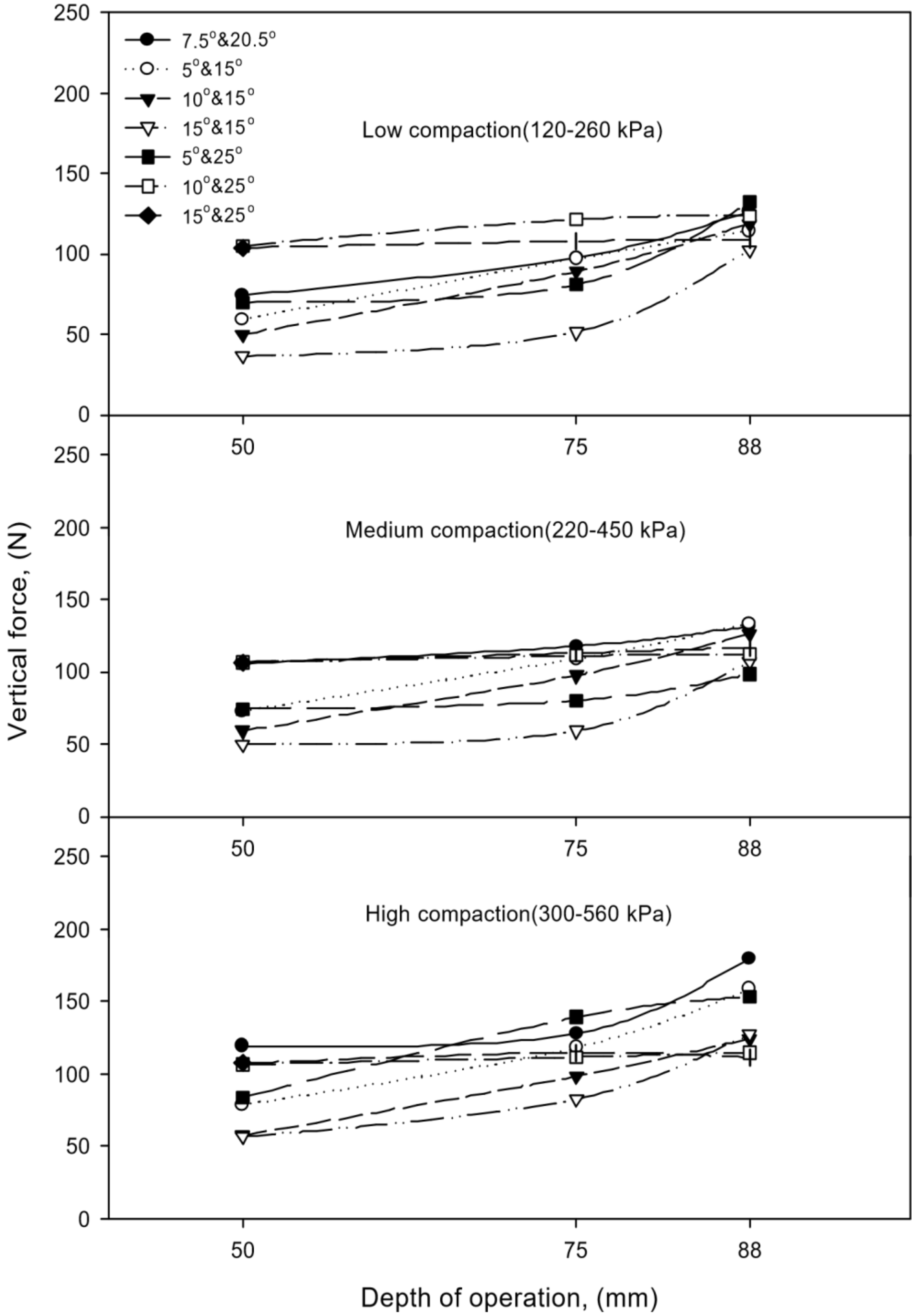

Figure 4. Vertical force of 460 mm coulter disc at various levels of combined angles, and soil compaction (12% soil moisture, and 8 km/h speed).

The highest values of the vertical force were obtained with 7.5°&20.5° combined angle at medium and high levels of soil compaction. However, the 10°&25° combined angle resulted in the highest values of the vertical force at low level of soil compaction. The 15°&15° combined angle resulted in the lowest values of the vertical force at various levels of soil compaction. The increase in the soil compaction from low to high did not produce appreciable change in the vertical force for all combined angles.

The increase in the soil moisture from 12% to 17% did not produce appreciable change in the vertical force at various levels of combined angles, soil compaction, and at different depths. The 7.5°&20.5° combined angle resulted in the highest values of the vertical force at various levels of soil compaction. However, there were no significant differences in the vertical force with other combined angles.

Side force

Figure 5 shows the side force for the 460 mm diameter coulter disc with the depth of operation at various levels of combined angles, soil compaction, 12% soil moisture, and at 8 km/h speed. The side force increased with an increase in the depth of operation for all combined angles at various levels of soil compaction.

The magnitude of the side force with all combination of angles were negative except for the 10°&25° and 15°&25° combined angles, they were positive. This means that the direction of the side force with negative values was toward left when looking from front. However, the direction of the side force was toward right with positive values. The highest values of the side force were obtained with 7.5°&20.5° combined angle. However, the 5°&25° and 15°&15° combined angles resulted in the lowest values of the side force at various levels of soil compaction.

In a comparison between the 10°&25° and 15°&25° combined angles, the side force with 10°&25° combined angle increased by 81%, 56%, and 59% than that with 15°&25° combined angle at low, medium, and high levels of soil compaction, respectively. The increase in the soil compaction from low to high produced substantial increase of 33%, 32%, 46%, 27%, 20%, 60%, and 12% in the side force for 7.5°&20.5°, 5°&15°, 10°&15°, 15°&15°, 5°&25°, 10°&25°, and 15°&25° combined angles, respectively.

Results of the side force at 17% soil moisture showed similar trends as that at 12% soil moisture except for the following differences:

- The 7.5°&20.5° and 5°&15°combined angles resulted in the highest values of the side force at various levels of soil compaction.
- There were none significant differences in the side force among 5°&25°, 10°&15°, and 15°&15° combined angles at various levels of soil compaction.
- The side force with 10°&25° combined angle increased by almost 87% than that with 15°&25° combined angle at different levels of soil compaction.
- The side force decreased by 16%, 7%, 43%, 49%, 53%, and 51% when the soil moisture increased from 12% to 17% for 7.5°&20.5°, 5°&15°, 10°&15°, 15°&15°, 5°&25°, and 10°&25° combined angles, respectively. However, the side force with 15°&25° increased by 41% when the soil moisture increased from 12% to 17%.

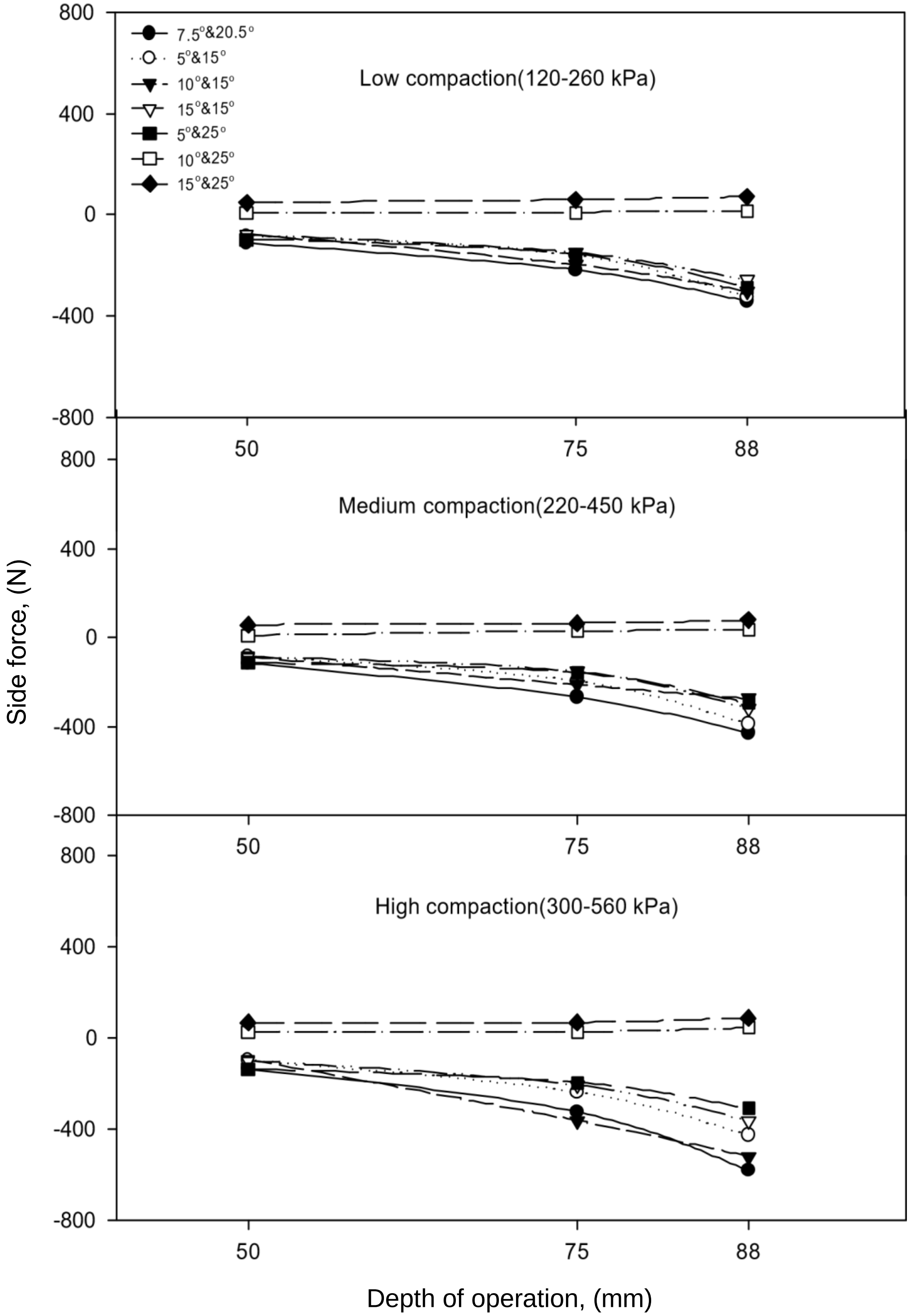

Figure 5. Side force of 460 mm coulter disc at various levels of combined angles, and soil compaction (12% soil moisture, and 8 km/h speed).

Soil strength of furrow wall

Figure 6 shows the soil strength of furrow wall of 460 mm diameter coulter disc with the depth of operation at various levels of combined angles, soil compaction, 12% soil moisture, and at 8 km/h speed.

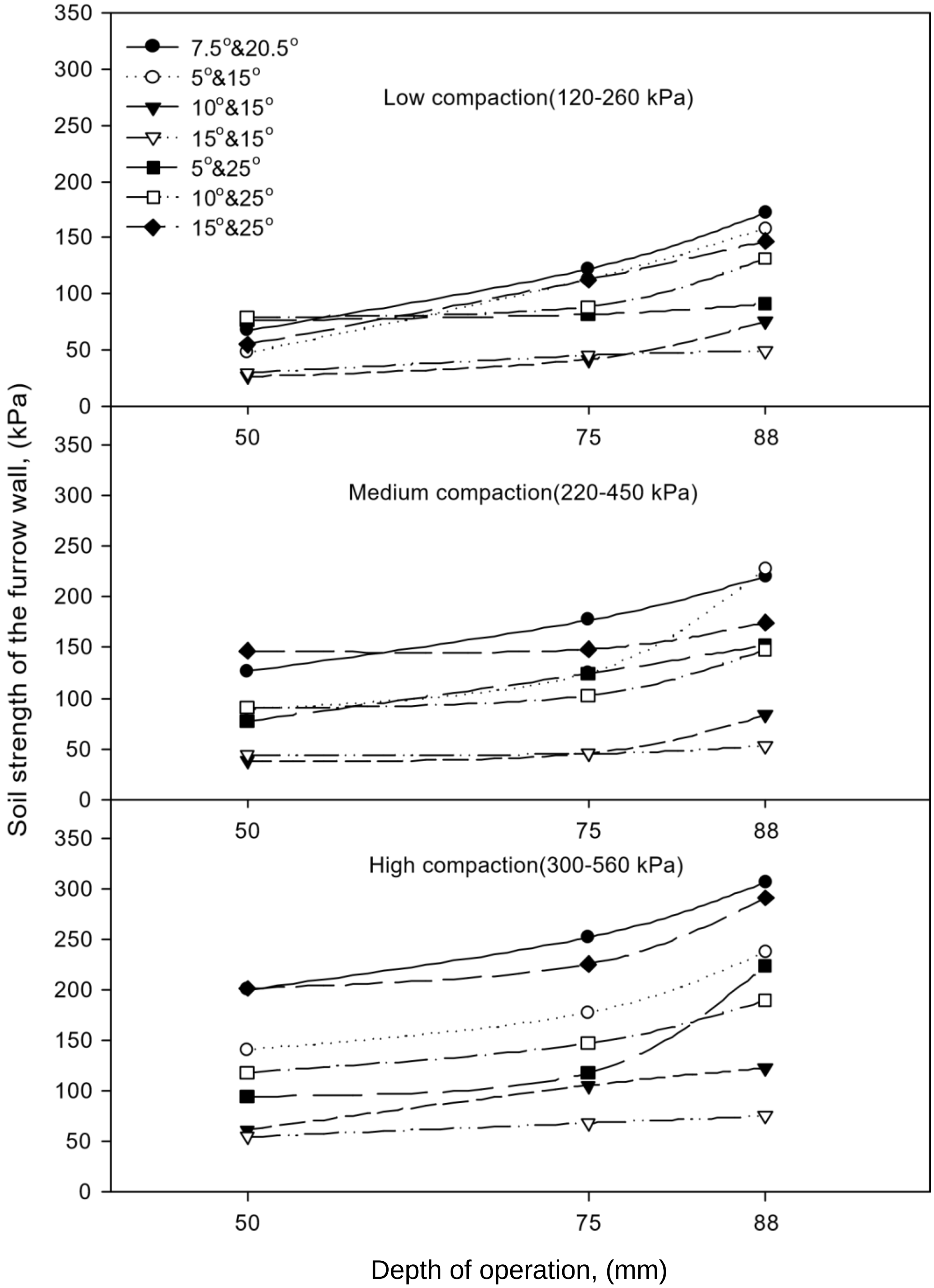

Figure 6. Soil strength of furrow wall of 460 mm diameter coulter disc at various levels of combined angles, and soil compaction (12% soil moisture, and 8 km/h speed).

The soil strength of furrow wall increased with an increase in the depth of operation for all combined angles. The highest values of the soil strength of furrow wall were obtained with 7.5°&20.5° combined angle at various levels of soil compaction, and at different depths. However, the 10°&15°, and 15°&15° combined angles resulted in the lowest values of the soil strength of furrow wall at various levels of soil compaction.

The increase in the soil compaction level from low to high produced an increase of 51%, 36%, 61%, 34%, 31%, 40%, and 50% in the soil strength of furrow wall for 7.5°&20.5°, 5°&15°, 10°&15°, 15°&15°, 5°&25°, 10°&25°, and 15°&25° combined angles, respectively.

Results of the soil strength of furrow wall at 17% soil moisture showed similar trends as that at 12% soil moisture except for the following differences:

- The 7.5°&20.5° and 15°&25° combined angles resulted in the highest values of the soil strength of furrow wall at low and medium levels of soil compaction. However, at high level of soil compaction, the highest values of the soil strength of furrow wall were obtained with the 7.5°&20.5°, and 5°&25° combined angles at different depths.
- The 5°&15° combined angle resulted in the lowest values of the soil strength of furrow wall at various levels of soil compaction.
- The soil strength of furrow wall increased by 21%, 51%, 9%, and 13% as the soil moisture increased from 12% to 17% for 7.5°&20.5°, 5°&15°, 5°&25°, and 10°&25° combined angles, respectively. However, the increase in the soil moisture from 12% to 17% caused a decrease of 51%, 45%, and 18% in the soil strength of furrow wall for 10°&15°, 15°&15°, and 15°&25° combined angles, respectively.

Part II: Results of 610 mm diameter coulter disc

Data in Table 2 show the draft, vertical force, side force, and the strength of furrow wall for the 610 mm diameter coulter disc for two operating depths at various levels of combined angles, low soil compaction, two levels of soil moisture, and at 8 km/h speed.

Draft force

Draft increased with an increase in the depth of operation for all combined angles at different levels of soil moisture. At two levels of soil moisture, the highest values of draft were obtained with 7.5°&20.5° combined angle. However, the moderate and lowest values of draft were obtained with 5°&25°, and 5°&15° combined angles, respectively. The draft decreased by 31%, 24%, and 32% when the soil moisture increased from 12% to 17% for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively. At 12% soil moisture, the draft increased by 71%, 78%, and 62% when the depth increased from 50 to 88 mm for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively. However, at 17% soil moisture, the increase in the draft was 83%, 73%, and 74% as the depth increased for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.

Table 2. Draft, vertical force, side force, and soil strength of the furrow wall for the 610 mm diameter disc coulter at different combined angles, depths, soil moisture, low soil compaction, and at 8 km/h speed.

Soil moisture	17%			12%		
Combined angles	7.5° &20.5°	5° &15°	5° &25°	7.5° &20.5°	5° &15°	5° &25°
Depth, (mm)	Draft, (N)					
50	77.94	66.26	74.59	173.90	72.82	148.56
88	462.10	242.06	288.76	606.97	334.14	386.72
	Vertical force, (N)					
50	71.00	55.14	57.21	153.95	94.36	203.53
88	505.82	321.52	430.83	654.40	454.55	444.14
	Side force, (N)					
50	84.29	38.98	72.88	322.35	112.31	197.05
88	1190.95	597.20	709.72	1357.32	846.03	909.40
	Soil strength of the furrow wall, (kPa)					
50	47.92	16.62	63.92	105.77	15.54	132.92
88	69.54	32.92	88.00	141.85	43.69	181.00

Vertical force

The vertical force showed similar trends as that with the draft except for the following differences:

- The increase in the depth from 50 to 88 mm resulted an increase of 81%, 80%, and 69% in the vertical force for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.
- The vertical force with 5°&15° combined angle decreased by 35%, and 22% compared with that for 7.5°&20.5°, and 5°&25° combined angles, respectively.
- The vertical force increased by 28%, 31%, and 25% when the soil moisture increased for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.

Side force

The side force showed similar trends as that with the draft and vertical forces except for the following differences:

- The increase in the depth from 50 to 88 mm resulted an increase of 84%, 89%, and 83% in the side force for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.
- The side force with 5°&15° combined angle decreased by 42%, and 13% compared with that for 7.5°&20.5°, and 5°&25° combined angles, respectively.
- The side force increased by 24%, 34%, and 29% when the soil moisture increased for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.

Soil strength of the furrow wall

The soil strength of the furrow wall increased with an increase in the depth of operation for all combined angles at different levels of soil moisture.

At 17% soil moisture, the soil strength of the furrow wall increased by 32%, 51%, and 28% when the depth increased from 50 to 88 mm for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively. However, at 12% soil moisture, the increase in the soil strength of the furrow wall was 25%, 65%, and 28% as the depth increased for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.

At two levels of soil moisture, the highest value of the soil strength of the furrow wall was obtained with 5°&25° combined angle. However, the soil strength of the furrow wall decreased by 53%, 17%, and 52% when the soil moisture increased from 12% to 17% for 7.5°&20.5°, 5°&15°, and 5°&25° combined angles, respectively.

Furrow profile and Area of soil disturbance

Figure 7 shows represented furrow profiles of 460 mm, and 610 mm coulter discs at three different combined angles, and 8 km/h speed. Similar results were obtained for other tests. The area under the curve was integrated to determine soil disturbance.

The area of soil disturbance with 460 mm diameter disc increased with an increase in the depth of operation for all combined angles. The highest values of the area of soil disturbance were obtained with 7.5°&20.5° combined angle at various levels of soil compaction, and at different depths (12% soil moisture, and at 8 km/h speed). However, the 5°&25°, and 5°&15° combined angles resulted in the lowest values of the area of soil disturbance at various levels of soil compaction. The increase in the soil compaction from low to high produced a decrease in the area of soil disturbance.

Results of the area of soil disturbance at 17% soil moisture showed similar trends as that at 12% soil moisture. However, the 5°&25° combined angle resulted in the lowest values of the area of soil disturbance at various levels of soil compaction, while the 7.5°&20.5° combined angle resulted in the highest values of the area of soil disturbance at medium level of soil compaction.

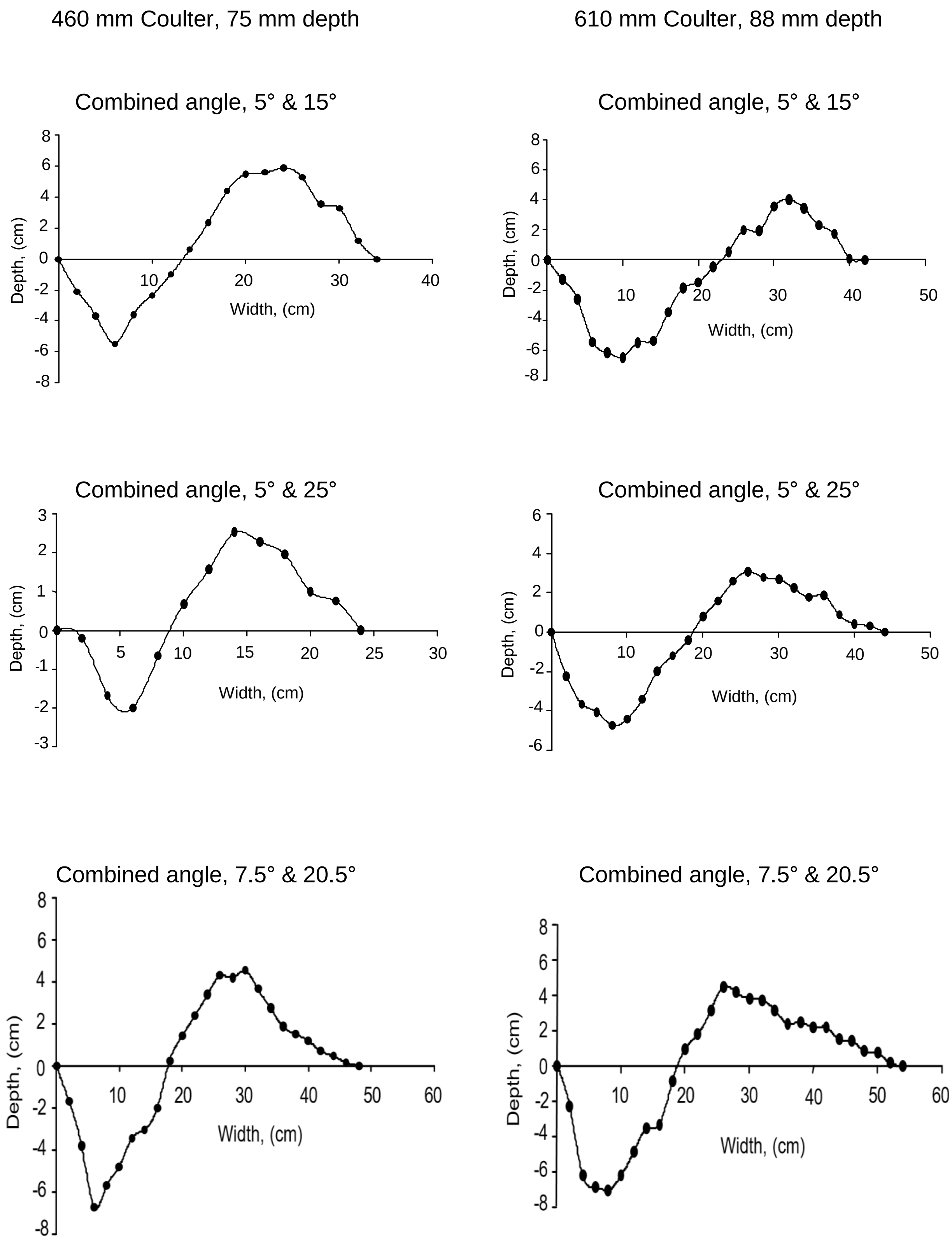

Figure 7. Soil profile for two coulters at various combined angles.

The area of soil disturbance with 610 mm diameter disc coulter increased with an increase in the depth of operation for all combined angles at different levels of soil moisture. The highest values of the area of soil disturbance were obtained with 7.5°&20.5° combined angle at both levels of soil moisture. The area of soil disturbance increased with the increase in depth of operation under all cases studied.

Conclusions

- For 460 mm diameter disc coulter, the 5°&25° combined angle resulted in the lowest values of draft, and side forces compared to other combined angles.
- There were no appreciable differences in the vertical force for 460 mm diameter disc coulter among all combined angles except for the 7.5°&20.5° combined angle that resulted in the highest values of the vertical force.
- The highest values of the soil strength of the furrow wall for 460 mm diameter disc coulter were obtained with 7.5°&20.5° combined angle. However, the 10°&15°, and 15°&15° combined angles resulted in the lowest values of the soil strength of the furrow wall.
- For 610 mm diameter disc coulter, the most optimum condition in terms of the lowest values of draft, vertical force, side force, and soil strength of the furrow wall was obtained at 5°&15° combined angle.
- The area of soil disturbance disc increased with an increase in the depth of operation for all combined angles with both size disc coulters.

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