PERFORMANCE OF POWERED-DISC COULTERS UNDER NO-TILL CROP RESIDUE IN THE SOIL BIN[1]

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Received 16 May 1985, accepted 27 December 1985

Kushwaha, R. L., A. S. Vaishnav, and **G. C. Zoerb**. 1986. Performance of powered-disc coulters under no-till crop residue in the soil bin. Can. Agric. Eng. **28**: 85–90.

Three types of 460-mm-diameter disc coulters were power-driven to evaluate their crop residue cutting ability in the soil bin. Rotational speeds up to twice the travel speed were used in the tests. Power consumption, draft and vertical forces were measured without straw and with straw density ranging from 1000 kg/ha to 5000 kg/ha. Observation and analysis of data indicated that the straw cutting performance of the plain coulter was nearly 100%. With the notched and the serrated coulters, the quantity of straw cut increased with the increase in the rotational speed and decreased with the increase in the straw density. Draft and vertical forces increased with the increase in the rotational speed and the straw density, but were considerably lower than those obtained with the free-rolling coulters. Power consumption increased with the increase in rotational speed and with the straw quantity. Since increasing the rotational speed of coulters to twice the travel speed had no effect on the quantity of crop residue cut, powering the coulters for no-till drills may not be desirable. A plain free-rolling coulter of approximately 460 mm diameter will perform satisfactorily under no-till practices over a wide range of crop residue density.

INTRODUCTION

Proper seed placement is a very important component of the crop production system. No-till seeding requires drills capable of cutting through large quantities of crop residue, penetrating untilled soil, and depositing the seed 25–50 mm deep. Problems associated with seed placement under no-till and minimum tillage practices are (1) density and toughness of crop residue, and (2) penetration resistance of the soil. Tests of Haybuster (Prairie Agricultural Machinery Institute 1978a) and Melroe (Prairie Agricultural Machinery Institute 1978b) no-till drills have indicated that under heavy crop residues, failure of the disc openers to cut through the surface residue resulted in the seed being placed either in the residue or on the soil surface. In softer soil the trash was pushed to the bottom of the furrow without being cut. The seed was placed on this trash resulting in poor germination. With the hoe drills, crop residue tends to collect and block the machine.

No-till and minimum tillage systems have considerable potential for saving energy and time, controlling wind and water erosion, reducing saline seeps, reducing soil moisture loss by evaporation, and increasing soil water through snow trapping. Special seeding machines have been designed in an attempt to overcome the problems in planting with no tillage. This requires extra investment for farmers already having conventional seeding machines.

An earlier study on straw-cutting performance of plain disc coulters (Kushwaha et al. 1986) showed that free-rolling coulters of 300 and 600 mm diameter were unable to cut all the crop residue. The 460-mm-diameter plain disc coulter was able to cut nearly 100% of the crop residue for most of the test conditions. Other types of coulters, specially notched coulters, are also commonly used on seeding machines. Choi and Erbach (1983) reported no significant difference on quantity of corn stalk sheared with four different types of coulters. Seeding machines with power-driven coulters are commercially available for pasture and range land rejuvenation by interseeding grasses, grains or legumes.

A study was, therefore, undertaken to determine the straw-cutting performance of notched and serrated coulters and the effect of power-driving them at a speed greater than travel speed in comparison to plain disc coulter. The objects of this study were (1) to evaluate and compare straw-cutting performance of notched and serrated coulters with that of the plain coulter, (2) to determine their straw-cutting performance by power-driving the coulters, and (3) to determine draft and vertical forces on powered disc coulters and compare them with the forces on free-rolling coulters.

LITERATURE REVIEW

No-till or reduced tillage is often promoted because these methods usually require about one-third to one-half of the fuel used in conventional tillage (Reid 1978). Several researchers (Dyck 1982; Krall et al. 1978; Klocke 1979) have worked on modifying the furrow opener and coulter arrangement on seeding machines to improve seed placement under no-till and minimum tillage practices. However, crop residue cutting still remains an unsolved problem.

Schaaf et al. (1980) conducted an intensive study on the performance of nine different coulters. Observations were made on draft requirements, vertical load, penetration ability and furrow shape for each coulter in a soil bin. However, these tests were conducted without straw and thus crop residue cutting ability of the coulters was not evaluated. The results indicated the following: (1) Penetration ability was inversely proportional and vertical force was directly proportional to the diameter of the coulter. (2) Coulter shape or style had no significant effect on draft or vertical force, but did influence furrow formation and amount of soil disturbance.

Earlier study by Kushwaha et al. (1986) on the performance of three common sizes of plain disc coulters indicated a varying degree of crop residue being cut by 300-mm-and 600-mm-diameter plain coulters. The quantity of crop residue cut was greatly influenced by the degree of soil compaction, density of crop residue and penetration depth. The straw-cutting performance of 460-mm-diameter coulter was nearly 100% within the test limits in the soil bin. Choi and Erbach (1983) studied the corn-stalk-cutting performance of plain, rippled, notched and fluted coulters of 410 mm diameter and reported that the type of coulter had no significant difference on quantity of corn stalk sheared.

No published work was found on power-driven coulters for seeding machines. The

[1]ASAE Paper no. 83-1514 presented at the 1983 winter meeting of the American Society of Agricultural Engineers.

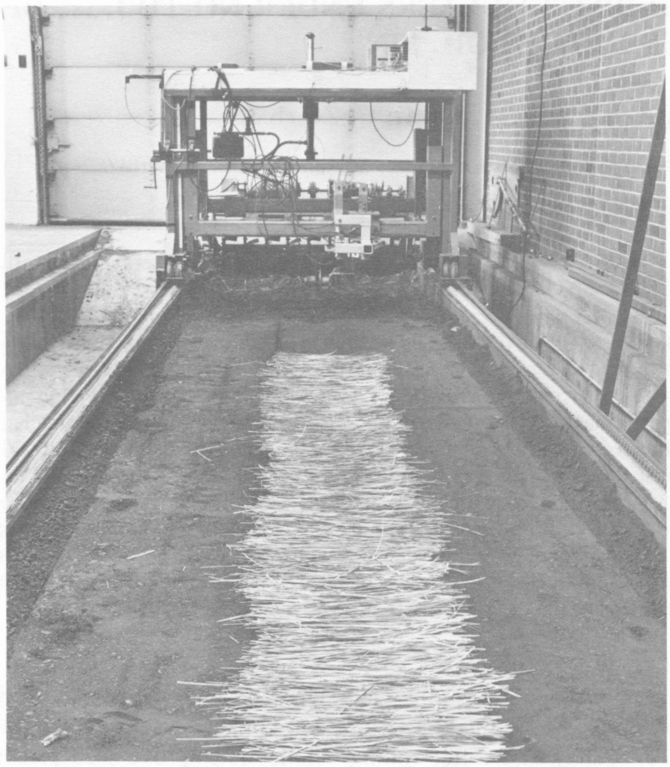

Figure 1. Soil bin and tool carriage showing straw spread for testing.

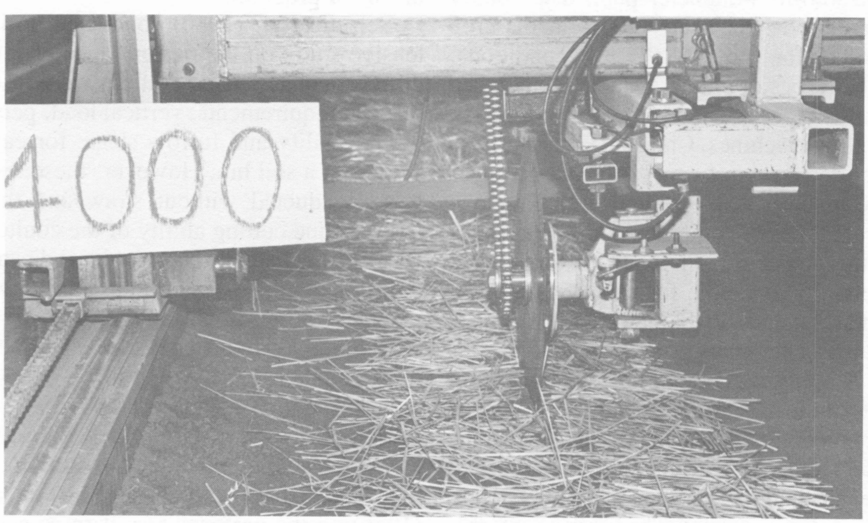

Figure 2. The force transducer assembly with plain coulter operating on straw.

Prairie Agricultural Machinery Institute (1978c) tested a John Deere 1500 Power-till seeder for pasture and rangeland and reported that its performance was very good. The power-till seeder was equipped with 12 power take-off driven cutter wheels which rotate in the direction of travel and cut a 13-mm-wide furrow for seed placement. The cutter wheel, 6.4 mm thick and 305 mm in diameter, rotates at 740 r/min with 1000 r/min power take-off.

Getzlaff (1953) and Getzlaff and Sohne (1959) conducted studies of forces on power-driven plow discs and reported a reduction up to 30% in draft forces with a 30% increase in rotational speed of the disc. However, the total power requirement increased with an increase in peripheral speed and was in all cases greater than the freely rotating disc.

MATERIALS AND METHODS

Tests were conducted in the soil bin facility of the Department of Agricultural Engineering, University of Saskatchewan. The soil bin, 1.75 m wide and 12.2 m long, was filled with clay loam to a depth of 0.3 m. The tool carriage is supported by two rails on each side of the bin (Fig. 1) and powered by an 11.2-kW motor equipped with speed control and electromagnetic clutch and brake. The carriage supports the two tool bars for mounting of multidirectional transducer. Each transducer consisted of a fixed end mounted on the tool bar and a free end on which the tool was mounted. The tool end was connected to the fixed end with six load cells (model SSM-500 from Interface Inc.); one to measure the force in the direction of travel (draft), two to measure the vertical force and three load cells to measure the side force (Fig. 2). The output from the force transducers was fed through amplifiers to an HP 2240 data processor for direct data acquisition.

Three types of 460-mm-diameter (4.5-mm- thick) disc coulters, namely, plain, notched, and serrated coulters, were used in this study (Fig. 3). The 460-mm-diameter size was selected for its better performance in a previous study reported by Vaishnav (1983). The serrated coulter was made by cutting V notches uniformly along the circumference of a plain disc coulter and by sharpening the resulting edges. All coulters were tested at 55-mm depth of penetration, and the effect of the three levels of depth (50 mm, 60 mm and 70 mm) was investigated with the notched coulter.

Tests were conducted at 6.4 km/h travel speed, the average speed at which small grain seeding machines are operated. Coulters were driven with a 0.8-kW electric motor coupled to a gear reducer box. The coulter and drive assembly were mounted on the force transducer in such a way that they did not affect the forces on the coulter (Fig. 4). The various coulter speeds were achieved by changing the drive sprocket. The ratios between travel and coulter rotational speeds are given in Table I.

The soil in the soil bin was clay loam (sand 47%, silt 14%, clay 29%) and was prepared so as to simulate field compaction levels at seeding time. The cone index data were collected at seeding time from no-tilled and fall-tilled fields at the Kernen and the Goodale farms of the University of Saskatchewan with a 30° cone penetrometer at surface, 50 mm and 100 mm depths. These cones index values were utilized to simulate soil compaction levels in the soil bin (Vaishnav 1983). The soil preparation procedure was as follows:

1. *Soil moisture*. A spray boom equipped with seven 8001 spray nozzles mounted on one of the tool bars was used for adding water. Uniformity of soil moisture was essential to obtain even compaction. Tests were conducted in the range of 15.6–19.5% (DB) soil moisture.

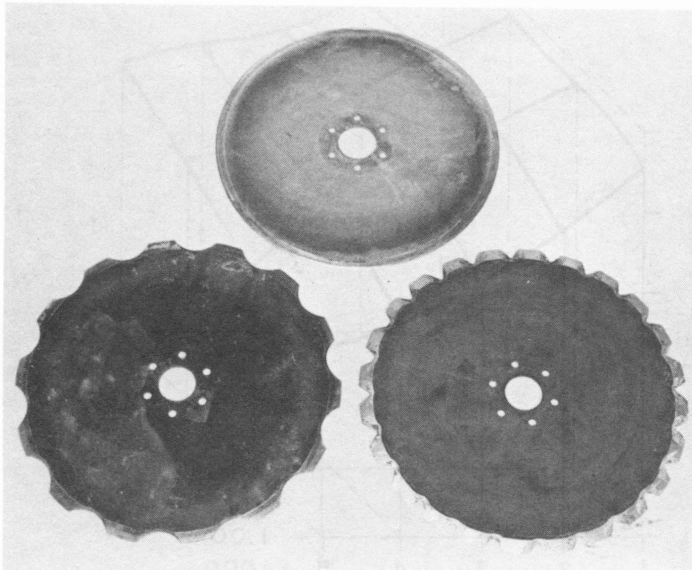

Figure 3. Plain, notched and serrated coulters.

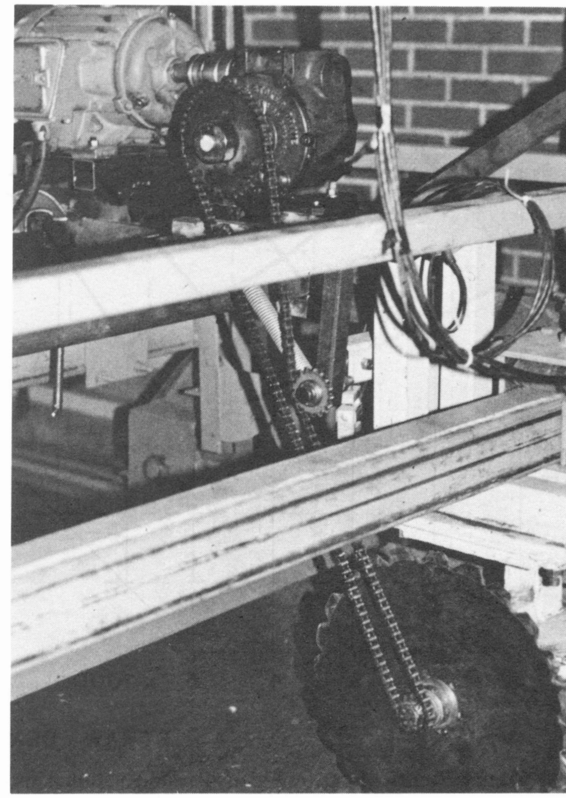

Figure 4. Drive mechanism to power the coulters.

TABLE I. LEVELS OF TEST PARAMETERS

Coulter edge	Speed ratio†	Straw density (kg/ha)	Depth (mm)
Plain	1.00	1000	55
Notched	1.33	2000	
Serrated	1.67	3000	
		4000	
	2.00	5000	
Notched	1.00	4000	50
	2.00		60
			70

†Coulter rotational speed/travel speed (1.00 = free rolling).

2. *Soil tilling*. A full width roto-tiller mounted on the soil bin carriage was used for uniform soil tilling through the width and length of the soil bin.

3. *Levelling*. An iron bar mounted on the rear tool bar was used for levelling the soil.

4. *Packing*. This was an important phase of soil preparation. Subsurface packing was performed by a sheep's foot roller and a plain roller was used to pack the surface soil. Cone index values were checked periodically for compactness of subsoil while packing with the sheep's foot roller. The key to uniform soil preparation was found to be leveling while packing. Extra soil brought to soft spots during packing resulted in uniform compaction. Once the subsoil was packed to desired field conditions the plane roller was used to smooth the surface and firm it. Six readings of soil resistance were taken at the surface, 50 mm and 100 mm depths with the 30° cone penetrometer before each test.

Tests were conducted on bare soil (without straw) and with straw at a disc depth of penetration of 55 mm. The coulters were adjusted for the desired depth of penetration and rotational speed. Twenty initial readings of each load cell were obtained with coulters clear of the soil surface. The carriage was then operated at a speed of 6.4 km/h with coulters running in the soil without straw. Soil force data were automatically collected at 50-ms intervals for the working distance of 6.1 m. At the end of the run, the coulters were lifted up and the carriage returned.

Wheat straw at densities from 1000 kg/ha to 5000 kg/ha was spread flat and perpendicular to the direction of coulter travel in the soil bin (Fig. 1). The straw was taken from rectangular bales which were nearly a year old. The straw moisture varied between 7 and 11% (WB). Kushwaha et al. (1983) found that for the minimum shear strength of wheat straw the moisture level was between 8 and 10%. The coulters were readjusted to the same depth of penetration and rotational speed. Data were collected with coulters running on the straw (Fig. 2). Two test runs were conducted with each set of variables. The notched coulter was further tested at a constant straw density of 4000 kg/ha at three depths of penetration. The summary of test parameters is given in Table I.

Observations were made to estimate the quantity and percentage of straw cut with each coulter by picking the uncut straw out of the coulter furrow and weighing it. Soil and straw samples were collected for moisture determination by the oven drying method. The soil force data collected during each test run were stored on a magnetic cartridge for processing later. Data were also collected for the power used in operating the coulters without straw and at a straw density of 4000 kg/ha.

RESULTS AND DISCUSSION

Straw-cutting performance was greatly influenced by the degree of soil compaction, and coulter type and rotational speed. The field soil compaction level was closely simulated in the soil bin. The range of cone index values obtained from no-tilled and fall-tilled fields were 40−100 kPa at the surface, 250−545 kPa at 50 mm depth, and 370-80-0 kPa at 100 mm depth. The corresponding range of

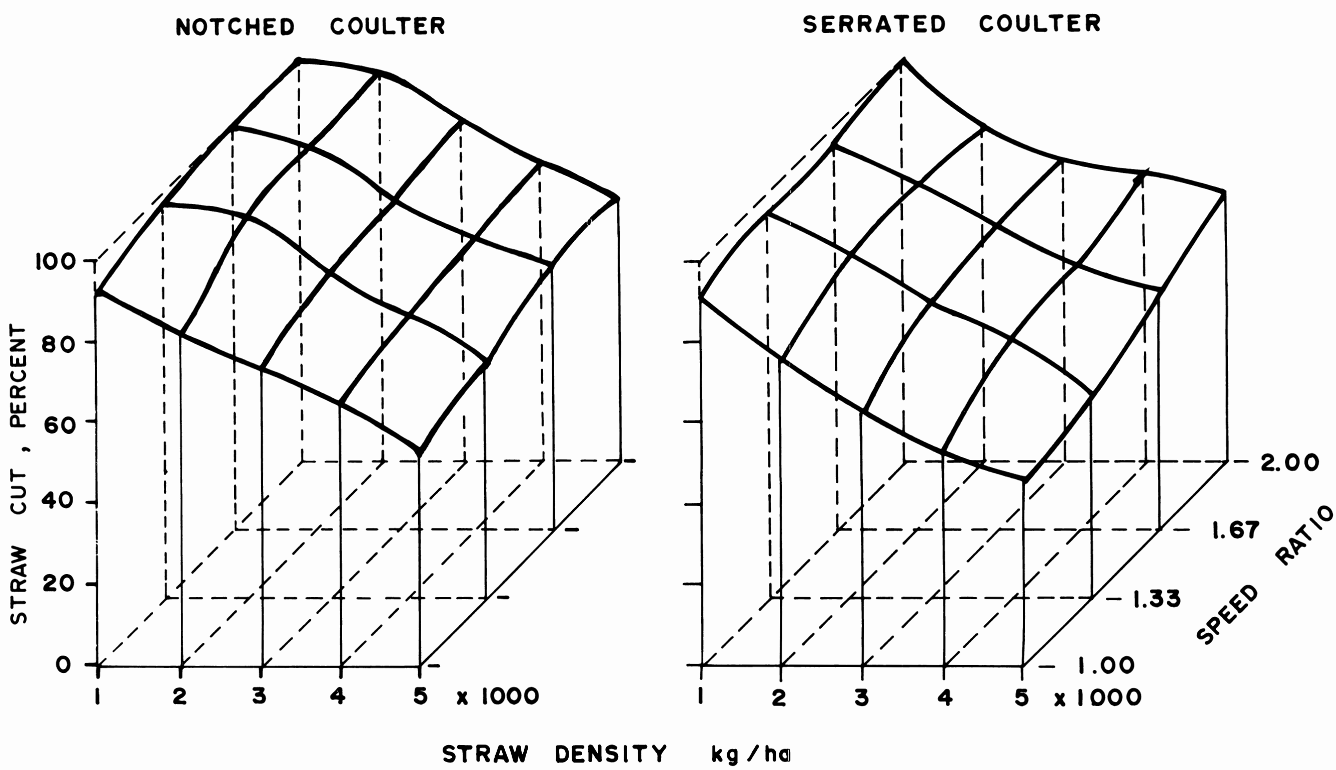

Figure 5. Effect of straw density and rotational speed on straw-cutting performance of notched and serrated coulters.

cone index values for the soil bin was 120–180 kPa, 390–690 kPa and 775–1090 kPa. The cone index values at the surface were greater in the soil bin because the surface was packed during soil preparation. Small variations in the soil moisture could also have influenced the soil compaction level.

The straw-cutting performance of the notched and serrated coulters is shown in Fig. 5. The plain coulter cut the straw nearly 100% at all the rotational speeds and straw densities tested. Vaishnav (1983) reported similar results for the free-rolling plain coulter. At higher rotational speeds the cut straws were thrown away from the furrow.

With the notched and serrated coulters, the quantity of straw cut increased with the increase in the rotational speed, but decreased with the increase in straw density (Fig. 5). However, the increase in the amount of straw cut was not proportional with the increase in the rotational speed. For a step increase of 33% in rotational speed, there was no significant increase in the quantity of straw cut from that of the free-rolling coulter. The effectiveness of notched and serrated coulters to cut straw at increased rotational speeds appeared to be reduced because of relative motion occurring at the straw and soil interface with the coulter edge. The notches and the serrations do not penetrate into the soil to the same depth as the plain edge, resulting in poor straw-cutting performance. At higher rotational speeds, straw pieces were held into the notches and serrations causing more soil disturbance. These straw pieces were thrown backward and sometimes stayed in the notches and were carried around the disc periphery.

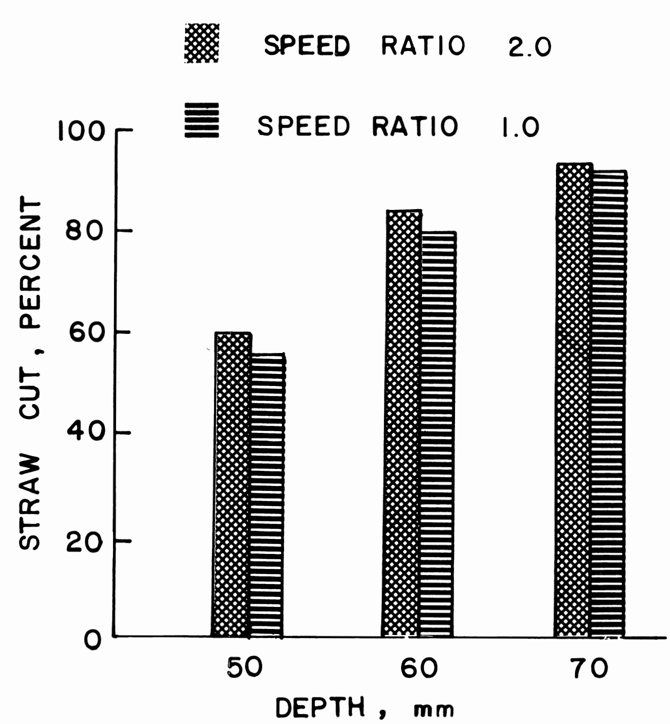

Figure 6. Effect of penetration depth at two rotational speeds on straw-cutting performance of notched coulter.

The straw-cutting performance of notched and serrated coulters was lower than that of the plain coulter except at low straw density and higher rotational speeds. The quantity of straw cut with the notched coulter varied from 58% at a speed ratio of 1.33 and at a straw density of 5000 kg/ha to 100% at speed ratios of 1.67 and 2.0 and at a straw density of 1000 kg/ha. The quantity of straw cut with the serrated coulter was lower than that of the notched coulter.

TABLE II. POWER CONSUMPTION (W) OF DRIVEN COULTERS AT 55-mm DEPTH AND 4000 kg/ha STRAW DENSITY

Coulter speed ratio	Plain: No straw	Plain: Straw	Notched: No straw	Notched: Straw
1.33	34.6	34.6 (0)†	64.5	103.9 (61)
1.67	86.6	86.6 (0)	86.6	138.6 (60)
2.00	121.1	173.2 (43)	121.1	199.2 (64)

†Numbers in parentheses indicate the percentage increase in power due to straw.

The performance of the notched coulter at three depths of penetration and at straw density of 4000 kg/ha is shown in Fig. 6. The quantity of straw cut increased with the increase in the depth of penetration. However, there was no significant change in the quantity of straw cut with the increase in the coulter rotational speed.

The external power requirement for rotation of plain and notched coulters with straw and no-straw at 55-mm depth of penetration and at 4000 kg/ha straw density is given in Table II. The power consumption of the notched coulter was higher with the straw than for the plain coulter. Power consumption increased with the increase in the rotational speed of both the coulters.

Draft and vertical forces on all coulters increased with the increase in the straw density. The increase in the draft force was not as great as in the vertical force. The magnitudes of these forces depended upon the degree of soil compaction, straw density and the quantity of straw cut. The rotation of the coulters decreased the magnitude of the draft and vertical forces in comparison to the forces acting with free-rolling coulters (Tables III and IV). This may have been caused by the rotation of the coulters assisting in penetration and in propelling the coulters forward, thus reducing the vertical and draft forces. Getzlaff (1953), and Getzlaff and Sohne (1959) also reported reduction in the draft force with power-driven plow discs. The draft and vertical forces were considerably less for the plain coulter than those for the notched and serrated coulter. There was no significant difference between the forces for the notched and the serrated coulter because of their closely related geometrical shapes.

Tests with the notched coulter at the straw density of 4000 kg/ha showed that the draft and vertical forces increased with the increase in depth of penetration (Table V). The increase in the vertical force was greater than the increase in the draft force. The vertical and draft forces also increased with the presence of straw.

TABLE III. DRAFT FORCE (N) ON COULTERS AT CONSTANT DEPTH OF 55 mm

Coulter speed ratio	Straw density (kg/ha): 0	1000	2000	3000	4000	5000
Plain coulter						
1.00	106.1	142.0	182.0	202.3	241.4	387.7
1.33	30.4	32.1	39.0	40.0	40.3	59.8
1.67	56.9	63.3	70.2	74.1	79.5	81.3
2.00	79.6	83.4	85.9	87.9	90.8	92.1
Notched coulter						
1.00	135.9	180.8	225.6	263.1	323.4	416.3
1.33	107.9	114.3	121.1	136.3	164.4	174.9
1.67	132.0	144.1	157.0	158.5	196.5	204.4
2.00	127.2	132.2	136.0	145.2	158.1	162.5
Serrated coulter						
1.00	138.3	193.5	235.6	275.4	350.1	428.6
1.33	107.6	125.1	138.8	156.8	167.3	177.6
1.67	123.2	127.3	133.8	143.8	158.1	168.8
2.00	111.4	124.6	134.2	135.6	140.4	156.5

TABLE IV. VERTICAL FORCE (N) ON COULTERS AT CONSTANT DEPTH OF 55 mm

Coulter speed ratio	Straw density (kg/ha): 0	1000	2000	3000	4000	5000
Plain coulter						
1.00	218.2	232.9	263.1	357.6	448.8	511.9
1.33	215.1	223.3	221.2	234.2	297.3	309.6
1.67	200.5	242.0	262.3	271.1	263.5	269.6
2.00	219.4	237.4	233.5	236.2	254.6	262.9
Notched coulter						
1.00	300.2	314.6	381.1	431.8	504.2	632.8
1.33	279.0	312.7	350.5	379.0	430.9	467.8
1.67	282.6	299.6	342.0	348.7	429.5	505.1
2.00	286.9	295.3	310.0	359.4	392.7	410.2
Serrated coulter						
1.00	297.3	355.0	418.0	487.0	563.0	687.2
1.33	304.8	345.0	348.0	432.9	447.2	482.4
1.67	263.1	297.9	314.2	379.1	417.1	469.0
2.00	284.2	342.5	384.9	414.4	439.0	463.7

TABLE V. EFFECT OF DEPTH ON VERTICAL AND DRAFT FORCES OF NOTCHED COULTER AT 4000 kg/ha STRAW DENSITY

Coulter speed ratio	Soil cover	Depth of penetration (mm): 50	60	70
		Vertical force (N)		
1.00	No straw	290.2	339.3	603.4
	With straw	305.4	395.3	631.1
2.00	No straw	244.6	257.7	424.1
	With straw	258.0	444.9	675.2
		Draft force (N)		
1.00	No straw	122.3	149.5	323.6
	With straw	139.1	243.2	351.1
2.00	No straw	123.2	132.3	157.9
	With straw	130.3	134.1	182.1

CONCLUSIONS

Straw-cutting performance and the soil forces obtained were affected by the varying degree of soil compaction (cone index) obtained with each soil preparation.

There was a poor correlation between the quantity of crop residue cut and the rotational speed of the coulters. The type of coulter had a greater influence on the straw-cutting performance than its rotational speeds. As reported in an earlier study (Kushwaha et al. 1986), the 460-mm free-rolling coulter performed at nearly 100%, it also cut straw nearly 100% at all densities and coulter rotational speeds tested.

With the notched and the serrated coulters, the quantity of straw increased with the increase in the rotational speed and decreased with the increase in the straw density. These coulters also caused greater soil disturbance and carried straw around the periphery at higher rotational speeds.

The increase in the depth of penetration increased the quantity of straw cut by the notched coulter. However, the rotational speed did not appear to contribute to the quantity of straw being cut.

Power consumption increased with the increase in rotational speed and with the straw density.

Draft and vertical forces increased with the increase in the rotational speed and the straw density, but were considerably lower than those obtained with the free-rolling coulters.

Since increasing the rotational speed of coulters to twice the travel speed had no effect on the quantity of crop residue cut, powering the coulters for no-till drills may not be desirable. A plain free-rolling coulter of approximately 460 mm diameter will perform satisfactorily under no-till practices over a wide range of crop residue.

ACKNOWLEDGMENT

We acknowledge the financial support provided by the Natural Sciences and Engineering Research Council of Canada, Ottawa, Ontario.

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