DEVELOPMENT AND EVALUATION OF A RESIDUE MANAGEMENT WHEEL FOR HOE−TYPE NO−TILL DRILLS

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ABSTRACT. *Adoption of conservation tillage in the Pacific Northwest lags that of the U.S. in part due to the lack of reliable seeding equipment for planting into the high residue densities encountered in this region. To overcome this problem, a drill attachment was developed to manage heavy residue next to the furrow opening tines of hoe−type no−till drills. The U.S. patented device consists of a fingered rubber wheel, a rubber inner ring, and a spring−loaded arm that pivots about vertical and horizontal axes. The performance of the device was evaluated in terms of stand establishment and yield in Oregon and Washington. Test site locations varied significantly in the amount and condition of crop residue and were planted to a variety of different crops. As compared to the standard no−till drill without the attachment, use of the residue management wheel was found to increase the stand establishment of small seeded crops such as canola and mustard by over 40% and large seeded crops such as wheat and barley by approximately 17%. Increases in stand establishment were attributed to fewer piles of residue covering the seed row. Use of the device also significantly increased crop yield by up to 12% in 8 of the 20 trials conducted ($P \leq 0.10$). Although the residue management wheel costs \$300 per unit to fabricate, using the device may be economically feasible if it results in significant improvements in both stand establishment and yield.*

Keywords. *Barley, Canola, Direct sowing, Drill performance, Mustard, No−tillage, No−till drill, Residue, Row cleaner, Seed drills, Seedling emergence, Stand establishment, Yield, Wheat.*

In the 2.5 million ha dryland cereal farming region of the inland Pacific Northwest (PNW) U.S., it has been well documented that conservation tillage systems are environmentally more sound than conventional full inversion tillage systems (WSU, 1987; Rasmussen and Albrecht, 1997; Wilkins et al., 1998; Papendick, 1998; Wuest et al., 1999; Veseth et al., 1986; Michalson, 1995). Benefits of conservation tillage systems include maintaining or increasing soil organic matter, increasing water infiltration rate, reducing wind and water erosion, reducing runoff, and reducing fuel and labor requirements by limiting the number of farming operations required to raise a crop. Despite these advantages, the percentage of no−till farmland in the PNW is only 7.5% and lags behind the national average of nearly 20% (CTIC, 2002). Limited adoption of this practice in the PNW is due not only to economic and agronomic concerns (Young and Upadhyay, 2003; Veseth and Wysocki, 2003) but also to the lack of trouble free, reliable seeding equipment for planting into the high residue densities, ranging from 3 t/ha to more than 10 t/ha, encountered in this region (Lindwall and Anderson, 1977; Erbach et al., 1983; Hyde et al., 1987; Wilkins et al. 1992; Slattery and Riley, 1996).

Commercial shank− and disc−type no−till drills were developed primarily for low crop residue conditions for crops planted in wide rows. In heavy crop residue or when row spacing is narrow, shank−type drills are prone to blockages between adjacent openers (Wilkins et al., 1983; Slattery, 1998a), causing operator frustration and reducing field capacity. They also tend to cause large clumps of residue to form (Slattery and Riley, 1996), which cover the crop row and choke out young seedlings. Another problem with shank−type drills is that the furrow opening shank disturbs the soil with sufficient force that the uncontrolled soil is thrown out of the seed furrow and occasionally onto the adjacent seed row. This adversely affects seeding depth uniformity, which is important for optimum seedling emergence and maximum yield of many crops, including cereals (Morrison and Gerik, 1985; Slattery, 1998b; Wilkins et al., 1992). Disc−type drills are able to operate without plugging in high residue densities, but are prone to pushing the crop residue into the seed zone or having the openers ride over the crop residue and deposit seed on the soil surface. Either of these scenarios can reduce germination and stand establishment (Hyde et al., 1987; Lindwall and Anderson, 1977). Excessive residue in the seed row also delays germination and depresses early plant growth due to phytotoxins produced during the early stages of residue decomposition (Wuest, 2000; Pittman and Horricks, 1972).

Equipment modifications to overcome these problems have included mounting a residue cutting coulter ahead of each furrow opener, increasing the spacing between openers by either increasing row spacing and/or adding ranks of toolbars to improve residue flow, utilizing row cleaning devices to move residue away from the furrow, and adding rolling shields next to each furrow opener to reduce soil throw.

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Although using coulters to cut residue in front of disc− or hoe−type no−till drill openers has been found to improve drill performance by enhancing residue flow (Hyde et al., 1979; Payton et al., 1985), coulters will not properly penetrate the soil without adding massive amounts of weight when residue densities are high or soils are extremely hard (Hyde et al., 1987). Because of the larger vertical forces required to penetrate thick mats of residue and hard soils, coulters can also cause smearing and increased compaction in the seed zone (Baker, 2003). Other drawbacks of coulters include being prone to damage in rocky soils and significantly increasing draft forces and therefore tractor power requirements (Hyde et al., 1987; USA, 1991, 1992). Deere and Co. developed a no−till seeder for pasture renovation that employs a powered cutter wheel in front of seed boots to cut through residue (Bucher et al., 1975). Although Payton et al. (1985) found that this device performed well in heavy wheat straw residue, the unit's PTO drive and three−point hitch mount were considered drawbacks when seeding large acreages. Production of the 2.5 m wide drill has since been discontinued due to high repair and maintenance costs and consumer demand for wider, higher field capacity drills.

Slattery (1998a) evaluated the effect of row spacing, rank spacing, and the number of ranks on the residue handling ability of a hoe−type no−till drill operating in more than 4 t/ha of wheat stubble. He found that increasing spacing between openers by increasing row spacing, increasing rank spacing, and adding ranks significantly reduced the frequency of blockages between adjacent openers and improved residue handling ability. Although Slattery recommended a drill with five ranks spaced 550 mm apart and 190 mm row spacing for seeding into wheat residue densities of 3.5 to 4.5 t/ha, this drill configuration was found to plug an average of one time per 100 m of run seeding into 4.1 t/ha of wheat residue. Fenster and Wicks (1977) made similar horizontal spacing recommendations of 250 to 360 mm row spacing with ranks spaced 510 mm apart for hoe−type no−till drills seeding into heavy residue. Increasing row spacing and number of ranks increases machine weight and cost and decreases the tracking stability of implements (Quick, 1985). Poor tracking results in uneven row spacing, especially on hillsides or while cornering.

Row cleaners are devices designed to move residue away from the seed row ahead of the furrow openers of no−till drills and row−crop planters. Numerous types and styles of row cleaning devices are commercially available, but most employ a rolling disc or pair of discs that are solid or composed of fingers in a spider wheel arrangement (Yetter, 2003). These types of devices are used effectively in the corn belt of the U.S. to clear corn or soybean stubble ahead of no−till seeders (Kaspar and Erbach, 1998). Although numerous growers using conservation tillage practices have tried different types of row cleaners in the PNW, they are not common due to inadequate performance when used to plant cereal crops in narrow rows in heavy wheat residue (Wittman, 2003). Researchers have also evaluated and developed row cleaning devices and shields. Johnson (1979) added a power−driven rake in front of a deep−furrow grain drill to move residue away from the seed row and improve its residue handling capabilities. This modification allowed the drill to operate in heavier density residue without plugging, but it had the disadvantage of wrapping large weeds and straw around the rake, and further development was needed. Wilkins et al. (1983) developed and tested two types of row cleaning wheels for use with hoe−type no−till drills. Although these devices reduced the incidence of drill plugging, they needed to be power driven and became plugged when wheat residue densities were greater than 5.6 t/ha. Desbiolles (2003) found that adding rolling disk−type shields mounted on either side of furrow openers reduced the amount of soil throw by 55% to 60% for hoe−type no−till drills. He cautioned, however, that they also increase cluttering within the implement frame and therefore promote drill plugging when used in high residue densities.

This body of literature is in agreement with the findings of Erbach et al. (1983) and Slattery and Riley (1996), who indicated that there is a lack of reliable, optimally performing seeding equipment for sowing into residue densities exceeding 2.5 to 4.5 t/ha. To address this problem, a project was initiated to develop technology to improve the performance of hoe−type no−till drills.

Objectives

The objectives of this project were to:

- Develop a seeder attachment to improve the residue handling ability and performance of hoe−type no−till drills.
- Evaluate the performance of the seeder attachment in terms of stand establishment and grain yield.

Residue Management Wheel Description

The seeder attachment developed is a U.S. patented prototype device (Siemens et al., 2002) that consists of a fingered rubber wheel, a rubber inner ring, a spring−loaded arm that pivots about vertical and horizontal axes, and associated assembly components (fig. 1). The unit is designed to attach to the tool bar of hoe−type no−till drills and be positioned so that the inner ring is next to the furrow opening shank, as shown in figure 2. The height of the residue wheel is adjusted such that during seeding, the ground−driven rubber fingered wheel and inner ring hold down and "walk" through crop residue, preventing it from building up on the furrow opener (fig. 3). They also help control soil disturbed by the furrow opener so that it stays within the seed row. When clumps of crop residue build up between the wheel and the shank, the arm holding the wheel is able to rotate away from the shank, causing the pile of crop residue to dislodge. After swinging out, forces on the wheel will naturally push it back into its operating position, close to the shank and in line with the direction of travel. Other features of the design are that the wheel has adjustable, spring−loaded down pressure and vertical height adjustment.

While the optimal residue management wheel geometry is dependent on opener type and seeding conditions, the geometry used in this study included a 43.5 cm outside diameter, 22.2 cm inside diameter, 2.54 cm thick rubber wheel with 27 fingers spaced equally around its perimeter. Each slightly curved finger was approximately 6.4 cm long and narrowed in width from base to tip from 3.2 cm to 2.1 cm. A durable, yet flexible, 60 durometer neoprene rubber was selected for the design so that the fingers were able to conform to the shape of the soil surface and provide a long footprint of about 20.3 cm to pin crop residue. The 29.9 cm outside diameter, 22.2 cm inside diameter, inner ring was also comprised of 60 durometer neoprene rubber. Because the furrow opener disturbs about 2.5 cm of soil on either side of

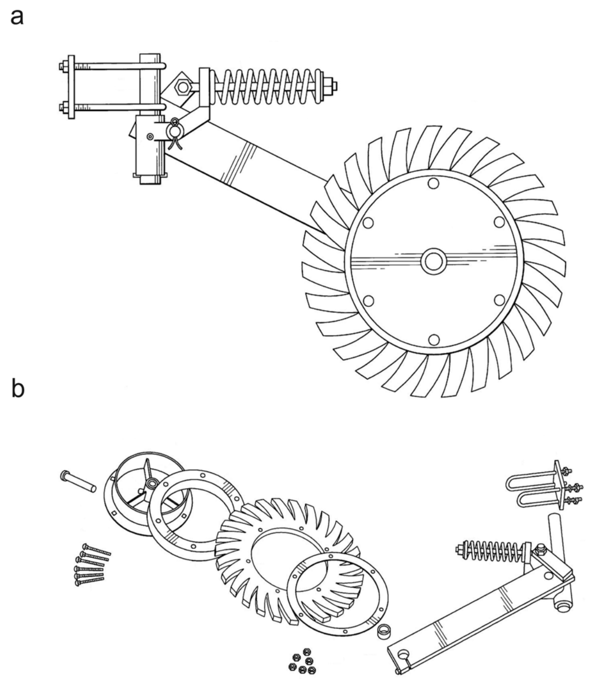

Figure 1. (a) Right side view and (b) exploded left side view of residue management wheel assembly (U.S. patent 6,345,671).

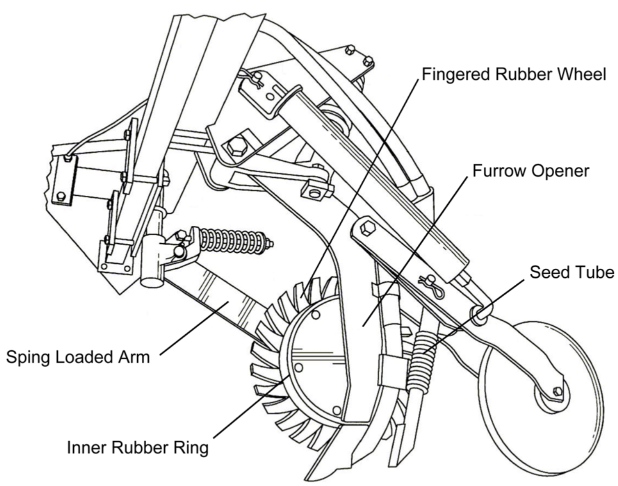

Figure 2. Residue management wheel assembly in operating position next to furrow opening shank of hoe−type seeding unit.

the shank, the primary function of the 5 cm thick inner ring is to act as a spacer to position the ground−driven rubber wheel so that it contacts undisturbed soil where good traction is provided. Its secondary function is to help walk through and pin crop residue that tends to lodge between the rubber fingered wheel and the furrow opener. The spring−loaded arm design is patterned after those commonly used with coulters or other types of rolling, ground−following tools. A spring with a moderate stiffness of 175 N/cm was selected so that it provided sufficient down pressure to pin crop residue to the soil surface yet was flexible enough to allow the wheel to easily roll over soil clods or clumps of residue. Spring pretension was adjusted such that a nominal down pressure force of 270 N was provided during normal operation.

Figure 3. Residue management wheel operating next to furrow opener in wheat residue.

Methods

The present invention was evaluated in crop years (CYs) 2000 and 2001 seeding a variety of different crops into winter wheat stubble including yellow mustard, winter canola, winter wheat, spring wheat, spring barley, and lupin at various locations in northeastern Oregon and southeastern Washington (tables 1 and 2). Site locations varied significantly in crop residue sizing method and density, and were selected to provide a wide range of possible no−till seeding conditions (tables 1 and 2).

Three types of combine−header arrangements were used to harvest the plots prior to sowing: a cylinder−type combine equipped with a stripper header, a rotary combine equipped with a conventional pick−up reel, and a cylinder−type combine equipped with a conventional pick−up reel. Each combine−header configuration conditioned and sized residue differently. Rotary−type combines tended to process straw taken into the combine more aggressively than cylinder−type combines; however, measurements of the observed difference in straw condition were not recorded. Combines equipped with stripper headers harvested primarily the heads of cereal crops and left tall, standing stubble ranging from 48 to 62 cm in height. Crops harvested with conventional sickle−bar headers cut the straw below the crop head and left shorter, 19 to 41 cm cereal stubble.

In some experiments, the residue was left standing; in other experiments, the residue was flailed, rotary mowed, harrowed, or forage chopped into smaller pieces ranging in length from 4 to 18 cm in length (tables 1 and 2). Combines equipped with straw choppers were also used to size crop residue taken into the combine into 17 cm length pieces. Some of the combines were equipped with chaff spreaders, while others were not. In fields where chaff spreaders were not used, plots were laid out perpendicular to the chaff rows so that each plot would have a similar distribution of crop residue. Amounts of residue present at the time of seeding ranged from a low of approximately 1.3 t/ha to a high of almost 10.5 t/ha, while stubble height ranged from less than 5 cm to slightly greater than 60 cm.

In CY 2000, all plots were seeded with a 3.7 m wide, 0.30 m row spacing, hoe−type no−till plot drill manufactured by Conserva−Pak® Seeding Systems of Indian Head, Saskatchewan, Canada. The performance of the residue wheel was evaluated by equipping one side of the drill (six openers) with the residue management wheel and the opposite side (six openers) without. This procedure was also used to evaluate the residue wheels at the Adams and Helix sites in CY 2001. Slightly different procedures were used at other locations in CY 2001. At the Pendleton and Moro sites, an additional six residue wheels were constructed and mounted on the drill so that all twelve drill openers were either equipped or not equipped with the residue wheels during seeding. At the Prescott location, the device was tested by mounting four wheels on a 36 opener, 11 m wide, 0.30 m row spacing commercial−scale Conserva−Pak® drill and comparing those rows with the rows planted without the wheels.

Depending on location, plot length varied from a minimum of 12.2 m to a maximum of 91.4 m. All experiments were a randomized complete block design with four replications, except for the winter wheat experiment at Pendleton, Oregon, in CY 2000. In this experiment, the plot was laid out as a split−plot design with two replications. Plots were seeded using standard fertility recommendations and the sowing rates indicated in tables 1 and 2. After the seedlings had emerged and the date of the last killing spring frost had passed, stand counts in each plot were taken using the following procedure. First, a random sampling location, at least 4.6 m from either end of the plot, was selected for each replication. The number of plants within 0.5 m of either side of the sampling location were then counted and recorded for the inner four rows of each 6−row plot. The outer rows of the plots were not counted to avoid edge effects. For the 12−row plots, the inner nine rows were counted and recorded. For the 11 m wide plots at the Prescott site, the four rows that were seeded using the wheels were counted at two locations and compared with stand counts taken from eight rows seeded with the standard opener. Yield was determined by harvesting five rows from each 6−row plot and nine rows from each 12−row plot with a plot combine. Yield data were not collected from the 11 m wide plots at the Prescott site.

RESULTS AND DISCUSSION

Results from the CY 2000 residue wheel experiment are shown in table 1. Depending on residue treatment, use of the residue management wheel was found to increase seedling stand count of winter canola by 43% to 53%, mustard by 41%, spring barley by 24%, lupin by 10%, spring wheat by 14% to 17%, and winter wheat by 17% to 19% as compared to the standard drill without the attachment (table 1). These differences were statistically significant at the P = 0.10, P = 0.05, or P = 0.01 probability levels, as indicated in table 1. In trials where residue densities were greater than 5 t/ha, increases in stand establishment averaged about 17% for large seeded crops such as spring and winter wheat. Increases were attributed to the residue wheel leaving a cleaner seed row, with fewer piles of residue and soil clods covering the furrow. For small seeded crops such as canola and mustard, cleaner seed rows were also estimated to account for an increase in stand establishment of about 17%. In these trials, however, stand

Table 1. Site description, seedling stand count, and yield results of residue management wheel evaluation studies in Oregon for crop year 2000.

Crop and Location	Combine−Header Type	Residue: Management	Residue: t/ha	Residue: Stubble Height (cm)	Residue: Cut Length (cm)[a]	Residue Mgmt. Wheel	Sowing Rate (seeds per m^2)	Stand: Plants per m^2 [b]	Stand: P value[c]	Stand: % Increase	Yield: t/ha[b]	Yield: P value[c]	Yield: % Increase
Winter Canola, Pendleton	Stripper	Chaff spreader, flail	5.1	<5	15	No Yes	417	103 *** 156	<0.01	51.5	0.60 NS 0.65	0.33	8.3
Winter Canola, Pendleton	Stripper	Chaff spreader, standing	5.1	48	NA	No Yes	417	122 *** 175	<0.01	43.4	0.65 * 0.73	0.10	12.3
Mustard, Helix	Rotary	No chaff spreader	4.4	19	NA	No Yes	171	42 *** 59	<0.01	40.5	1.38 *** 1.45	<0.01	5.1
Spring Barley, Moro	Cylinder	Chaff spreader	1.8	29	NA	No Yes	352	136 ** 169	0.04	24.3	2.65 ** 2.73	0.04	3.0
Lupin, Adams	Rotary	Chaff spreader	3.6	21	NA	No Yes	66	41 * 45	0.09	9.8	0.86 ** 0.93	0.03	8.1
Spring Wheat, Adams	Stripper	Chaff spreader, standing	9.8	62	NA	No Yes	284	136 * 155	0.10	14.0	3.91 * 4.14	0.07	5.9
Spring Wheat, Adams	Cylinder	Straw chopper, chaff spreader	9.8	22	17	No Yes	284	133 * 155	0.07	16.5	4.43 NS 4.47	0.64	0.9
Winter Wheat, Pendleton	Cylinder	Flail	6.7	<5	15	No Yes	265	213 *** 250	<0.01	17.4	6.73 NS 5.93	0.14	−11.9
Winter Wheat, Pendleton	Cylinder	Rotary mow	6.7	<5	18	No Yes	265	213 *** 254	<0.01	19.2	5.55 NS 5.99	0.30	7.9

[a] Average length of residue that had been mechanically sized into smaller pieces with a straw chopper during harvest or with a secondary operation post−harvest.
[b] *, **, *** indicate that means between use and non−use of residue management wheels in the same in residue treatment row and column are significantly different by the LSD test at the P = 0.10, P = 0.05, and P = 0.01 levels, respectively. NS = not significant.
[c] P−value of the two−way ANOVA test statistic for comparison between means.

establishment was increased by over 40%. A logical explanation for the additional 23% increase could not be formulated. Statistically significant increases in stand establishment of 9% and 24% were also observed in the lupin and spring barley trials, respectively. This result was not expected since residue densities were less than 5 t/ha and there was not a significant visual difference in the seedbed condition in either treatment. One possible explanation for this is that the residue wheel prevented moist soil from being thrown out of the seed row, thereby improving seed germination and early seedling vigor. Data to support this hypothesis, however, were not collected.

Use of the residue management wheel also resulted in increases in crop yield in eight of the nine trials conducted at probability levels indicated in table 1. In one winter wheat trial at Pendleton, yield was lower by 12%, but the reduction was not statistically significant at the 90% level of confidence. Statistically significant ($P \leq 0.10$) yield increases were found in four of the trials, including those seeded to winter canola, mustard, spring barley, lupin, and spring wheat, where yield increases were 12%, 3%, 5%, 8%, and 6% greater, respectively. It is not known if these increases were due to higher established plant densities or the result of a cleaner seed row and therefore healthier seedlings with more vigor and yield potential. Although there was a 40% difference in mustard stand establishment, large increases in mustard yield were not expected since mustard compensates for low plant densities by increasing branching and pod set (Saskatchewan AFRR, 2000). Similarly, although there were large differences between treatments in canola stand establishment, yield increases were less than 13% (0.08 t/ha) and statistically significant ($P \leq 0.10$) in only one of the two trials. Significant yield increases did not occur in the other trial because the sowing rate was high (417 seeds/m^2), and adequate plant stands of over 103 plants/m^2 were present in both treatments. This result is consistent with that of Berglund and McKay (2002) and Wilkins et al. (2002), who showed that stand establishment does not significantly influence canola yield when plant densities range from 43 to 172 plants/m^2.

Table 2. Site description, seedling stand count, and yield results of residue management wheel evaluation studies in Oregon and Washington for crop year 2001.

Crop and Location	Combine−Header Type	Residue: Management	Residue: t/ha	Residue: Stubble-Height (cm)	Residue: Cut Length (cm)[a]	Residue Mgmt. Wheel	Sowing Rate (seeds per m^2)	Stand: Plants per m^2 [b]	Stand: P value[c]	Stand: % Increase	Yield: t/ha[b]	Yield: P value[c]	Yield: % Increase
Spring Barley, Moro	Cylinder	Chaff spreader	2.5	22	NA	No	273	95 NS	0.45	5.3	0.80 *	0.09	10.0
						Yes		100			0.88		
Spring Barley, Moro	Cylinder	Chaff spreader	1.9	19	NA	No	273	93 NS	0.88	0.0	0.89 *	0.09	9.0
						Yes		93			0.97		
Spring Wheat, Adams	Rotary	No chaff spreader	5.2	27	NA	No	285	125 NS	0.27	16.0	2.47 NS	0.18	14.6
						Yes		145			2.83		
Spring Wheat, Helix	Rotary	No chaff spreader	4.1	31	NA	No	284	169 NS	0.46	3.0	3.03 ***	<0.01	6.9
						Yes		174			3.24		
Spring Wheat, Prescott	Rotary	Chaff spreader, harrow	10.1	<5	18	No	297	175 ***	<0.01	34.9	−−	−−	−−
						Yes		236			−−		
Spring Wheat, Prescott	Rotary	Chaff spreader, flail	10.1	18	16	No	297	186 ***	<0.01	23.1	−−	−−	−−
						Yes		229			−−		
Spring Wheat, Prescott	Rotary	Chaff spreader, standing	10.1	41	NA	No	297	186 ***	<0.01	19.4	−−	−−	−−
						Yes		222			−−		
Spring Wheat, Pendleton	Cylinder	Straw chopper, chaff spreader	10.5	30	17	No	285	117 NS	0.53	−4.3	3.42 NS	0.56	2.9
						Yes		112			3.52		
Spring Wheat, Pendleton	Cylinder	Straw chopper, chaff spreader, flail	10.5	12	17	No	285	122 NS	0.56	7.4	3.62 NS	0.46	2.5
						Yes		131			3.71		
Spring Wheat, Pendleton	Stripper	Chaff spreader, forage chop	10.5	23	4	No	285	113 *	0.09	16.8	3.48 NS	0.99	0.0
						Yes		132			3.48		
Spring Wheat, Stanfield	Rotary	Chaff spreader, standing	1.3	20.3	NA	No	241	93 *	0.05	23.7	0.83 NS	0.98	0.0
						Yes		115			0.83		
Winter Wheat, Pendleton	Cylinder	Straw chopper, chaff spreader	10.5	30	17	No	286	87 NS	0.54	3.4	3.40 NS	0.70	1.8
						Yes		90			3.46		
Winter Wheat, Pendleton	Cylinder	Straw chopper, chaff spreader, flail	10.5	12	17	No	286	97 NS	0.55	−9.3	3.46 NS	0.33	−4.3
						Yes		88			3.31		
Winter Wheat, Pendleton	Stripper	Chaff spreader, forage chop	10.5	23	4	No	286	100 NS	0.88	4.0	3.31 NS	0.84	3.3
						Yes		104			3.42		

[a] Average length of residue that had been mechanically sized into smaller pieces with a straw chopper during harvest or with a secondary operation post−harvest.

[b] *, **, *** indicate that means between use and non−use of residue management wheels in the same in residue treatment row and column are significantly different by the LSD test at the P = 0.10, P = 0.05, and P = 0.01 levels, respectively. NS = not significant.

[c] P−value of the two−way ANOVA test statistic for comparison between means.

Seeding conditions were unusually wet during CY 2001 (Greenwalt, 2002), which negatively affected the performance of the residue management wheel. The heavier wet residue tended to accumulate on the shank rather than get pulled to the residue wheel side of opener. This resulted in more residue clumping and a more obstructed seed row in CY 2001 than in the drier CY 2000. Even so, increases in stand establishment and yield were found when the residue management wheel was used during CY 2001. Increases in seedling stand establishment were found in 11 of 13 trials, including increases of 0% to 5% in spring barley, 3% to 34% in spring wheat, and 3% to 4% in winter wheat at the P−values indicated in table 2. Statistically significant ($P \leq 0.10$) increases in stand establishment were found in four of nine trials where residue densities were high (>10.1 t/ha) and in one trial where residue density was low (<1.5 t/ha). Higher stands were again attributed to the residue wheel leaving a cleaner seed row.

Use of the residue management wheel was also found to increase yields in eight of the eleven trials where yield data were collected in CY 2001 at probability levels indicated in table 2. Statistically significant ($P \leq 0.10$) increases in yield were found in three of the trials, including the two spring barley trials and the spring wheat trial at Helix, where increases in yield were greater than 9% and 7%, respectively. In five of the trials, use of the device increased yield by 2% to 15% at P−values ranging from 0.18 to 0.84 (table 2). Significant differences might have occurred in more of the trials if cereal crop yields were not compromised by Hessian fly infestation in CY 2001 (Smiley et al., 2002). Additionally, there were no yield data obtained in three of the five trials where stand establishment increases were significantly greater.

During these trials, the residue management wheel was used to seed more than 60 ha with a 3.7 m wide plot drill. This is equivalent to more than 180 ha on a commercial farm, since commercial drill widths are typically at least 3 times as wide as the plot drill used in the study. For the approximately 34 hours that the unit was operated, the residue management wheel performed reliably with no mechanical failures. Rubber components of the wheel showed little wear and could be used on many more hectares. Some of the brass bushings used to support residue wheel axles were worn and would need replacement in an estimated additional 34 hours. In a commercial application, more expensive roller bearings could be used to extend the life of this component. Currently, the unit costs about $300 per unit to fabricate, which would add $10,800 to the $46,800 purchase price of a commercial−sized drill with 36 tines. Additional durability studies are needed so that component life can be determined and an accurate economic analysis on the cost effectiveness of the device can be made. It is questionable whether the device is justifiable on stand establishment improvements alone, since sowing rates can be increased at nominal expense. However, if using the device also results in significant yield increases, then the residue management wheel may be an economically viable agricultural tool.

Conclusions

A residue management wheel consisting of a rubber fingered wheel, an inner ring, a spring−loaded arm, and associated assembly components was developed to manage heavy residue next to the furrow opening tines of hoe−type no−till drills. The device received a U.S. patent in February 2002. Studies conducted to evaluate its performance showed that use of the residue management wheel improved stand establishment and yield for a variety of crops in a wide range of residue densities and stubble conditions. It should be noted, however, that the device was observed to perform better in dry rather than wet residue and that the residue wheel may promote drill plugging in wet conditions.

For small seeded crops, such as mustard and winter canola, use of the residue management wheel was found to increase stand counts by more that 40%. Some of this increase was due to the observed fewer piles of residue and clods covering the seed row. The remainder could not be explained, and further study is warranted. The study also showed that for larger seeded crops, such as wheat and barley, use of the residue management wheel significantly increased stand counts by approximately 17% in CY 2000 and by over 17% in certain heavy residue conditions in CY 2001. In trials where residue density was greater than 5 t/ha, increased stand counts were also attributed to cleaner seed rows with fewer piles of residue covering the seed row. Further study is needed to determine the cause of the increased stands in residue densities less than 5 t/ha.

Use of the residue management wheel also significantly increased crop yield up to 12% in 8 of the 20 trials conducted ($P \leq 0.10$). Significant differences may have occurred in more of the trials if sowing rates were lower or if the growing season was more conducive to high crop yields. Additional study is needed to determine if increased yields are due to increases in stand establishment or due to a cleaner seed row resulting in a healthier seedling with more vigor and yield potential. Further testing is also warranted to determine if the residue management wheel could be used to reduce seeding rates without negatively affecting crop yield.

The design operated without mechanical failure for approximately 34 hours, equivalent to about 180 hectares of commercial seeding. More testing is needed to determine component life so that an accurate analysis of the device's cost effectiveness can be made. Further testing is also needed to determine the effectiveness of the invention when used with other types of no−till drill geometries. Although the residue management wheel costs an estimated $300 per unit to fabricate, using the device may be economically feasible if it results in significant improvements in stand establishment and crop yield. The USDA−ARS owned patent (U.S. patent 6,345,671) on the device is currently available for licensing to a manufacturer.

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