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COMPARISON OF CLEANING PERFORMANCE FOR ROW CLEANERS ON A STRIP TILLAGE IMPLEMENT

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ABSTRACT Strip tillage implements remove the residue from previous crops and form a seedbed ready for planting. An experiment was conducted to evaluate 5 row-cleaning devices. The proportion of residue removed by the implement was used as the performance indicator. Each of the 5 devices was evaluated at 2 speeds and orientations on the implement. The devices were tested in two blocks (fields) of corn residue (one high residue and one medium residue), and one field of wheat residue. An analysis was conducted, using a mixed effects model, to compare the performance of the cleaners operating in the different conditions. All cleaners performed well, with no statistical difference in mean performance. All row cleaners performed more consistently in wheat residue, compared with performance in corn residue. Numerically, the consistency of the different cleaners was different, with one configuration performing less consistently than the other four.

Keywords: corn residue, wheat residue, residue manager, machine performance

INTRODUCTION Strip-tillage is an agronomic practice used in minimum tillage row-crop production in the United States and Canada. It can be defined as, "any row-crop cultural practice that restricts soil and residue disturbance to less than 25% of the field area" (Morrison and Sanabria, 2002). The tillage can be shallow or deep, and within each of these two categories it may be minimal or intense. The configurations chosen from the above-listed options will depend upon the type of soil, the climate, the crop and the management scheme in the farming operation (Morrison and Sanabria, 2002). Generally, the portion of the field that is tilled becomes the seedbed (berm) for the crop while a vast majority of the accumulated surface residue is moved to the inter-row zones as shown in Figure 1. Fertilizer is usually applied at the same time and can be in the form of a solid (ie. urea or phosphate), liquid (ie. urea ammonium nitrate) or gas (anhydrous ammonia), with the latter being the most common type. Strip tillage and fertilizer application operations are often completed in the fall, followed by seeding in spring, however both the strip-till and seeding operations may be performed in the spring.

Commentaire [T1]: As a general view, references to figures should appear in sequential order. Further, I'm not sure that it makes sense to include an appendix with a 10-page technical paper. If you want to insert the figure, include it as part of the paper...and look for ways to trim the "fat" from the rest of the paper.

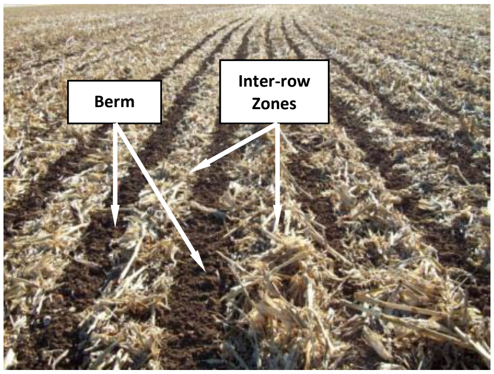


Figure 1. A corn field which has undergone the strip tillage operation showing the berms as long dark vertical lines of soil and the corn residue which has been moved to the inter-row zones.

The adoption of strip tillage as a mainstream field management practice is growing across the American Midwest. It is difficult to associate an increase in strip-tillage with a specific factor, however the combination of a variety of factors may be playing a role. As the costs of fuel, labor and equipment rise, farmers and farm managers are constantly looking for ways to reduce or at least hold production costs to current levels, while also seeking more agronomically and environmentally sound practices. With strip-tillage, cost savings are realized because there are at least two fewer field passes as compared to conventional tillage (Wolkowski, 2000). Studies by Al-Kaisi et al. (2005) have indicated that by using strip-tillage, the amount of soil organic carbon (SOC) increased by 11.4% as compared to a moldboard plow tillage treatment after three years. Similar results in this study were also apparent with soil organic nitrogen (SON). Using strip tillage also has significant effects on soil temperature and moisture content. Various studies (Swan et al., 1996; Morrison and Sanabria, 2002; Wolkowski et al., 2000; and Licht and Al-Kaisi, 2005) have come to similar conclusions. Strip-tillage increased the soil temperature as compared to no-till conditions allowing for faster plant germination and better early growth. With regards to soil moisture content or soil moisture retention, strip-tillage was able to better conserve moisture than conventional tillage

OBJECTIVES The primary objective of this study was to compare the performance of row cleaners used on strip-tillage implements.

EXPERIMENT DESIGN The experiment was designed as a completely randomized block design. The response variable was cleaning performance of the row cleaners. There were four fixed factors: row cleaner configuration, travel speed, row unit orientation and the residue moisture content at the time the field operation was conducted (covariate). The experiment was conducted in two corn-field locations (heavy corn-on-corn residue, and medium residue) and one wheat-field location near Dumas, Texas on February 10-12, 2009.

Machine Nomenclature To allow the easy identification of row positions on the machine, the rows were numbered 1 through 16 from left to right as viewed from the rear of the machine,. Although a 16-row machine (12.2 m wide with 0.76 m row spacing) was used in the experiment only row cleaners 1 through 8 (left side) of the machine were used in the experiment.

The layout of a typical strip tillage row unit is shown in Figure 2, and a commercial Case IH machine is shown in Figure 3. From front to rear, the row units employed in these machines consist of:

1. a leading coulter to cut residue and create a path for the mole knife,
2. a row cleaner to move the residue to the inter-row spacing, operating directly in front of the knife,
3. a mole knife used to fracture & loosen the soil and apply fertilizer,
4. a pair of berm-building disks mounted so as to capture the soil thrown aside and bring it back together to form a seedbed ridge or berm and
5. a rolling basket to firm and shape the ridge into a proper berm.

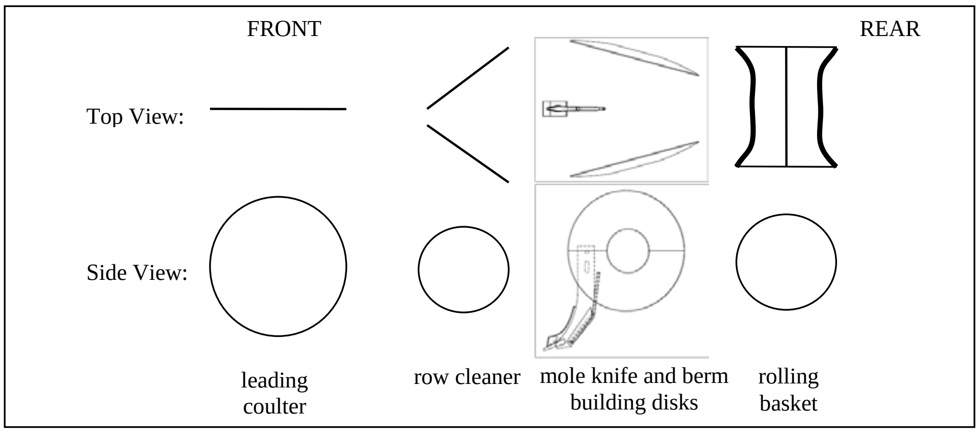


Figure 2. Top and side view schematic of a typical strip tillage row unit.

(a) **(b)**

Figure 3. 'a' strip tillage equipment. 'b' side view of a single strip-tillage unit.

Dry matter residue measurements were used as an indicator of cleaning performance. Cleaning performance was defined as the mass of material removed as compared to the initial mass present, calculated as:

$$Cleaning\ Performance = \frac{(initial\ mass - final\ mass)_{\ in\ sampling\ area}}{(initial\ mass)_{\ in\ sampling\ area}} \quad (1)$$

The residue quantities were recorded from a row sampling area 2 m in length and 0.25 m in width centred on the knife path of each row unit. A quadrat (rigid rectangular section) constructed from lumber with the above-noted inner dimensions defined the sampling area. Hand-operated clippers were used to sever any residue intersecting the perimeter of the interval sampling area. In the case where a piece of residue or a root ball was partially exposed or protruding from the ground, and was within the interval sampling area, it was pulled from the ground and included within the mass measurement. Any residue covered entirely by soil was not included.

A five-step process was used to collect residue from a single interval sampling area. The following describes the process.

1. The location of the sampling area was located. The row location was identified by counting the number of rows from the center of the plot for the corn stubble or by measuring the distance from the center of the plot in wheat stubble. The interval location was identified in both corn and wheat stubble by measuring the distance from one edge of the plot to the nearest edge of the sample quadrat.
2. While holding the quadrat firmly in place, crop residue intersecting the quadrat perimeter was cut along the inner edge.
3. The crop residue within the quadrat was then collected and placed in a holding container.
4. The material was then weighed (Scout Pro SP2001, Ohaus, Pine Brook, NJ) with a resolution of ± 0.1 g, and the dry mass of the residue was determined, using the moisture content determinations.

Each plot was subdivided into a grid 16 machine row units in width (8 row units per pass with 2 passes) and 20 m (ten sample intervals of 2 m) in length. The locations of the initial and final sample measurements were randomly selected for each of the two passes. The final mass measurements were taken from the same interval for all row units of each pass to account for and minimize any interactive effects between row units. The three initial residue measurement locations were randomly chosen from each pass from all of the remaining sampling areas in the grid. Locations were chosen to ensure a minimum of 2 m between the final measurement intervals of the two passes, as well as 2 m and/or a one-row buffer between any given initial and final residue mass measurement. This was done to ensure that any final measurements could not be influenced by any of the initial measurements. Before the machine passed through the field, initial residue measurements for each plot were recorded. The average dry matter mass of these six measurements was recorded as the initial mass measurement for the plot. After the completion of both machine passes, final mass measurements from all remaining rows of interest were taken from their respective intervals.

There were four fixed factors in the experiment. They were row cleaner configuration, machine travel speed, row cleaner orientation and residue moisture content at the time of operation. The five row cleaner configurations were: a prototype residue manager (Alpha prototype), an offset-disk row cleaner with 0.33-m (13-in) disks (Offset-13), an offset-disk row cleaner with 0.46- m (18-in) disks (Offset-18), a parallel-disk row cleaner with 0.33-m (13-in) disks (Parallel), and the Case IH production row cleaner (Production). In corn, speeds were 8 km/h (5 mph) and 10.4 km/hr (6.5 mph), while in wheat the speeds were 8 km/h (5 mph) and 11.2 km/h (7 mph). The row unit orientations were a front and a rear position. Being a covariate, the residue moisture content at the time of operation was observed and recorded at the time of the field trials.

Due to the blocking nature of the experiment, three random factors were used. From the top level to the bottom level of nesting these were the field location, the plot, and the pass. There were three field locations with heavy and medium levels of corn residue (Locations I and II, respectively) and wheat residue (Location III). Each location consisted of ten plots which were each randomly assigned a particular configuration and speed. Each plot had two passes nested within – one pass in one direction and the second in the opposite direction of the first.

Several parameters were measured to characterize the conditions during the experiment. These included residue moisture measurements, as well as soil moisture content and texture measurements. During the initial and final residue mass measurements, residue moisture measurements were recorded once per hour. The moisture measurements were completed according to ASABE Standard S358.2 utilizing a micro-wave oven as a drying method (ASABE, 2008). Soil moisture content measurements were recorded once per morning and afternoon session per location and are shown in Table 1. The soil samples were collected immediately after the operation from two rows in a random plot. Samples were dried using a microwave oven according to ASTM Standard D4643-08 (ASTM, 2008).

Table 1. Soil moisture content during the test runs

Date	Soil Moisture Content (d.b.) (kg kg^{-1})		
	Location I	Location II	Location III
February 10, 2009	0.186	0.142	0.177
February 11, 2009	0.221	0.165	0.146
February 12, 2009	0.196	0.155	0.150

Soil texture at each location was determined by a commercial laboratory (MTVL Laboratories Inc., New Ulm, MN), using a composite soil sample from those collected for soil moisture content. Results are shown in Table 2.

Table 2. Soil property lab-test results (MTVL Laboratories Inc., New Ulm, MN)

Property	Location I	Location II	Location III
Bulk density, loose (g cm^{-3})	1.02	1.11	1.10
Bulk density, packed (g cm^{-3})	1.21	1.29	1.28
Sand (%)	35.0	20.0	47.5
Silt (%)	32.5	65.0	32.5
Clay (%)	32.5	15.0	20.0
Soil Texture	Clay loam	Silt loam	Sandy loam

Several factors were held constant throughout the experiment. The operating depth and configuration of the 16-row implement (NT5310, Case IH, Racine, Wisconsin) was not changed from how the producer normally used it. The mole knife depth was approximately 0.23-0.25 m (9-10 in.). The machine was equipped with 0.46-m (18-in) diameter wavy coulters, 0.46-m (18-in) diameter berm building disks mounted in convex fashion and the production roller baskets. In addition, the machine was operated in such a manner as to keep the row units operating in the mid-row region of the previous year's corn crop (in Locations I & II).

METHOD OF ANALYSIS A separate analysis for each crop type was performed. Thus, two locations were used in the corn analysis and a single location was used for wheat. For the main corn and wheat datasets, performance data were used from rows 2 through 6. It was assumed that the data of row cleaners separated by a minimum of 0.6 m would be independent of one another. Therefore, there were three replicates available in the front orientation (rows 2, 4, & 6) and two replicates available in the rear orientation (rows 3 & 5). Unless otherwise indicated, all residue mass measurements have been presented on a dry-mass basis. They were converted using the various moisture measurements taken throughout the duration of the field trials as appropriate.

A linear mixed effects model was used to identify potential differences between the mean performance values for the various configurations, travel speeds, orientations, and residue humidity at operating time. The mixed effects model included both the fixed and random factors in its analysis and adjusted the degrees of freedom appropriately for each level of spatial blocking and/or nesting. By adjusting the degrees of freedom, this model effectively dealt with the unbalanced dataset. Although the mixed effects model provided coefficients for each term to be used in an empirical model, the goal was to use the model selection process and the p-values of each fixed factor to determine which fixed factors had a statistically significant effect on cleaning performance. The statistical tests were conducted using three different subgroups of the data for each crop-type:

1. The front orientation only with four configurations,
2. The rear orientation only with all five configurations (including the prototype) and
3. Both orientations combined with four configurations.

The decision to perform a separate analysis for the front and rear orientations arose from two issues. First, there were zero measurements for one of the configurations in the front orientation which meant that the statistical equations were unsolvable for the front orientation. Secondly, because any front row is immediately adjacent to two rear rows and vice-versa, they are not completely independent of one another. Combining both orientations (Test 3 in the above list) was completed only if there were no significant factors in the tests for each individual orientation.

Quantitatively, consistency was defined as how close each configuration operated to the mean performance value. The indicator used to quantify consistency was the range of the performance data, excluding any outliers in the distribution. The *boxplot.stats()* function in R (R Development Team, 2009), using its default settings was used to extract the appropriate data points from each distribution for a particular configuration. The formula used to calculate consistency was:

$$Consistency(\%) = 100 * (1 - range), \qquad (2)$$

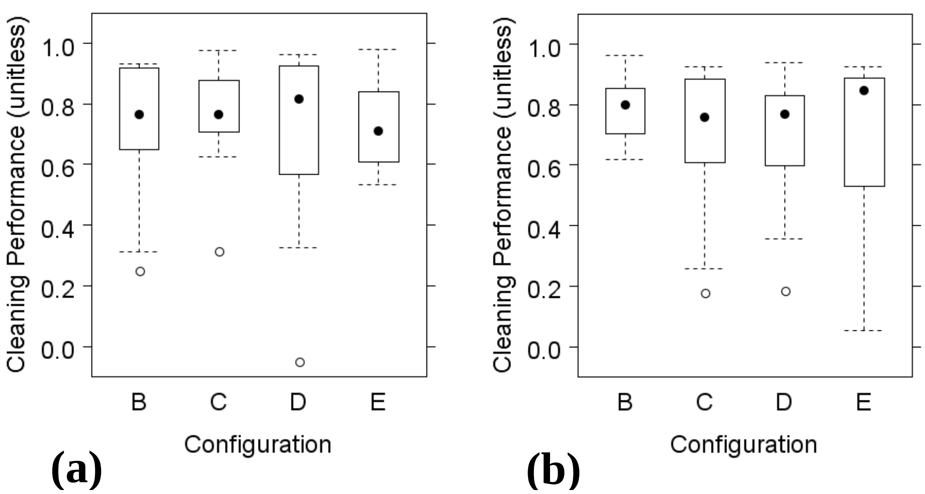
where:

$$Range = P_{\max} - P_{\min}, \qquad (3)$$

P_{max} = maximum cleaning performance value (excluding outliers) and
P_{min} = minimum cleaning performance value (excluding outliers).

A higher consistency was more desirable, with a value of 100% meaning that the performance data for a particular configuration were the same value. The consistency calculation yielded a single number from a distribution of cleaning performance for a particular configuration and thus no statistical comparison analysis was performed.

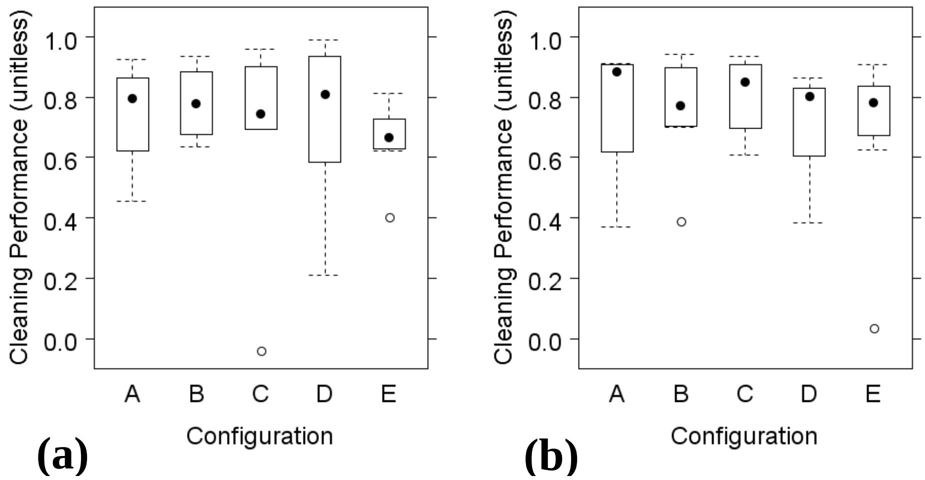
RESULTS AND DISCUSSION The cleaning performance for the front orientation for Locations I & II is shown in Figure 4. Figure 4a represents the performance at low speed (8 km/h) while Figure 4b shows performance at high speed (10.4 km/h). The black dot for each configuration represents the median cleaning performance, while the box contains the 25th and 75th percentile values. The dashed whiskers represent the smaller value of 1: the maximum (minimum) value of the data or 2: a 1.5 time the inter-quartile range of the data (~2 standard deviations). (Crawley, 2007) Figure 4 illustrates little difference between the median performance, with different amounts of data variation for each configuration. The Alpha Prototype was unable to fit on the front orientation of the machine and was therefore not tested.



Legend:	● median	○ outlier	--- whiskers (~± 2 standard deviations)	▯ 1st & 3rd quartiles
Configuration Key: **A:** Prototype	**B:** Offset-13	**C:** Offset-18	**D:** Parallel	**E:** Production

Figure 4. Cleaning performance versus configuration for the front orientation in corn residue. 'a' represents low speed (8 km/h) and 'b' represents high speed (10.4 km/h).

The cleaning performance for the rear orientation for locations I & II is shown in Figure 5. Figure 5a represents the low speed (8 km/h) data while Figure 5b represents the high speed (10.4 km/hr) results. Here again, as in Figure 4, there was little difference between the median performance, with the exception of the Production configuration at low speed. There was a large degree of variation amongst the data and plenty of overlap in the cleaning performance values between the five configurations.

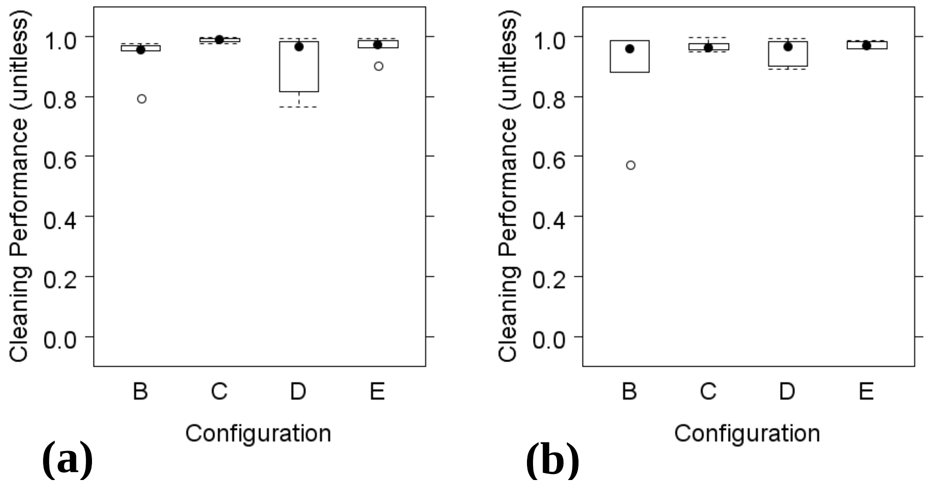


Legend:	● median	○ outlier	--- whiskers (~± 2 standard deviations)	▯ 1st & 3rd quartiles	
Configuration Key:	**A:** Prototype	**B:** Offset-13	**C:** Offset-18	**D:** Parallel	**E:** Production

Figure 5. Cleaning performance versus configuration for the rear orientation in corn residue. 'a' represents low speed (8 km/h) and 'b' represents high speed (10.4 km/h).

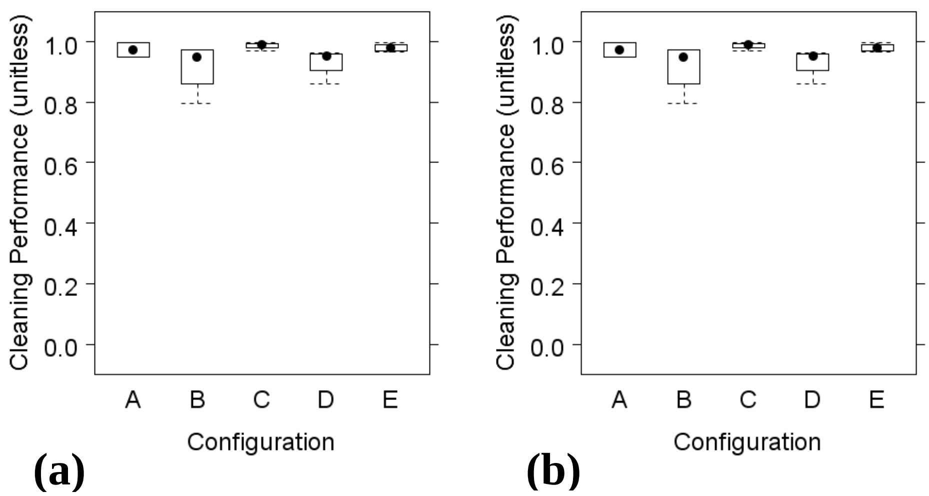
Figures 6 and 7 show the plots of cleaning performance versus row cleaner configuration for wheat residue for the front and rear orientations, respectively. In each of Figures 6a and 7a represent the low speed (8 km/hr) results while Figures 6b and 7b represent the high speed (11.2 km/hr) results. Here again, the median performance values were similar, but there was much less variation in the performance values than in the corn residue. Variance in the performance measurements within wheat stubble was enhanced due to locations in the field where excessive chaff had been distributed by the combine during the harvest of the previous year. Again, the Alpha Prototype was unable to fit on the front orientation of the machine and was therefore not tested.

A natural logarithmic transform was employed for cleaning performance data. The maximal model for corn was constructed using main effects for configuration, travel speed and residue moisture content at time of operation as well as an interaction effect between configuration and travel speed. For wheat, the maximal model consisted of main effects for configuration and speed. A main effect for residue moisture content at the time of operation and an interaction effect between configuration and travel speed could not be included in the maximal model for wheat due to singularities in the solving process. None of the factors, either for the front or rear orientations in corn or wheat residues, had a statistically significant effect on the mean cleaning performance.



Legend:	● median	○ outlier	--- whiskers (~± 2 standard deviations)	▯ 1st & 3rd quartiles	
Configuration Key:	**A:** Prototype	**B:** Offset-13	**C:** Offset-18	**D:** Parallel	**E:** Production

Figure 6. Cleaning performance versus configuration for the front orientation in wheat residue. 'a' represents low speed (8 km/hr) and 'b' represents high speed (11.2 km/hr).



Legend:	● median	○ outlier	--- whiskers (~± 2 standard deviations)	▯ 1st & 3rd quartiles	
Configuration Key:	**A:** Prototype	**B:** Offset-13	**C:** Offset-18	**D:** Parallel	**E:** Production

Figure 7. Cleaning performance versus configuration for the rear orientation in wheat residue. 'a' represents low speed (8 km/h) and 'b' represents high speed (11.2 km/h).

The overall consistency of cleaning performance for each configuration is shown in Table 3. The values were calculated including all data collected for a particular configuration. Consistency values were also calculated using data subsets by orientation and speed, however the trends for each crop were very similar to the overall consistency values. For corn, the Offset-13 & Offset-18 configurations had the greatest consistency while the parallel configuration was substantially less consistent. In wheat stubble, all configurations performed very well, when compared to operation in corn residue. In wheat stubble, there was no definitive configuration that was substantially better or worse than another given configuration.

Table 3. Consistency of cleaning performance results

Configuration	Consistency (%)	
	Corn	Wheat
Alpha Prototype	44	95
Offset-13	66	80
Offset-18	59	94
Parallel	19	82
Production	42	96

CONCLUSION The median cleaning performance values were relatively large and similar over all test conditions. The statistical results also indicated that there was no difference in mean cleaning performance between the five configurations and both travel speeds. The consistency of cleaning performance in corn residue was approximately the same for each configuration with the exception of the Parallel configuration. Cleaning performance consistency for wheat residue was very high and relatively equal for all five configurations. Due to the higher degree of variability of cleaning performance in corn residue, further studies should focus upon large, thick amounts of low density residue as opposed to more friable residue such as wheat stubble, where the cleaning performance observed was excellent. By focusing only on heavy amounts of trash it may prove easier to distinguish clear differences in cleaning performance between different configurations. As the residue moisture content at the time of operation was only measured in this experiment, it may be warranted to complete trials at 2-3 different residue moisture contents to see if any identifiable relationship is present.

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