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Grain Residuals and Time Requirements for Combine Cleaning

H. M. Hanna, D. H. Jarboe, G. R. Quick

Abstract. *Emerging identity-preserved grain markets depend on avoidance of commingling grain at harvest. Knowledge of where grain resides in a combine, cleaning labor requirements, and resulting purity levels would assist producers. Measurements were made of grain and other material residing in different areas of rotary- and cylinder-type combines in replicated clean-outs during corn and soybean harvest and also in preliminary clean-outs during oat harvest. Concentration of the prior (i.e., commingled) grain was measured in the first grain harvested of the subsequent crop.*

Total material remaining in the combine ranged from 38 to 84 kg (84 to 186 lb), 61% of which was whole grain. The greatest amounts of corn and soybean material [8 to 34 kg (17 to 74 lb)] were found in the grain tank and rock trap. Intermediate amounts were found in the head or feederhouse, elevators, and at times the cylinder/rotor (soybeans), the unloading auger (soybeans, oats), and rear axle/chopper area. The least amounts were found in the cleaning shoe and straw walkers (cylinder-type machine). Time spent to clean the combine varied from about 2 to 7 hours. Cleaning the head, grain tank, threshing rotor/cylinder, and cleaning shoe required more time than other areas. Immediately after cleaning, small amounts of prior (commingled) grain and foreign material, 0.1 to 1.1 kg (0.2 to 2.5 lb), were found in the first 35 L (bushel) of subsequent grain harvested. Following clean-outs, commingled grain levels dropped below 0.5% after 700 L (20 bu) were harvested. Over 6 kg (14 lb) of wheat were found during the first clean-out of a combine following 20 ha (50 acres) of oat harvest (no physical clean-out prior to oat harvest).

Keywords. *Clean, Clean-out, Combine, Commingle, Corn, Grain, Harvester, Identity-preserved, Labor, Oats, Residual, Soybean.*

Differentiated, identity-preserved grain and oilseed market opportunities are developing for U.S. farmers. An important factor in further development is customers' confidence in the farmer's ability to deliver consistent products of high purity levels. Reaction and fines have been swift at times when genetically-modified grain with market restrictions becomes commingled in the grain trade (Gillis, 2002). To deliver a consistent product of high purity, farmers will need to be knowledgeable of where residual grain and oilseeds are most likely to be harbored in their most complex piece of machinery, the combine, and what the most effective clean-out techniques are.

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Although some measurements of residual grain have been made at commercial elevators (Ingles et al., 2003, 2006) few measurements of the amount of grain remaining in a combine after field emptying have been reported. In a study on management techniques to control insect infestation in wheat, Quick (1977) found 42 kg (92 lb) of wheat and crop residue in an Australian pull-type combine. Greenlees and Shouse (2000) found 27 kg (59 lb) of corn residue during a 1.5 person-hour clean-out in a relatively small-capacity John Deere 4420 combine. After a limited clean-out, the percentage of an earlier-harvested grain variety entering the grain tank dropped to about 2% in the first minute of harvesting a second crop. Sampling during the next 7,000 L (200 bu) harvested indicated the percentage of the earlier-harvested variety dropped below 1%, but was still present in a low concentration that fluctuated randomly. Impure grain exiting the combine at random intervals suggests continued low-level contamination as grain is randomly scoured from numerous locations during subsequent harvest. With purity objectives of 99.5% or greater (and in many cases, a stated 0% tolerance for impurity), growers and processors are at great risk of having loads rejected (Zinkand, 2003). The presence of even small amounts of a food allergen or toxin can cause immediate chaos in markets, destroying years of market development and brand trust.

Estimates of potential grain in various parts of the combine and labor required would allow farmers to better evaluate costs for various purity requirements. Future growth of these emerging, value-added markets for farmers will greatly depend on the producer's ability to use improved field production techniques to reliably deliver high purity products.

Objectives

Field measurements were taken during harvest with the following objectives:

- To determine the amount of corn or soybeans and other foreign material remaining in various regions of a combine (e.g., grain tank, head, feederhouse, rock trap, cleaning shoe, etc.) after operating the grain tank auger "empty" for one minute.
- To determine time required to clean different areas of a combine.
- To determine the concentration of impure grain in the next grain harvested after cleaning.
- To establish statistical confidence levels on the level of purity achieved following combine clean-out procedures.

Materials and Methods

Combines

Both rotary- and cylinder-type threshing combines manufactured by Case (earlier International; Racine, Wis.) and John Deere (Moline, Ill.) were evaluated in replicated clean-out tests during various seasons. Model numbers, size of selected components, and hours of use at the time of clean-outs are listed in tables 1 and 2. Each combination of combine with gathering heads was evaluated only during a single harvest season.

Clean-out Procedures

In the field prior to actual cleaning, the unloading auger was operated for 1 to 2 min after the grain tank appeared empty. When in-cab controls were available on newer combines, chaffer and sieve screens in the cleaning shoe were opened and fan speed was increased to maximum. Concave clearance around the rotor or cylinder was maximized. The head was lowered to cutting height and the separator and feederhouse drives were alternately engaged and disengaged at least twice, usually while driving across rows to dislodge grain.

At the clean-out location, the head was removed and the combine was cleaned top-to-bottom and front-to-back using compressed air and pry bars to dislodge grain for collection either on tarps or a concrete surface, or a shop vacuum was used to collect material (particularly for the grain tank and interior cavities). Virtually all visible grain (except as noted later in the bottom of the unloading auger) was collected from the combine during the following procedures.

The roof of the operator's cab was vacuumed and vacuuming was used extensively inside the grain tank starting at the top and including ledges, steps, lights, sensors, wiring, and around a window (if present) to the cab. If hinged tank extensions were present, they were opened and closed. Grain was vacuumed from around and inside the bubble-up intake auger (able to be opened on the John Deere 9650, 9750 STS, and 9660 STS). At the bottom of the tank, grain was vacuumed from floor cross-augers. As a final step in the tank area, grain was cleaned from the sump. This was facilitated by opening access (clean-out) doors below the sump and using compressed air to dislodge grain before finishing vacuuming of the sump. After cleaning the grain tank sump, approximately 0.57 m^3 (2 ft^3) of wood chips [pine, 0 to 13 mm (0.5 in.) long] were put into the sump to flush residual grain from the turret unloading auger. If a spring-loaded check was present to prevent grain spillage at the end of the auger it was either clamped open or springs were removed and the auger operated for 1 min. If access panels were present on the unloading auger (typically one or two) they were removed for

Table 1. Combines used and size of selected features.

Harvest Year	Mfg. and Model	Thresher Type	Grain Tank Size, L (bu)	Head Width, m (ft)		Unloading Auger Length, m (ft)
				Corn[a]	Soybean	
2003	Deere 9500	Cylinder	7,190 (204)	4.6 (15)	9.1 (30)	4.3 (14)
2003	Deere 9660 STS	Rotary	8,810 (250)	6.1 (20)	9.1 (30)	6.6 (22)
2003	Deere 9410	Cylinder	6,420 (182)		4.6 (15) (oats)	4.9 (16)
2004	Case 2388	Rotary	10,750 (305)	6.1 (20)	7.6 (25)	5.5 (18)
2004	Deere 9750 STS	Rotary	6,350 (180)	6.1 (20)	9.1 (30)	6.1 (20)
2005	Deere 9650	Cylinder	10,050 (285)	6.1 (20)	9.1 (30)	6.1 (20)
2005	International 1460	Rotary	6,170 (175)	3.0 (10)	4.0 (13)	4.3 (14)

[a] Row spacing on all corn heads was 0.76 m (30 in.).

Table 2. Gathering head models, engine power, and combine age (measured by hours).

Harvest Year	Mfg. and Model	Gathering Head Model		Engine Power, kw (hp)	Separator Hours
		Corn	Soybean		
2003	Deere 9500	Deere 643	Deere 930	160 (215)	1,378
2003	Deere 9660 STS	Deere 893	Deere 630	227 (305)	10
2003	Deere 9410		Deere 915 (oats)	142 (190)	425
2004	Case 2388	Case 1083	Case 1020	209 (280)	680
2004	Deere 9750 STS	Deere 893	Deere 930	242 (325)	619[a]
2005	Deere 9650	Deere 893	Deere 930	242 (325)	1,005
2005	International 1460	International 843	International 820	127 (170)	3,172[b]

[a] Combine was a prototype. Actual hours were likely greater.
[b] Engine hours (separator hours not measured on this older combine).

localized cleaning and/or to improve flushing. Remaining wood chips and grain were vacuumed from the sump and grain tank cross-augers as well as the exit of the unloading auger.

The feederhouse was cleaned by first lowering it to the ground and using compressed air to blow off the exterior. Exterior panels were removed and any access doors above and/or below the feeder were opened. Grain was removed from all joints, crevices, and power transmission components such as pulleys, belts, and driveshafts. Material was blown and vacuumed from inside the feederhouse and the feeder chain was shaken to dislodge grain. If a feed accelerator was present, it was cleaned and combined with feederhouse material. After cleaning the feederhouse it was raised and the hydraulic cylinder stop engaged to gain entry to the rock trap area. The rock trap door was opened and after initial prying to dislodge crop, compressed air and a vacuum were used to remove material. Depending on combine geometry, in some cases the rock trap was cleaned prior to the feederhouse to avoid dislodged material from falling into the upper feederhouse area. A rock trap was not present on the International 1460 and material cleaned at the top of the feederhouse before the rotor was included with other feederhouse cleanings.

Clean-out steps in the threshing area differed somewhat depending on whether the combine was a rotor or cylinder machine. On rotary combines, all access doors present on one or both sides of the combine (depending on make/model) were removed to expose the concave and rotor. The concave screen was cleaned with compressed air and mechanical prying as necessary. After material was dislodged the concave and rotor were vacuumed first, making sure the top of the rotor was cleaned and then working toward the bottom of the area including the concave, ledges, wiring, beater, pre-cleaner, auger pans, and accessible sieves. If reasonably accessible, concave sections were occasionally removed to gain further access to the rotor. On cylinder combines, access doors were opened on both sides of the combine and a door beneath the rock trap to expose the clean-grain augers. Material was dislodged with a combination of compressed and vacuum airflow as well as prying. The rear cylinder area was accessed at times through the straw walkers, which were also cleaned. Grain and other residue were vacuumed from clean grain augers beneath the cylinder/concave area.

General procedures in the cleaning shoe area depended on accessibility of the individual combine model. The clean-grain and tailings augers across the bottom of the combine were opened by removing bolts securing the housing. On one machine where access was limited by hydraulic hoses to a tailings cross auger, flushing with wood chips was used. Doors at the bottom of the clean-grain and tailings elevators were opened and material dumped. The ability to remove and replace sieves in a reasonable time (e.g., less than 1 h) varied among combines. Machines with newer features such as an electronic wiring harness and sieve-opening controls or components in front of the sieves that were not easily removed precluded removal of one or more sieves on several machines. This was offset to some degree by a more open architecture that allowed material to be easily removed from the sieves. If sieves could not be removed, material was cleaned on sieves in place and at edges between sieves and inner combine wall. Material that could not be reached by vacuuming was blown to the bottom cross-auger and vacuumed. Grain and residue in the clean grain and tailings elevators were alternately vacuumed and blown as well as the chains shaken to dislodge grain. Access doors at the top of the elevators (if present) were opened for further cleaning. On one combine, the cross auger at the top of the tailings elevator was able to be removed for cleaning. If a moisture meter was present, it was opened and cleaned.

Cleaning of the chopper depended on location. Material from the Case 2388 chopper was separately collected from inside the rear of the combine. Because the chopper location on the John Deere combines was near the exterior rear axle, it was impractical to sub-divide its material from that of the rear axle. On the John Deere 9750 STS, the chopper was raised electronically and the blades were lowered by removing a bolt on each side of the knife bank. A chopper was not present on the International 1460. Cleaning of the exterior of the combine included using compressed air and vacuum to remove residue from the spreader assembly and rear axle. Other general cleaning areas included the front axle, engine compartment, under gull wing doors and safety panels, steps, ladders, toolboxes, and fire extinguisher. During the second year, smaller amounts of material from general locations not easily associated with major areas were collected separately and categorized as from the combine's chassis.

The head was cleaned while detached from the combine. The corn head was cleaned by first removing all ears and large residue from the exterior. Vacuum and compressed air were then used around gathering chains, deck plates, and snapping rolls. Snouts and shielding between rows were raised and safety shields removed to clean residue not previously exposed. The auger, feed pan area, and back of the head were also cleaned. For the grain platform large residue and stems were first removed from the exterior. Material was cleaned from the reel, auger, and cutterbar areas. Auger inspection plates and safety shields were removed for further cleaning and inspection. Both outside and inside of crop dividers were cleaned.

Safety Equipment and Procedures

Personal protective equipment (PPE) was used during cleaning. Generally dusty conditions required use of a respiratory dust mask and safety glasses in many circumstances. In specific situations where protruding or sharp edges were encountered, such as on straw walkers, cardboard, knee pads, and gloves were used. Similarly a hard hat was useful when working around tight spaces. All access doors, safety shields, sieves, and fasteners were properly re-installed before continuing harvest. Although some producers commonly operate the machine for a few minutes with access doors open to promote escape of any remaining grain, this was not done because of possible flying projectiles or temptation to be near an opening during operation.

Cleaning Samples

Samples from individual areas of the combine were collected in large cotton bags and kept in cool storage during harvest for later processing to sort grain from other residue. To separate large residue, whole grain, and smaller pieces including foreign material, a three-stage cleaning process was done. Samples were first pre-cleaned by removing ears and large material that stayed on a larger screen. Pre-cleaning screen size varied with year to gain sorting efficiency:

9.5-mm (3/8-in.) rectangular (year 1), 11.1-mm (7/16-in.) round (year 2), and 11.1- × 25.4 mm (7/16- × 1-in.) expanded metal (year 3). The second cleaning stage used an aspirator (closed circuit duo aspirator tester; Carter-Day Intl., Minneapolis, Minn.) to remove lighter large residue as well as small foreign material without removing split soybeans or smaller corn. The third stage of cleaning used a laboratory air screen cleaner (Kamas Westrup type LA-LS; Westrup A/S, Slagelse, Denmark) for final sorting of grain, foreign material, and any remaining non-grain large residue. A 11.1-mm (28/64-in.) round-hole screen was used to scalp further large residue from the samples. For corn, 7.1-mm (18/64-in.) and 4.8-mm (12/64-in.) round-hole screens were used to separate clean grain from broken corn and foreign material (BCFM). For soybeans an intermediate 6.4-mm (16/64-in.) round-hole screen was used to separate any residual corn and 4.0- × 19.1-mm (10/64- × 3/4-in.) slotted and 3.2-mm (8/64-in.) round-hole screens were used to separate whole and split soybeans from smaller foreign material. In the first year, because these sieve sizes were unavailable a 3.2- × 19.1-mm (8/64- × 3/4-in.) slotted screen was used to separate whole soybeans from combined smaller foreign material and split soybeans. Wood chips in residuals from the unloading auger and grain tank sump were removed as possible and not included in residual weights, however wood pieces that had been ground to sizes smaller than grain were difficult to separate and some of these pieces became included in smaller foreign material.

In addition to this equipment, a spiral separator (Westrup laboratory spiral separator, Westrup, Inc., Plano, Tex.) with five helices was used to separate soybeans from corn samples during analysis for commingled grain after a clean-out had occurred.

Field Procedures and Statistical Design

Combine clean-outs were scheduled to alternate between corn and soybean harvest in order to detect the amount of preceding crop (residual) in the first few pounds of the next crop harvested. Unless otherwise noted, 21,000 L (600 bushels) of soybeans or 50,000 L (1,400 bushels) of corn were harvested between clean-outs. A smaller amount of soybeans were harvested between clean-outs as yield per acre is inherently less for soybeans and harvest conditions limit the amount of time available in each harvest season. Each combine was cleaned a minimum of three times in both corn and soybeans to determine amounts of grain, large residue, and foreign material in various parts of the machine. To determine if the amount of throughput prior to cleaning affected amounts of material left in the machine for cleaning, during the first harvest season the John Deere 9660 STS was also cleaned after three additional replications of harvesting 100,000 L (2,800 bushels) of corn. Labor time was measured the first harvest season during three corn clean-outs of the John Deere 9660 STS and during the second and third seasons for all combines cleaned. Due to the perennial problem of a limited time window during fall harvest and some difficulty with combine availability, only two soybean clean-out replications were done in fall 2005 with the John Deere 9650 combine.

During the first harvest season, samples for measuring residual of the prior crop harvested were taken as the first material exited the unloading auger within the new crop being harvested. Some residual samples to detect previous crop harvested were lost in the field as grain was unloaded before a sample was taken. Procedures for measuring residual grain were altered after the first season so that samples for commingling were collected at various points during harvest of the first grain tank full of grain after cleaning.

Preliminary Clean-Out Measurements in Oats

Preliminary to the corn and soybean clean-outs, three replicated clean-outs of oats were done on a John Deere 9410 combine (tables 1 and 2) to aid in establishing the clean-out protocol. As the combine operators were anxious to complete most of the summer small grain harvest ahead of potential storms that might lodge grain, the combine had previously harvested small grains including wheat followed by over 20 ha (50 acres) of oat harvest before the first clean-out. Six ha (15 acres) of oats were harvested between the first and second clean-outs and 0.8 ha (2 acres) were harvested between the second and third clean-outs.

Procedures used were similar to those followed for corn and soybeans. During cleaning, 6.4-mm (16/64-in. round-hole) and 1.6-mm (4/64-in.) slotted screens were used in the air screen cleaner. In addition, a cylindrical cleaning machine (Hart Uni-Flow Kestor, Simon-Carter Co., model ZS2) with 7.5-mm (19/64-in.) recessed screen was used to separate wheat seeds from oats.

Results and Discussion

During tests, the John Deere 9500, John Deere 9660 STS, Case 2388, John Deere 9750 STS, John Deere 9650, and International 1460 were used for 32, 35, 15, 20, 11, and 27 separator hours, respectively. Differences in total number of separator hours were mainly due to becoming familiar with the machine and the size of the combine, as well as becoming more efficient in measuring parameters (residual grain, labor, commingled concentration) during each clean-out.

Key Results from an Initial Study in Oats

The grain tank and rock trap contained greater amounts of total material than other areas of the combine (table 3). Sixty-six percent of the total material removed from the combine was separated as whole oats. These two areas, and to a lesser extent the unloading auger, held the greatest amounts of residual grain. Interestingly, 6.40 kg (14.10 lb) of wheat were cleaned from the combine in the first clean-out following over 20 ha (50 acres) of oat harvest (without pre-cleaning the machine prior to oat harvest). Just 0.38 and 0.02 kg (0.85 and 0.05 lb) of wheat were found in the second and third clean-outs, respectively. This tends to refute the idea of “plug” flow, i.e., forcing all of an old crop out of the machine by simply harvesting a new crop. A simple flush of harvesting a small area of new crop may have limited potential for ensuring crop purity if tolerances for commingled crop are low.

Because the frequency of residual grain exiting the combine at low levels from a previous crop is unknown and occurs in a random fashion, it is difficult to predict the percentage of commingled grain present at any given point. If the 6.4 kg (14.1 lb) of wheat remaining in the combine after 20 ha (50 acres) of oat harvest had instead exited the combine uniformly over the 20 ha (50 acres), this amount of wheat

Table 3. Kg (lb) of oats and residue collected from John Deere 9410 during clean-out.[a]

Combine Area	Foreign Matter	Wheat	Oats	Lg. Residue	Total
Grain platform	0.53 (1.17)b	0.01 (0.03)b	0.50 (1.10)d	2.36 (5.20)ab	3.40 (7.50)b
Feederhouse	0.67 (1.48)b	0.08 (0.17)b	0.58 (1.27)d	0.38 (0.83)bc	1.70 (3.75)b
Rock trap	5.23 (11.53)a	0.14 (0.30)b	10.76 (23.72)b	2.75 (6.07)a	18.88 (41.62)a
Cylinder	0.54 (1.18)b	0.03 (0.07)b	1.19 (2.63)d	0.14 (0.30)c	1.90 (4.18)b
Cleaning shoe	1.26 (2.78)b	0.05 (0.10)b	2.08 (4.58)d	0.49 (1.08)bc	3.88 (8.55)b
Grain tank	1.15 (2.53)b	1.89 (4.17)a	17.84 (39.33)a	0.20 (0.43)bc	21.08 (46.47)a
Tailings/Elevators	0.67 (1.48)b	0.03 (0.07)b	3.05 (6.72)cd	0.05 (0.10)c	3.80 (8.37)b
Unloading auger	0.09 (0.20)b	0.04 (0.08)b	7.23 (15.95)bc	0.03 (0.06)c	7.39 (16.29)b
Rear axle/Chopper	0.80 (1.77)b	0.01 (0.02)b	0.16 (0.35)d	2.71 (5.98)a	3.68 (8.12)b
Straw walkers	0.00 (0.00)b	0.00 (0.00)b	0.00 (0.00)d	0.07 (0.15)c	0.07 (0.15)b
Total	10.94 (24.12)	2.27 (5.01)	43.39 (95.65)	9.16 (20.20)	65.77 (145.00)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.

would represent commingling of about 0.01% [assuming 2,700 kg/ha (75 bu/acre) oat yield].

Grain Cleaned from Areas of the Combine

Amounts of grain, foreign material, and larger residue present in various areas of the combine are shown in tables 4-15. Assuming corn ears to be 50% grain by mass and excluding broken grain, grain amounts ranged from 47% to 76% of total material removed from the combine. The grain tank and rock trap (feederhouse/rotor area of International 1460) contained the greatest amounts of total material in all but 2 of 13 cases. For soybean harvest, a larger mass of material was found in the grain tank than rock trap while for corn harvest, a larger mass of material was found in the rock trap than the grain tank. Although the rock trap is fixed in volume, the density of corn material present may have been greater than the density of soybean material because of ears being present.

Intermediate amounts of corn were collected from the head and/or feederhouse, elevators (9500), rear axle area (9660 STS), and unloading auger (9650, 9750 STS). Intermediate amounts of soybeans were collected from the grain platform or feederhouse (except small 1460) and also the cylinder or rotor (1460, 2388, 9500, 9660 STS), elevators (9500, 9660 STS), unloading auger (except small 1460), and rear axle/chopper area (1460, 9500, 9660 STS, 9750 STS).

Minor amounts of material were collected from the cleaning shoe for both crops. Relatively low amounts of material were collected in the straw walker area (cylinder-type combines) for both crops and in the rotor area when corn had been harvested (although amounts were somewhat greater for the 1460 and 2388, perhaps because of the open concave at the top). There was not a statistical difference in total amounts of material cleaned from the 9660 STS combine after harvesting 50,000 or 100,000 L (1,400 or 2,800 bu), indicating that this amount of harvesting was probably adequate to fill most corners of the combine.

Labor Requirements

Time required for cleaning a specific machine with the same worker frequently, but not always was reduced to about ¾ or 2/3 of the time required during initial cleaning that season. In some instances however, perhaps due to random variability of crop conditions or worker productivity, clean-out time was not shortened. The time spent cleaning corn from areas of the John Deere 9660 STS for the last three replications in the first harvest season is shown in table 16. Time spent cleaning during the second and third harvest seasons are shown in tables 17-20. Because a different set of workers cleaned the combines each harvest season, clean-out times among combines were unable to be directly compared.

Both the John Deere 9750 STS cleaned during 2004 and John Deere 9650 cleaned during 2005 used the same models of corn and soybean gathering heads (table 2). Partial information regarding the variability of time required by different sets of cleaning workers during different harvest

Table 4. Kg (lb) of corn and residue collected from John Deere 9500 during clean-out.[a]

Combine Area	BCFM[b]	Corn	Ears	Lg. Residue	Total
Corn head	2.25 (4.95)b	0.66 (1.45)de	2.88 (6.35)b	0.39 (0.86)c	6.17 (13.61)c
Feederhouse	0.73 (1.62)de	1.38 (3.05)cde	0.17 (0.37)c	0.14 (0.30)c	2.43 (5.35)def
Rock trap	4.51 (9.94)a	5.50 (12.12)b	12.86 (28.35)a	1.01 (2.23)b	23.88 (52.64)a
Cylinder	1.03 (2.26)cd	1.44 (3.18)cde	0.01 (0.02)c	0.29 (0.64)c	2.77 (6.10)de
Cleaning shoe	0.08 (0.18)ef	0.01 (0.03)e	0.05 (0.12)c	0.10 (0.21)c	0.24 (0.54)f
Grain tank	1.07 (2.36)cd	9.26 (20.41)a	0.00 (0.00)c	0.00 (0.00)c	10.33 (22.77)b
Tailings/Elevators	1.60 (3.53)bc	2.21 (4.88)cd	0.05 (0.10)c	0.10 (0.21)c	3.96 (8.72)cd
Unloading auger	0.00 (0.00)f	2.94 (6.48)c	0.00 (0.00)c	0.00 (0.00)c	2.94 (6.48)d
Rear axle/Chopper	0.28 (0.61)ef	0.05 (0.12)e	0.00 (0.00)c	0.19 (0.41)c	0.52 (1.14)ef
Straw walkers	0.00 (0.00)f	0.00 (0.00)e	0.00 (0.00)c	1.77 (3.90)a	1.77 (3.90)def
Total	11.54 (25.45)	23.46 (51.72)	16.02 (35.31)	3.97 (8.76)	55.00 (121.25)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Broken corn and foreign material.

Table 5. Kg (lb) of corn and residue collected from John Deere 9660 STS during clean-out.[a]

Combine Area	BCFM[b]	Corn	Ears	Lg. Residue	Total
50,000 L (1,400 bu)[c]					
Corn head	2.16 (4.77)b	0.77 (1.70)bc	1.56 (3.43)b	0.22 (0.49)c	4.71 (10.39)c
Feederhouse	0.61 (1.34)c	1.74 (3.84)b	0.08 (0.18)c	0.06 (0.13)c	2.49 (5.49)de
Rock trap	4.02 (8.86)a	8.22 (18.12)a	5.55 (12.23)a	0.17 (0.37)c	17.95 (39.58)a
Rotor	0.49 (1.08)c	0.15 (0.34)bc	0.00 (0.00)c	0.14 (0.31)c	0.78 (1.73)e
Cleaning shoe	0.12 (0.26)c	0.01 (0.03)bc	0.00 (0.00)c	1.25 (2.76)b	1.38 (3.05)de
Grain tank	2.22 (4.90)b	7.62 (16.81)a	0.00 (0.00)c	0.00 (0.00)c	9.85 (21.71)b
Tailings/Elevators	0.86 I(1.90)c	1.14 (2.51)bc	0.00 (0.00)c	0.03 (0.06)c	2.02 (4.46)de
Unloading auger	0.00 (0.00)c	0.98 (2.15)bc	0.00 (0.00)c	0.00 (0.00)c	0.98 (2.15)de
Rear axle/Chopper	0.85 (1.87)c	0.02 (0.05)bc	0.00 (0.00)c	2.13 (4.69)a	2.99 (6.60)cd
Total	11.33 (24.98)	20.66 (45.55)	7.18 (15.84)	4.00 (8.81)	43.17 (95.17)
100,000 L (2,800 bu)[c]					
Corn head	1.28 (2.82)b	0.96 (2.11)c	0.17 (0.37)b	0.17 (0.37)cd	2.57 (5.67)de
Feederhouse	0.67 (1.48)bc	5.21 (11.49)b	0.15 (0.33)b	0.04 (0.09)d	6.07 (13.39)c
Rock trap	3.66 (8.07)a	10.47 (23.09)a	2.64 (5.83)a	0.43 (0.95)bc	17.21 (37.94)a
Rotor	0.85 (1.87)bc	0.54 (1.18)c	0.00 (0.00)b	0.08 (0.18)d	1.47 (3.23)e
Cleaning shoe	0.15 (0.32)c	0.03 (0.06)c	0.00 (0.00)b	0.75 (1.65)b	0.92 (2.03)e
Grain tank	1.71 (3.76)b	8.85 (19.52)a	0.00 (0.00)b	0.00 (0.00)d	10.56 (23.29)b
Tailings/Elevators	0.91 (2.01)bc	1.00 (2.21)c	0.00 (0.00)b	0.00 (0.01)d	1.92 (4.23)de
Unloading auger	0.00 (0.00)c	1.28 (2.82)c	0.00 (0.00)b	0.00 (0.00)d	1.28 (2.82)e
Rear axle/Chopper	0.92 (2.03)bc	0.02 (0.04)c	0.00 (0.00)b	2.54 (5.59)a	3.47 (7.66)d
Total	10.14 (22.36)	28.36 (62.52)	2.96 (6.53)	4.01 (8.84)	45.47 (100.25)

[a] Values followed by a different letter within each pre-harvested amount and column are statistically different at a 95% confidence level.
[b] Broken corn and foreign material.
[c] Liters (bushels) of grain harvested between clean-outs.

Table 6. Kg (lb) of corn and residue collected from Case 2388 during clean-out. [a]

Combine Area	BCFM[b]	Corn	Ears	Lg. Residue	Total
Corn head	1.98 (4.37)abc	1.67 (3.68)c	0.67 (1.48)b	1.05 (2.32)ab	5.38 (11.86)c
Feederhouse	2.18 (4.81)ab	2.35 (5.19)c	0.00 (0.00)b	0.25 (0.55)bc	4.78 (10.54)cd
Rock trap	3.38 (7.46)a	9.12 (20.11)b	9.70 (21.38)a	1.30 (2.87)a	23.51 (51.82)a
Rotor	1.76 (3.89)bcd	1.92 (4.24)c	0.00 (0.00)b	0.22 (0.48)c	3.91 (8.61)cd
Cleaning shoe	0.48 (1.06)de	0.44 (0.97)c	0.00 (0.00)b	0.03 (0.06)c	0.95 (2.09)cd
Grain tank	1.75 (3.85)bcd	15.61 (34.42)a	0.00 (0.00)b	0.00 (0.00)c	17.36 (38.27)b
Tailings/Elevators	0.31 (0.69)e	0.68 (1.49)c	0.00 (0.00)b	0.00 (0.00)c	0.99 (2.18)cd
Unloading auger	0.25 (0.56)e	0.40 (0.88)c	0.00 (0.00)b	0.00 (0.00)c	0.65 (1.44)d
Chopper	0.96 (2.11)bcde	0.15 (0.34)c	0.00 (0.00)b	0.80 (1.77)abc	1.91 (4.21)cd
Rear axle	0.69 (1.53)cde	0.01 (0.02)c	0.00 (0.00)b	0.14 (0.31)c	0.84 (1.85)d
Chassis	0.74 (1.63)cde	0.02 (0.04)c	0.00 (0.00)b	0.13 (0.28)c	0.88 (1.95)d
Total	14.50 (31.96)	32.38 (71.38)	10.37 (22.86)	3.92 (8.64)	61.15 (134.82)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Broken corn and foreign material.

Table 7. Kg (lb) of corn and residue collected from John Deere 9750 STS during clean-out. [a]

Combine Area	BCFM[b]	Corn	Ears	Lg. Residue	Total
Corn head	2.23 (4.91)abc	1.02 (2.24)c	2.42 (5.34)a	0.49 (1.09)a	6.16 (13.57)cd
Feederhouse	3.23 (7.12)a	4.57 (10.07)b	0.00 (0.00)b	0.39 (0.86)ab	8.19 (18.05)bc
Rock trap	3.00 (6.61)ab	11.37 (25.07)a	0.88 (1.93)a	0.46 (1.01)a	15.70 (34.61)a
Rotor	1.95 (4.30)abcd	0.39 (0.85)c	0.00 (0.00)b	0.35 (0.77)ab	2.69 (5.92)de
Cleaning shoe	0.60 (1.32)cd	0.56 (1.23)c	0.00 (0.00)b	0.10 (0.23)bc	1.26 (2.78)de
Grain tank	1.53 (3.37)abcd	10.79 (23.79)a	0.00 (0.00)b	0.00 (0.00)c	12.32 (27.16)ab
Tailings/Elevators	0.64 (1.40)cd	1.43 (3.16)c	0.00 (0.00)b	0.01 (0.03)c	2.08 (4.59)de
Unloading auger	0.24 (0.54)d	5.96 (13.15)b	0.00 (0.00)b	0.00 (0.00)c	6.21 (13.69)cd
Rear axle/Chopper	1.42 (3.12)bcd	0.05 (0.12)c	0.00 (0.00)b	0.25 (0.56)abc	1.72 (3.80)de
Chassis	0.57 (1.25)cd	0.27 (0.60)c	0.00 (0.00)b	0.02 (0.04)c	0.86 (1.89)e
Total	15.39 (33.94)	36.41 (80.28)	3.30 (7.27)	2.08 (4.59)	57.18 (126.06)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Broken corn and foreign material.

Table 8. Kg (lb) of corn and residue collected from John Deere 9650 during clean-out.[a]

Combine Area	BCFM[b]	Corn	Ears	Lg. Residue	Total
Corn head	0.10 (0.21)ab	2.39 (5.28)bc	4.48 (9.87)b	2.05 (4.52)bc	9.02 (19.88)c
Feederhouse	0.05 (0.10)bc	2.45 (5.40)bc	0.00 (0.00)c	1.71 (3.77)bc	4.20 (9.26)de
Rock trap	0.17 (0.38)a	13.68 (30.15)a	9.04 (19.92)a	6.13 (13.51)a	29.01 (63.95)a
Cylinder	0.01 (0.02)c	0.90 (1.98)cd	0.00 (0.00)c	0.64 (1.42)de	1.55 (3.42)de
Straw walkers	0.00 (0.00)c	0.00 (0.00)d	0.00 (0.00)c	2.36 (5.20)b	2.36 (5.20)de
Cleaning shoe	0.02 (0.04)bc	0.24 (0.53)cd	0.00 (0.00)c	1.28 (2.83)cd	1.55 (3.41)de
Grain tank	0.16 (0.36)a	15.86 (34.97)a	0.00 (0.00)c	0.71 (1.57)de	16.74 (36.90)b
Tailings/Elevators	0.15 (0.32)a	1.22 (2.68)cd	0.00 (0.00)c	0.29 (0.63)e	1.65 (3.64)de
Unloading auger	0.02 (0.05)bc	4.35 (9.60)b	0.00 (0.00)c	0.00 (0.00)e	4.38 (9.66)d
Rear axle	0.02 (0.05)bc	0.30 (0.67)cd	0.20 (0.44)c	0.61 (1.34)de	1.13 (2.50)e
Total	0.69 (1.53)	41.39 (91.26)	13.71 (30.23)	15.78 (34.79)	71.58 (157.81)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Broken corn and foreign material.

Table 9. Kg (lb) of corn and residue collected from International 1460 during clean-out.[a]

Combine Area	BCFM[b]	Corn	Ears	Lg. Residue	Total
Corn head	0.05 (0.12)c	4.03 (8.89)c	2.92 (6.44)a	1.17 (2.59)bc	8.18 (18.03)bc
Feederhouse	0.39 (0.85)b	9.04 (19.94)b	0.29 (0.65)b	1.58 (3.49)b	11.31 (24.93)b
Rotor	0.07 (0.16)c	2.58 (5.68)cd	0.00 (0.01)b	3.07 (6.77)a	5.72 (12.61)cd
Cleaning shoe	0.03 (0.07)c	0.64 (1.41)cd	0.00 (0.00)b	0.68 (1.51)cd	1.36 (3.00)de
Grain tank	0.76 (1.68)a	15.67 (34.55)a	0.00 (0.00)b	0.13 (0.28)d	16.56 (36.50)a
Tailings/Elevators	0.02 (0.04)c	0.15 (0.34)d	0.00 (0.00)b	0.09 (0.19)d	0.25 (0.56)e
Unloading auger	0.00 (0.00)c	0.25 (0.56)d	0.00 (0.00)b	0.00 (0.00)d	0.25 (0.56)e
Rear axle	0.12 (0.27)bc	0.35 (0.78)cd	0.00 (0.00)b	1.10 (2.43)bc	1.57 (3.47)de
Total	1.45 (3.19)	32.73 (72.15)	3.22 (7.10)	7.82 (17.25)	45.22 (99.69)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Broken corn and foreign material.

Table 10. Kg (lb) of soybean and residue collected from John Deere 9500 during clean-out.[a]

Combine Area	FM/Splits	Soybean	Lg. Residue	Total
Grain platform	2.84 (6.26)ab	0.54 (1.18)cd	0.99 (2.18)bc	4.37 (9.63)c
Feederhouse	0.60 (1.33)cde	1.08 (2.39)cd	0.20 (0.43)cd	1.88 (4.15)cd
Rock trap	3.76 (8.30)a	5.01 (11.04)b	2.27 (5.00)a	11.04 (24.34)b
Cylinder	1.45 (3.19)bcde	1.79 (3.95)c	0.52 (1.14)bcd	3.76 (8.28)c
Cleaning shoe	0.17 (0.38)de	0.02 (0.05)d	0.05 (0.10)d	0.24 (0.53)d
Grain tank	2.00 (4.42)abcd	17.44 (38.45)a	0.00 (0.00)d	19.45 (42.87)a
Tailings/Elevators	1.90 (4.19)abcde	2.13 (4.69)c	0.00 (0.00)d	4.03 (8.88)c
Unloading auger	0.00 (0.00)e	2.01 (4.44)c	0.00 (0.00)d	2.01 (4.44)cd
Rear axle/Chopper	2.41 (5.31)abc	0.06 (0.13)d	1.36 (2.99)b	3.82 (8.42)c
Straw walkers	0.00 (0.00)e	0.00 (0.00)d	0.04 (0.09)d	0.04 (0.09)d
Total	15.14 (33.38)	30.08 (66.32)	5.41 (11.93)	50.63 (111.63)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.

Table 11. Kg (lb) of soybean and residue collected from John Deere 9660 STS during clean-out.[a]

Combine Area	FM/Splits	Soybean	Lg. Residue	Total
Grain platform	1.52 (3.36)de	0.49 (1.08)c	1.59 (3.51)a	3.60 (7.94)c
Feederhouse	0.38 (0.83)ef	1.12 (2.48)bc	0.16 (0.36)c	1.66 (3.67)cd
Rock trap	4.49 (9.90)a	3.23 (7.13)b	1.40 (3.09)a	9.13 (20.12)b
Rotor	1.61 (3.56)de	0.14 (0.31)c	0.60 (1.33)b	2.36 (5.20)cd
Cleaning shoe	0.61 (1.35)ef	0.03 (0.07)c	0.03 (0.06)c	0.67 (1.48)d
Grain tank	3.98 (8.78)ab	12.85 (28.34)a	0.00 (0.00)c	16.83 (37.11)a
Tailings/Elevators	2.93 (6.47)bc	0.88 (1.95)bc	0.00 (0.00)c	3.82 (8.42)c
Unloading auger	0.18 (0.39)f	2.30 (5.06)bc	0.00 (0.00)c	2.47 (5.45)cd
Rear axle/Chopper	1.95 (4.31)cd	0.49 (1.09)c	1.45 (3.20)a	3.90 (8.60)c
Total	17.67 (38.95)	21.55 (47.51)	5.24 (11.55)	44.45 (98.00)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.

Table 12. Kg (lb) of soybean and residue collected from Case 2388 during clean-out. [a]

Combine Area	FM	Splits	Soybean	Lg. Residue	Total
Grain platform	0.86 (1.89)c	0.05 (0.11)c	1.17 (2.59)c	0.52 (1.15)	2.61 (5.75)c
Feederhouse	2.01 (4.43)c	0.05 (0.12)c	2.59 (5.71)c	0.20 (0.43)	4.85 (10.69)c
Rock trap	4.44 (9.78)ab	0.16 (0.36)bc	8.39 (18.50)b	0.89 (1.96)	13.88 (30.60)b
Rotor	6.44 (14.20)a	0.64 (1.41)b	1.85 (4.07)c	0.99 (2.18)	9.92 (21.86)b
Cleaning shoe	1.07 (2.35)c	0.11 (0.25)bc	0.16 (0.36)c	0.15 (0.32)	1.49 (3.28)c
Grain tank	1.47 (3.25)c	1.68 (3.71)a	21.71 (47.87)a	0.00 (0.00)	24.87 (54.83)a
Tailings/Elevators	0.22 (0.49)c	0.19 (0.42)bc	0.53 (1.16)c	0.00 (0.01)	0.94 (2.08)c
Unloading auger	0.17 (0.37)c	0.18 (0.40)bc	2.32 (5.11)c	0.68 (1.50)	3.35 (7.38)c
Chopper	1.72 (3.79)c	0.00 (0.01)c	0.02 (0.05)c	0.33 (0.73)	2.08 (4.58)c
Rear axle	0.93 (2.04)c	0.02 (0.05)c	0.02 (0.04)c	0.33 (0.73)	1.30 (2.86)c
Chassis	2.39 (5.27)bc	0.02 (0.05)c	0.06 (0.13)c	0.12 (0.27)	2.59 (5.72)c
Total	21.71 (47.86)	3.13 (6.89)	38.82 (85.59)	4.21 (9.28)	67.87 (149.63)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.

Table 13. Kg (lb) of soybean and residue collected from John Deere 9750 STS during clean-out. [a]

Combine Area	FM	Splits	Soybean	Lg. Residue	Total
Grain platform	2.05 (4.51)bcd	0.17 (0.37)de	1.62 (3.58)bcd	0.92 (2.03)b	4.75 (10.48)cde
Feederhouse	2.39 (5.27)bc	0.68 (1.50)cde	3.59 (7.92)bcd	0.71 (1.56)bc	7.37 (16.25)bcd
Rock trap	2.03 (4.48)bcd	0.26 (0.57)cde	4.91 (10.83)bc	0.32 (0.70)cd	7.53 (16.59)bc
Rotor	1.76 (3.89)bcd	0.15 (0.34)e	0.33 (0.72)d	0.20 (0.45)d	2.45 (5.40)e
Cleaning shoe	1.23 (2.72)bcd	1.08 (2.37)c	0.76 (1.67)d	0.01 (0.03)d	3.08 (6.80)cde
Grain tank	1.45 (3.19)bcd	4.10 (9.04)a	14.21 (31.32)a	0.00 (0.01)d	19.76 (43.56)a
Tailings/Elevators	0.54 (1.19)cd	1.05 (2.32)cd	1.24 (2.74)cd	0.01 (0.03)d	2.84 (6.27)de
Unloading auger	0.22 (0.49)d	2.01 (4.44)b	4.96 (10.94)b	0.00 (0.00)d	7.20 (15.87)bcd
Rear axle/Chopper	8.39 (18.49)a	0.24 (0.54)cde	0.10 (0.21)d	1.62 (3.58)a	10.35 (22.81)b
Chassis	2.64 (5.81)b	0.31 (0.69)cde	1.22 (2.69)cd	0.10 (0.21)d	4.26 (9.40)cde
Total	22.70 (50.04)	10.06 (22.18)	32.94 (72.62)	3.90 (8.60)	69.59 (153.43)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.

Table 14. Kg (lb) of soybean and residue collected from John Deere 9650 during clean-out. [a]

Combine Area	FM	Splits	Soybean	Lg. Residue	Total
Grain platform	0.15 (0.34)	0.03 (0.07)	0.82 (1.80)	0.93 (2.05)	1.94 (4.27)
Feederhouse	0.12 (0.26)	0.39 (0.86)	3.67 (8.08)	2.01 (4.43)	6.18 (13.62)
Rock trap	1.03 (2.26)	7.65 (16.87)	12.12 (26.73)	7.92 (17.45)	28.72 (63.31)
Cylinder	0.04 (0.09)	0.07 (0.16)	0.32 (0.70)	1.22 (2.68)	1.64 (3.62)
Straw walkers	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.42 (3.12)	1.42 (3.12)
Cleaning shoe	0.05 (0.11)	0.05 (0.10)	0.09 (0.20)	1.77 (3.90)	1.95 (4.31)
Grain tank	0.91 (2.01)	2.04 (4.49)	29.94 (66.00)	0.62 (1.36)	33.50 (73.85)
Tailings/Elevators	0.55 (1.22)	0.42 (0.93)	0.79 (1.75)	0.23 (0.50)	2.00 (4.41)
Unloading auger	0.03 (0.06)	0.29 (0.65)	5.60 (12.35)	0.00 (0.00)	5.92 (13.06)
Rear axle	0.01 (0.03)	0.02 (0.05)	0.26 (0.58)	0.84 (1.85)	1.14 (2.51)
Total	2.88 (6.35)	10.95 (24.15)	53.60 (118.17)	16.93 (37.33)	84.40 (186.08)

[a] Due to harvest constraints only two soybean clean-outs were accomplished. Because of this, statistical differences were not calculated.

Table 15. Kg (lb) of soybean and residue collected from International 1460 during clean-out. [a]

Combine Area	FM	Splits	Soybean	Lg. Residue	Total
Grain platform	0.01 (0.03)b	0.03 (0.07)b	0.51 (1.13)b	0.49 (1.08)cd	1.05 (2.31)c
Feederhouse	0.05 (0.11)b	0.06 (0.14)b	0.89 (1.97)b	0.78 (1.72)cd	1.78 (3.93)c
Rotor	0.10 (0.21)b	0.20 (0.43)b	0.88 (1.95)b	3.73 (8.23)b	4.91 (10.82)b
Cleaning shoe	0.01 (0.03)b	0.07 (0.16)b	0.17 (0.38)b	1.01 (2.23)c	1.27 (2.81)c
Grain tank	0.30 (0.67)a	1.65 (3.64)a	21.28 (46.92)a	0.39 (0.85)cd	23.62 (52.08)a
Tailings/Elevators	0.07 (0.16)b	0.05 (0.12)b	0.19 (0.42)b	0.11 (0.25)d	0.43 (0.95)c
Unloading auger	0.00 (0.01)b	0.01 (0.02)b	0.05 (0.12)b	0.00 (0.00)d	0.07 (0.15)c
Rear axle	0.05 (0.10)b	0.05 (0.12)b	0.08 (0.18)b	4.89 (10.77)a	5.07 (11.17)b
Total	0.60 (1.32)	2.13 (4.70)	24.07 (53.07)	11.40 (25.13)	38.20 (84.22)

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.

Table 16. Time (person-minutes) spent cleaning out various areas of John Deere 9660 STS combine. [a]

Combine Area	Time
Corn head	25.6a
Feederhouse	8.0c
Rock trap	4.1d
Rotor	25.8a
Cleaning shoe/elevators	9.6c
Grain tank	20.0b
Unloading auger	5.5d
Rear axle/chopper	4.7d
Total[b]	103.3

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Excludes time to gather and put away supplies (tarp, compressed air, safety equipment, etc.).

Table 17. Time (person-minutes) spent cleaning out various areas of Case 2388 combine. [a]

Combine Area	Time
Head	51.3b
Feederhouse	37.5c
Rock trap	12.5d
Rotor	52.5b
Cleaning shoe	82.5a
Grain tank	52.5b
Tailings/elevators	16.3d
Unloading auger	15.0d
Chopper	17.5d
Rear axle	11.3d
Chassis	17.5d
Total[b]	366.4

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Excludes time to gather and put away supplies (tarp, compressed air, safety equipment, etc.).

Table 18. Time (person-minutes) spent cleaning out various areas of John Deere 9750 STS combine. [a]

Combine Area	Time
Head	58.3abc
Feederhouse	50.0bcd
Rock trap	17.5de
Rotor	72.5ab
Cleaning shoe	88.3a
Grain tank	51.3bc
Tailings/elevators	15.0e
Unloading auger	12.5e
Rear axle/chopper	35.0cde
Chassis	32.5cde
Total[b]	432.9

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Excludes time to gather and put away supplies (tarp, compressed air, safety equipment, etc.).

Table 19. Time (person-minutes) spent cleaning out various areas of John Deere 9650 combine. [a]

Combine Area	Time
Head	32.4ab
Feederhouse	25.2bc
Rock trap	19.8cde
Cylinder	34.4a
Straw walkers	19.0cde
Cleaning shoe	21.6cd
Grain tank	36.0a
Tailings/elevators	8.0f
Unloading auger	16.6de
Rear axle	12.6ef
Total[b]	225.6

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Excludes time to gather and put away supplies (tarp, compressed air, safety equipment, etc.).

Table 20. Time (person-minutes) spent cleaning out various areas of International 1460 combine. [a]

Combine Area	Time
Head	21.7c
Feederhouse	27.0bc
Rotor	37.7ab
Cleaning shoe	18.0cd
Grain tank	41.7a
Tailings/elevators	6.1e
Unloading auger	8.7de
Rear axle	17.9cd
Total[b]	178.8

[a] Values followed by a different letter within each column are statistically different at a 95% confidence level.
[b] Excludes time to gather and put away supplies (tarp, compressed air, safety equipment, etc.).

seasons was noted in that only about half the time was spent cleaning these heads during the 2005 harvest as in the 2004 harvest (tables 19 and 18, respectively). Although combine models were different, it was also noted that total time spent cleaning the combine was only about half as long in 2005 as in 2004.

The relative difference between time values among seasons (ranging from 2 to 7 h) do suggest that actual clean-out time to remove all visible material may be a function of both the person(s) cleaning the combine and accessibility into different combine areas. Relative amounts of time spent cleaning in different areas tended to be consistent across combines. Areas requiring the longest time were the head, rotor/cylinder, grain tank, and cleaning shoe (9750 STS, 2388). If a rock trap was not present (1460) additional time was required to clean the feederhouse. The rear axle (1460, 9750 STS), chopper and chassis (9750 STS) required an intermediate amount of time on some combines. Cleaning time for other areas was generally shorter.

Previous Crop in First Grain Harvested of Subsequent Crop after Cleaning

For the 9500 and 9660 STS combines used in the first season, amounts of residual grain from a previous crop (including foreign material with small grain fragments indistinguishable between crops) after cleaning in the first grain harvested of a subsequent crop is shown in table 21. Amounts ranged from 0.54 to 1.13 kg (1.18 to 2.50 lb) of prior residual material. Using a pooled error variance from both machines for each crop, a 95% confidence interval was constructed of the amount of residual present in the first grain harvested of the new crop. Using these cleaning techniques on these machines, a 95% confidence level indicates a range of 0.20 to 1.84 kg (0.43 to 4.05 lb) of corn and 0 to 2.10 kg (0 to 4.64 lb) of soybean in approximately the first 14 kg (30 lb) of grain harvested. During the first harvest season grain was not sampled for residual previous crop after this first amount harvested. In visual observation of further grain falling from the unloading auger into a grain wagon after this collection, very little commingled grain was observed which seemed to agree with decreasing levels (<0.1%) measured by Greenlees and Shouse (2000).

During the second and third seasons' harvest, samples were taken for residual grain from the first grain unloaded and at three other points during unloading of the first grain tank full (table 22). The error variance of each combine was used to construct a 95% confidence level of the concentration of commingled grain after these relative amounts of grain had been unloaded. Commingled grain levels measured during the first grain unloaded were less than 2% and lowered to less than 0.5% after 700 to 1,800 L (20 to 50 bu) had been unloaded. Commingled grain in the first 35 L (bushel) was less than 0.1 kg (0.2 lb) from the International 1460. Although most commingled concentrations fell below 0.05% after 3,500 L (100 bu) were unloaded, they did not uniformly decrease and in some cases (9650, 9750 STS) slightly increased, suggesting a possible random release of a small quantity of residual grain during subsequent harvest.

After wood chips were flushed through the unloading auger, a small but probably significant amount of grain remained visible between the flighting and the auger tube on most combines. A 6.4-mm (0.25-in.) uniform layer of grain residing in a 305-mm (12-in.) arc along the bottom of the unloading auger would result in 7.7 or 8.2 kg (17 or 18 lb) of corn or soybeans, respectively. Difficult-to-flush and reach grain in the bottom of the unloading auger may have been the major source of residual material in the first part of the new crop harvested.

Table 21. Amounts of residual (grain from previous crop plus foreign material) in the first grain unloaded of a new crop for John Deere 9500 and 9660 STS combines.[a]

Combine/Crop	N[c]	Residual kg (lb)[d]	Residual %[d]	Clean Grain Range, kg (lb)[b] Low	Clean Grain Range, kg (lb)[b] High
9500					
Corn	1	0.54 (1.18)	3.01	–	17.80 (39.25)
Soybean	1	0.68 (1.50)	6.70	–	10.16 (22.40)
9660					
Corn	4	1.13 (2.50)	7.72	10.33 (22.77)	22.38 (49.33)
Soybean	2	0.87 (1.91)	13.10	5.92 (13.05)	12.24 (26.98)

[a] Combine was alternately cleaned of corn and soybean.
[b] Amounts of first new crop being unloaded from which residual was separated.
[c] N equals number of samples of that crop from that machine.
[d] Residual is previous crop plus smaller pieces of broken grain of new crop being harvested and foreign material.

Table 22. Concentration of commingled grain in sample following cleaning and unloading specific amounts of subsequent grain for four different combine models.

Make/Model	L (bu.) Harvested	Commingled Grain (%) Average	95% Confidence Interval Low	95% Confidence Interval High
Case 2388	35 (1)	0.3621	0.0000	0.8652
	700 (20)	0.0281	0.0000	0.1000
	3500 (100)	0.0035	0.0000	0.0069
	7000 (200)	0.0002	0.0000	0.0006
John Deere 9750	35 (1)	1.3228	0.0000	2.7312
	1800 (50)	0.0057	0.0019	0.0094
	3500 (100)	0.0030	0.0000	0.0091
	6000 (170)	0.0146	0.0000	0.0885
John Deere 9650	35 (1)	0.2757	0.0000	1.3577
	700 (20)	0.1048	0.0000	0.4578
	3500 (100)	0.0141	0.0000	0.0456
	7000 (200)	0.0253	0.0000	0.1152
International 1460	35 (1)	0.0434	0.0160	0.0707
	700 (20)	0.0187	0.0004	0.0369
	3500 (100)	0.0072	0.0010	0.0135
	5300 (150)	0.0081	0.0015	0.0147

CONCLUSIONS

Based on the combines and conditions tested:

- The greatest amounts of corn and soybean material were found in the grain tank and rock trap. Intermediate amounts were found in the head or feederhouse, elevators, and at times the cylinder/rotor (soybeans), the unloading auger (soybeans, oats), and rear axle/chopper area. The least amounts were found in the cleaning shoe and straw walkers (cylinder-type machine). Within an entire individual combine an average of 61% of the total material (across all combine/crop combinations) was whole grain.
- Time spent to clean the combine of visible material typically reduced after the combine had been cleaned one or two times, but varied from 2 to 7 h. Cleaning the head, grain tank, threshing rotor/cylinder, and cleaning shoe (depending on accessibility) required the longest times.
- After this level of cleaning, 0.1 to 1.1 kg (0.2 to 2.5 lb) of residual previous grain and foreign material were found in approximately the first 35 L (bushel) of subsequent crop harvested. Following clean-outs, commingled grain levels dropped below 0.5% after 700 L (20 bu) were harvested, but did not always uniformly decrease below this level.
- Simple flushing of the combine by harvesting a small area of new crop without physically cleaning the combine may have limited potential for ensuring crop purity if tolerances for commingled crop are low. Over 6 kg (14 lb) of wheat were found during the first clean-out of a combine after 20 ha (50 acres) of oats had been harvested (no physical clean-out prior to oat harvest).

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