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H. M. Hanna, D. H. Jarboe

Abstract. *Growers of identity-preserved crops desire to keep grain separate throughout the production process. Earlier research has demonstrated that some locations in a combine such as cleaning and threshing areas harbor relatively smaller amounts of grain, but require relatively large amounts of time to clean. Omitting clean-out in some areas and flushing residual grain with new grain in the first grain tank full may lower commingled grain concentration to acceptable levels for some customers.*

A Case IH 7010 combine alternating harvest between corn and soybean crops received either a full, abbreviated, or no clean-out before harvesting the subsequent crop. During unloading of the first grain tank full in the new crop, grain samples were collected. Commingled grain concentration with full clean-out was at or below 0.1% in the first 35 L (bushel) and 700 L (20 bu) harvested and less than 0.01% after 3500 L (100 bu) had been harvested. Abbreviated and no clean-outs reached below 0.7% commingled concentration after 700 L (20 bu) were harvested, below 0.05% after 3500 L (100 bu) harvested, and below 0.035% after 11,300 L (320 bu) harvested, although commingled concentration did not always consistently decrease with increased flushing after low concentrations were obtained. Clean-out time required was 6.5 person-h (person-hour) and 2.5 person-h for full and abbreviated clean-outs, respectively. Thirty-two kg (70 lb) of biomaterial were collected during full clean-out with the greatest amounts in the rotor and head areas.

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

Varietal purity standards have long been present in the seed industry for field production and finished products. In the early 1900s, organizations developed to inspect seed for varietal purity, enabling farmers to select products with high purity levels (Robinson and Knott, 1963; Hackleman and Scott, 1990). The Organization for Economic Co-operation and Development seed certification schemes limit maximum off-type seeds to 0.5% for basic (parent) seed and 1.0% for certified seed (OECD, 2010). More recently emerging identity-preserved grain markets have also developed to capitalize on adding value by segregating grains. Hurburgh (1994) developed a system for grain elevators to segregate soybeans with high and low processing values. Hurburgh estimated that an elevator could net approximately $2.57/Mg ($0.07/bu) using this system.

Commingling of grain can easily occur at harvest, limiting potential segregated grain value. Ingles et al. (2003, 2006) measured grain residuals in receiving and handling operations at a commercial elevator. In an early project inspecting grain residuals in a pull-type combine as a haven for potential insect movement between fields, Quick (1977) found 42 kg (92 lb) of wheat and crop residue inside the combine. Later work has focused on not just residual grain, but also the amount of commingled grain following cleaning of the combine. After a relatively short 1.5 person-h cleanout in a small capacity combine (John Deere 4420, Moline, Ill.) Greenlees and Shouse (2000) found commingled grain at a 2% level in the first minute of harvest of a second crop. Commingled levels dropped below 1% after 7,000 L (200 bu) of harvest but fluctuated randomly at low concentration.

Field measurements by Hanna et al. (2009) with four rotary and two conventional cylinder combine models (Case IH 1460, 2388; John Deere 9500, 9650, 9660, 9750) indicated that after a complete cleaning in all areas of the combine, commingled grain percentage drops to less than 0.5% after the first 700 L (20 bu) of subsequent grain harvest. Simple flushing by sacrificing a limited amount of new grain without prior cleaning has been suggested as a possible method to avoid excessive time cleaning. Hanna et al. (2009) reported finding 6 kg (14 lb) of wheat remaining in a combine after 20 ha (50 acres) of oat harvest, thus the effectiveness of a flush without cleaning may depend on what frequency residual grain exits the combine. Hanna et al. (2009) also reported that some areas requiring significant amounts of time to clean (e.g., cleaning shoe) contain quite small amounts of the total grain remaining in the combine. Other locations such as the rotor and threshing area had intermediate amounts of biomaterial, but took a significant amount of cleaning time relative to the amount of grain removed.

Growers of identity-preserved crops, seeking to most effectively use valuable time during harvest, want to know the amount of commingling expected not just from a full

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clean-out of all visible grain within the combine, but also the percentage of commingled grain present from an abbreviated clean-out. Such an abbreviated clean-out would be based on omitting those areas of the combine that require significant amounts of time to clean, yet harbor smaller amounts of grain than other areas such as the grain tank, rock trap, or head. In addition, if some portion of initial harvest in the new crop could be sacrificed to help flush residual grain from the combine, the loss in value-added crop might be compensated by reduced cleaning time. Values generated would be used to validate potential clean-out procedures for a diverse customer base for identity-preserved crops (e.g., some may desire less than 0.1% or 0.5% commingled grain while others may accept up to 1% or 2% commingled grain).

Objectives

- To measure the concentration of commingled grain in harvest of the first grain tank full of a subsequent crop following full, abbreviated, and no clean-outs.
- To further evaluate efficiency, the amount of material collected and time required for cleaning different areas of the combine are also measured.

Materials and Methods

Combine

During 2007 harvest, a Case IH 7010 rotary combine (CNH, Racine, Wis.) was used. It had an 11,100-L (315-bu) grain tank with extensions for an effective volume during tests of about 10,600 L (300 bu). The unloading auger was 7.3 m (24 ft) long and the "no drip" apparatus was removed for tests. The 9-L Iveco engine rated at 260 kW (350 hp) had 290 kW (390 hp) maximum including an 18-kW (25-hp) power boost and 11-kW (15-hp) unloading boost. The combine initially had 102 engine hours and 24 separator hours and used an additional 41 separator and 99 engine hours during tests. Gathering heads used were an 8-row, 76-cm (30-in.) head (Case IH 2408) for corn and a 10.7-m (35-ft) grain platform (Case IH 2020) for soybeans.

Treatments

The combine was either fully cleaned out by cleaning virtually everything that could be accessed and seen, cleaned in an abbreviated clean-out, or was not cleaned (no clean-out) between alternating harvests of corn and soybeans. An abbreviated clean-out omitted cleaning in the rotor, cleaning shoe, chopper, rear axle, unloading auger, and chassis areas. Prior clean-outs (Hanna et al., 2009) on other combines suggested that these areas generally harbor smaller amounts of grain for the labor required to clean them. All material removed from the combine during a full or abbreviated clean-out was collected in cloth bags and placed in refrigerated storage for later sorting and analysis. Labor time required for inspection and removal of biomaterial within different areas of the combine during full and abbreviated clean-outs was recorded.

Clean-Out Procedures

Field Procedures

Each clean-out was randomly replicated three times during alternating harvest of corn and soybeans (i.e., six each full, abbreviated, and no clean-outs). Approximately 50,000 L (1400 bu) of corn or 21,000 L (600 bu) of soybeans were harvested before each clean-out to re-load material in the combine, but still allow time for a series of replicated clean-outs in a narrow harvest window (Hanna et al., 2009). Following harvest of this amount of grain, a field self clean-out was always done. This consisted of removing the head, opening the sieves, and widening the concave clearance to maximum values, then after disengaging power and shutting off the engine, opening the elevator and rock trap doors. Following removal of bystanders from the area, the combine was operated with fan and rotor at maximum speeds. The unloading auger was also operated. The combine was driven over end rows and operated on rough ground in an attempt to dislodge grain and let the combine self-clean to some extent. Power was disengaged and the engine turned off before closing the elevator and rock trap doors to complete these field self-cleaning operations.

Collecting Residual Grain Inside Combine

After harvest of crop "A" and completed field self clean-out, the combine was driven to the Iowa State University Agricultural Engineering Farm shop and was cleaned unless no clean-out was being done.

The head was removed and the combine was cleaned top-to-bottom and front-to-back. The combine was either fully cleaned (all parts of the combine cleaned including head, feederhouse, rock trap, rotor, cleaning shoe, tailings/elevators, grain tank, unloading auger, chopper, rear axle, and chassis), partially cleaned in an abbreviated clean-out (cleaned only head, feederhouse, rock trap, tailings/elevators, and grain tank), or not cleaned at all depending upon the replicated treatment to be done. Tools used to remove and collect grain were shop vacuums, high-pressure compressed air and pocket knives and screw-drivers to dislodge material. A pneumatic wrench speeded minor disassembly (e.g., concave removal). Virtually all visible grain was collected from the combine in the areas to be cleaned using the following procedures.

Inside the grain tank vacuum, air was used starting at the top including ledges, steps, lights, sensors, wiring, and around a window to the cab. Hinged grain tank extensions were opened and closed repeatedly, and bounced lightly on supports to dislodge grain not seen. Grain was vacuumed from around and inside the bubble-up intake auger, which could be accessed by opening a small door located on the upper part of the auger. The bubble-up auger was then lowered to three different positions in order to remove grain from underneath it. Grain was vacuumed from the floor cross-augers and then the sump as a final step. This was facilitated by using a smaller flexible hose on the end of the vacuum attachment to suck remaining grain out of the sump. This small vacuum hose was then used through the bottom access door from below into the sump. When cleaning the unloading auger during a full clean-out approximately 0.04 m^3 (1.5 ft^3) of wood chips [pine, 0 to 13 mm (0.5 in.) long] were packed into the sump to flush residual grain from the turret auger. After powering the unloading auger to push wood chips through the auger to scour and clean grain, 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 out the interior. Grain was removed from all joints, crevices, and feederhouse chains. Material was repeatedly blown and vacuumed from inside the feederhouse and the feeder chain was shaken to dislodge grain. Remaining material left on the feederhouse chain was removed by manual prying.

After cleaning the feederhouse, it was raised and the hydraulic cylinder stop engaged to gain entry to the rock trap. The rock trap door was opened and after initial prying to dislodge grain and other plant material, compressed air and vacuum were used for removal. Pulling down the rubber seal between the feederhouse and rotor dislodged additional grain from the rock trap area.

Access panels and rotor concaves were removed to clean the rotor and threshing area. Visible material was vacuumed first to reduce dust created during subsequent use of compressed air. The front rotor section was vacuumed and lodged material pried out. Concaves were then cleaned out along with the remaining rotor cage. Rasp bar sections were then blown with compressed air from the back side to clean residue behind them. Concaves were then reattached and remaining residue in the rotor area was vacuumed. Residue falling on the shaker pan below the rotor that delivers material to the aft cleaning shoe was assumed to be from the rotor and was collected with the rotor sample.

Cleaning of the chopper was done after the rotor due to its location below the rotor. Material left on the cleaning shoe was minimal after the field self clean-out, therefore, any material that fell from the chopper on to the cleaning shoe at this time was collected as chopper material. Residue in the chopper was pulled out by hand to reduce contamination in the lower areas of the combine. Chopper material was collected from each end of the rotor, then the rotor was rotated to get additional residue out of chopper blades.

Electronic motors that control sieve adjustments (commonly used on newer combines) were judged to preclude removal of sieves without incurring excessive removal and reinstallation time. Clean-out of the cleaning shoe area was accomplished by first removing the covers of lower cross-augers and then forcing compressed air through sieves that had been opened to maximum width. Grain remaining lodged in the sides of the sieves was pried out. Lower cross-augers were then checked to make sure any debris that was left in them was removed by the vacuum before replacing the cross-auger covers.

Cleaning the elevators included opening lower doors and shaking the conveyer chain to dislodge any material. The moisture sensor on the back of the clean grain elevator was opened and emptied, and then reassembled.

Gathering heads were cleaned after detachment from the combine. Initial cleaning of the corn head included removing ears and large residue from the exterior. Previously unexposed residue was removed by raising snouts and shielding between rows and removing safety shields. Vacuum and compressed air were alternately used around gathering chains, deck plates, and snapping rolls. Auger, feed-pan, and other areas at the rear of the head were also cleaned.

On the grain platform, large residue and stems were first removed from the exterior. Cleaning then progressed on the reel, auger, and cutterbar areas. Auger inspection covers and safety shields were removed for additional inspection and cleaning. The inside and outside of crop dividers were cleaned. All covers (e.g., snouts, safety shields over drive areas on side and rear of head) were replaced after cleaning.

Cleaning of additional exterior areas of the combine included using compressed air to remove residue from the spreader assembly and rear axle. Combine "chassis" material was collected from ledges behind access panels, above the fuel tank, an area above the rotor, standing platforms next to the rotor, and also around the outside of the feederhouse, its guards and shields.

After cleaning, minor combine adjustments were made as necessary for crop "B."

Safety Equipment and Procedures

Generally dusty conditions required use of a dust mask in many circumstances. Safety glasses were used for shop work and as dust conditions warranted. In tight conditions with poor visibility, headlamps were used for artificial light in order to see all residues remaining in the combine. All access doors, safety shields, sieves, and fasteners were re-installed before continuing harvest.

Commingled Sample Collection

Following a clean-out treatment, the combine operator moved into crop "B," and harvested approximately 700 L (20 bu) of grain before stopping to unload. A sample was taken from the first grain exiting the unloading auger (the "1st" 35 L or bushel) and a second sample was collected when the tank was almost empty (700 L or the "20th" bushel). The combine operator then harvested a full grain tank and unloaded it into a wagon with engine speed at idle. Twenty-four seconds after grain started to come out the auger, a third sample was taken representing 3500 L of harvest (or the "100th" bushel). A fourth and final sample was collected when the grain tank was nearly empty representing 11,300 L (or the "320th" bushel). Samples weighing approximately 3 kg (7 lb) were collected by passing a coffee can on a wand through the grain stream. If the previous clean-out treatment was abbreviated or no clean-out, the combine was cleaned in the field to remove material from previous crop "A" that might contaminate a residual sample when the combine was cleaned in subsequent cleaning treatments.

Cleaning Samples

Samples were processed after field harvest to sort grain from other residue (residual samples) and corn from soybeans (commingling samples). For residual samples to separate large residue, whole grain, and smaller pieces including foreign material, a three-stage cleaning process was done. Samples were first pre-cleaned using a larger screen (11.1- × 25.4-mm (7/16- × 1-in.) expanded metal with diamond-shaped openings) that removed ears and large material. An aspirator (closed circuit duo aspirator tester; Carter-Day Intl., Minneapolis, Minn.) was used in second-stage cleaning to remove lighter large residue as well as small foreign material without removing split soybeans or smaller corn seed particles. Third stage 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 non-grain large residue that still remained. An 11.1-mm (28/64-in.) screen scalped any large residue from the samples. For corn, 7.1- and 4.8-mm (18/64- and

12/64-in.) screens separated clean grain from broken corn and foreign material (BCFM). For soybeans, an intermediate 6.4-mm (16/64-in.) screen separated 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 separated whole and split soybeans, respectively, from smaller foreign material.

For analysis of commingled grain after a clean-out had occurred, a spiral separator (Westrup laboratory spiral separator; Westrup, Inc., Plano, Tex.) with five helices was used to separate round soybeans from relatively flatter corn kernels. After using the spiral separator, if any whole soybeans were still visible in the corn, they were separated from the corn by processing with a belt separator (Westrup LA-BS laboratory grader; Westrup, Inc., Plano, Tex.). If small, odd-shaped foreign material remained the sample was processed with a 3.6-mm (9/64-in.) slotted shaker to remove smaller foreign material. These remaining smaller pieces were then hand sorted to separate visible pieces of corn and soybean.

Statistical Analysis

Combine areas where material was collected in both abbreviated and full clean-outs (head, feederhouse, rock trap, tailings/elevators, and grain tank) had six samples of collected material each from corn and soybean harvest. Combine areas where material was only collected during a full clean-out (rotor, cleaning shoe, unloading auger, chopper, rear axle, and chassis) had only three samples of collected material from each crop. Because of the uneven number of times samples were collected, statistical comparisons among residual amounts of biomaterial and clean-out labor times were separated into two groups, those areas where material was collected during both full and abbreviated clean-outs and those areas where material was only collected during a full clean-out.

Because samples of commingled grain concentration were taken after 35, 700, 3500, and 11,300 L had been harvested (1st, 20th, 100th, and 320th bu) within replicated full, abbreviated, or no clean-out treatments, data were analyzed using a split-plot analysis of variance for repeated measures data. This type of analysis produced a better statistical fit than alternative models as measured by the statistical Akaike Information Criterion. Main plot effects were the crop, clean-out type, and their interaction. The split plot effect was the number of bushels of subsequent crop flushed through the combine.

Since commingled grain concentration tends to decay rapidly (exponentially during the first grain tank unloading) as the number of liters (bushels) flushed through the combine increases, statistical variance also decays exponentially during this period. To construct statistical confidence intervals, the percentage of commingled grain was transformed using log(Y+0.00333) to equalize within-group variances and allow use of a pooled variance from all data. A constant was added to all values to avoid problems when there was no measured commingled grain (i.e., when Y = 0). The value of 0.00333 was chosen because it was the smallest observed non-zero value for the percent of commingled grain in corn. The same transformation was used for both corn and soybean data so the two could be compared.

A 95% confidence interval for the median percent commingled grain by treatment, amount of flushed liters (bushels), and crop was computed by backtransforming endpoints of the 95% confidence interval for the mean transformed response. An upper 95% prediction bound, i.e., the number that is above 95% of all predicted observations of commingled grain, was computed by backtransforming the 95% prediction bound for transformed values. That prediction bound was computed by $bound = t_{df,0.95}\ s\ (1+1/\sqrt{n})$ where s is the estimated standard deviation of an observation, df is the associated degrees of freedom, and n = 3 replicates per group mean.

Results and Discussion

Residual Material Cleaned from Combine

Almost 31 kg (68 lb) of total material were removed from the combine in a full clean-out after corn harvest (total material sum of tables 1 and 2). Over 33 kg (73 lb) of material were removed in a full clean-out after soybean harvest (total material sum from tables 3 and 4). Assuming ear corn to be 50% grain by weight and neglecting small grain pieces in BCFM or FM, 56% of total corn material and 36% of total soybean material were grain. Total residuals were generally less than reported by Hanna et al. (2009), with smaller than expected amounts collected from the grain tank and rock trap areas. In contrast to the earlier study, the rotor contributed significantly to the total.

Within the additional areas cleaned during full clean-outs (table 2), the largest amount of total corn material and the largest amount of corn grain was collected from the rotor area. The rotor also had numerically the largest amount of material and corn grain when considering all areas of the combine (tables 1 and 2). In soybeans, the rotor had the greatest amount of soybeans and total material in the additional areas cleaned during full clean-out, however when all areas of the combine (tables 3 and 4) were included, the grain platform also had a significant amount of total material.

For areas that were cleaned in both abbreviated and full clean-outs (tables 1 and 3), the head consistently held the most total material and significant amounts of grain

Table 1. Amount of corn and residue collected from Case IH 7010 during clean-outs.[a]

Combine Area	BCFM kg (lb)	Corn kg (lb)	Ears kg (lb)	Lg. Residue kg (lb)	Total kg (lb)
Corn head	2.10 (4.64)a	2.07 (4.56)a	0.93 (2.05)a	1.11 (2.45)a	6.21 (13.70)a
Feederhouse	0.36 (0.79)b	2.37 (5.23)a	0.42 (0.93)ab	0.14 (0.30)b	3.28 (7.24)b
Rock trap	0.16 (0.35)b	0.49 (1.09)b	0.17 (0.37)b	0.05 (0.11)b	0.87 (1.91)d
Tailings/elevators	0.02 (0.05)b	0.16 (0.35)b	0.00 (0.00)b	0.00 (0.01)b	0.19 (0.41)d
Grain tank	0.32 (0.71)b	1.59 (3.50)a	0.00 (0.00)b	0.09 (0.19)b	2.00 (4.41)c
Total	2.97 (6.54)	6.68 (14.73)	1.52 (3.35)	1.39 (3.06)	12.55 (27.67)

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

Table 2. Amount of corn and residue collected from Case IH 7010 during full clean-out.[a]

Combine Area	BCFM kg (lb)	Corn kg (lb)	Ears kg (lb)	Lg. Residue kg (lb)	Total kg (lb)
Rotor	2.22 (4.90)a	7.92 (17.45)a	0.14 (0.31)	1.22 (2.68)ab	11.49 (25.33)a
Cleaning shoe	0.77 (1.69)b	0.72 (1.59)b	0.00 (0.00)	0.16 (0.36)b	1.66 (3.65)bc
Unloading auger	0.01 (0.02)c	0.68 (1.51)b	0.00 (0.00)	0.00 (0.00)b	0.69 (1.52)c
Chopper	0.04 (0.09)c	0.03 (0.07)b	0.00 (0.00)	0.27 (0.60)b	0.34 (0.76)c
Rear axle	0.07 (0.16)c	0.03 (0.06)b	0.00 (0.00)	0.19 (0.41)b	0.28 (0.62)c
Chassis	1.03 (2.28)b	0.36 (0.80)b	0.00 (0.00)	2.52 (5.55)a	3.91 (8.63)b
Total	4.15 (9.14)	9.74 (21.48)	0.14 (0.31)	4.35 (9.60)	18.38 (40.51)

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

Table 3. Amount of soybeans and residue collected from Case IH 7010 during clean-outs.[a]

Combine Area	FM kg (lb)	Splits kg (lb)	Soybean kg (lb)	Lg. Residue kg (lb)	Total kg (lb)
Platform	4.21 (9.29)	0.11 (0.25)b	1.84 (4.05)a	3.11 (6.86)a	9.28 (20.45)a
Feederhouse	0.49 (1.08)	0.04 (0.08)b	0.60 (1.32)b	0.15 (0.33)b	1.27 (2.81)b
Rock Trap	2.32 (5.12)	0.06 (0.13)b	0.23 (0.50)b	0.66 (1.46)b	3.27 (7.21)b
Tailings/elevators	0.02 (0.05)	0.03 (0.06)b	0.14 (0.31)b	0.04 (0.08)b	0.22 (0.48)b
Grain Tank	0.28 (0.61)	0.60 (1.33)a	1.44 (3.17)a	0.02 (0.05)b	2.34 (5.15)b
Total	7.33 (16.15)	0.84 (1.85)	4.24 (9.35)	3.98 (8.78)	16.37 (36.10)

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

Table 4. Amount of soybeans and residue collected from Case IH 7010 during full clean-out.[a]

Combine Area	FM kg (lb)	Splits kg (lb)	Soybean kg (lb)	Lg. Residue kg (lb)	Total kg (lb)
Rotor	4.03 (8.88)a	0.45 (1.00)a	3.88 (8.55)a	0.80 (1.76)	9.16 (20.19)a
Cleaning Shoe	0.55 (1.21)c	0.58 (1.28)a	0.59 (1.30)b	0.16 (0.36)	1.88 (4.15)bc
Unloading Auger	0.01 (0.02)c	0.53 (1.17)a	0.46 (1.02)b	0.00 (0.00)	1.00 (2.21)bc
Chopper	0.50 (1.10)c	0.01 (0.02)b	0.02 (0.05)b	0.61 (1.34)	1.13 (2.50)bc
Rear axle	0.34 (0.76)c	0.03 (0.07)b	0.03 (0.06)b	0.20 (0.45)	0.60 (1.33)c
Chassis	1.49 (3.29)b	0.08 (0.18)b	0.18 (0.39)b	1.53 (3.37)	3.28 (7.23)b
Total	6.92 (15.26)	1.69 (3.72)	5.16 (11.37)	3.30 (7.28)	17.06 (37.61)

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

compared to areas such as the rock trap (corn) or tailings/elevators. After corn harvest, the feederhouse held intermediate amounts of material, particularly grain. Although significant amounts of grain were present in the grain tank, numerically greater amounts of grain were present in the head than in the grain tank. The tailings/elevators and rock trap (in corn) had minor amounts of material.

Comparing areas that were only cleaned during full clean-outs, outside the rotor and threshing area, the chassis had the next largest amount of total material. The cleaning shoe held a statistically similar amount of total material with a greater percentage of it being grain. The amount of material generally decreased in other areas in the following order: unloading auger (after flushing with wood chips), chopper, and rear axle.

Unique Aspects of Combine Affecting Cleaning

Although total clean-out residual amounts from previously cleaned combines of earlier vintage were often greater than 45 kg (100 lb) (Hanna et al., 2009), the total amount of material collected from the Case IH 7010 was less than 34 kg (75 lb) despite having larger grain tank and engine sizes. Self cleaning by operating the combine initially with open elevator and rock trap doors allowed some of the material to exit that had been captured in earlier tests without self-cleaning (Hanna et al., 2009). Noticeable amounts of material fell out when the rock trap door was opened before operation suggesting bridging of material was not as significant as frequently observed.

Although the grain tank and rock trap held the largest amounts of grain and biomaterial in prior tests (Hanna et al., 2009), areas holding the greatest amounts of material in this combine were the rotor and head. Minimization of horizontal ledges and ”catch” points seemed to contribute to reduced residual in the grain tank since self-cleaning did not affect this area (sump door at unloading auger entrance was not opened in self-cleaning). The quantity of residual material in the head may have been at least partially due to the size of the head, particularly in clean-out of soybeans [10.7 m (35 ft) wide]. The rotor and threshing area were relatively accessible after side panels and concave sections were removed. This accessibility exposed significant amounts of material below the front of the rotor on the shaker pan and on upper interior ledges. Material immediately above the rotor area added somewhat to residuals collected from the chassis. Opening the cross-augers below the cleaning shoe allowed accessibility to material that fell from this area after sieves were opened.

Table 5. Time (person-hours) spent cleaning out various areas of Case IH 7010 combine during abbreviated clean-outs.[a]

Combine Area	Time
Head	1.368a
Feederhouse	0.408bc
Rock trap	0.278c
Tailings/elevators	0.057d
Grain tank	0.545b
Total[b]	2.656

[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.).

Labor Requirements

Cleaning only the areas included in an abbreviated clean-out required 2.66 person-h time (table 5). The head required the longest cleaning time, the grain tank, feeder-house, and rock trap intermediate amounts of time and the tailings/elevators the least amount of time.

Cleaning additional areas during a full clean-out added an extra 3.88 person-h of time (table 6). Relative inaccessibility in the rotor area may have resulted in more time being spent cleaning in this area. Areas behind individual rasp bars did not hold as much biomaterial as other points, but required significant time to clean. Intermediate amounts of cleaning time were spent on the chassis and cleaning shoe with lesser time spent on the unloading auger, chopper, and rear axle.

Although earlier results (Hanna et al., 2009) suggested omission of the rotor from an abbreviated cleaning, this area might be re-considered on this combine. Somewhat counter-balancing the significant amount of grain and biomaterial present, however, is the significant amount of time spent to clean in this area. One compromise on this particular combine might be to clean in the rotor area, but only clean the front of the grain pan below the rotor and the upper interior ledges that seemed to hold the greatest amount of material during cleaning. Removal and re-installation of concaves took approximately 0.5 person-h.

Commingled Grain Amounts

Average commingled grain percentage for each combination of crop, clean-out method, and level of liters (bushels) flushed along with the expected high and low values within a 95% confidence range surrounding the median commingled percentage for each treatment are listed in table 7. These high and low values represent the upper and lower bounds of the expected true mean commingled percentage for each treatment. The last column of table 7 lists the commingled grain percentage that would not be expected to be exceeded 95% of the time for any single observed value (i.e., following any single clean-out).

Table 6. Time (person-hours) spent cleaning out various areas of Case IH 7010 combine during full clean-out.[a]

Combine Area	Time
Rotor	2.125a
Cleaning shoe	0.542b
Unloading auger	0.292c
Chopper	0.278c
Rear axle	0.083c
Chassis	0.558b
Total[b]	3.878

[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.).

Because the upper limit of the 95% confidence interval represents an upper bound for the expected true commingling percentage for a given clean-out technique, these values will be considered to compare clean-out techniques. With a full clean-out, commingled grain percentage in the first bushel harvested was under 0.1% for soybeans and just over 0.1% for corn in the first bushel harvested. Commingled grain percentage in the first bushel following abbreviated and no clean-out techniques was considerably (and statistically) greater. Abbreviated and no clean-outs following corn produced expected upper commingled grain percentages of 1.3% and 3.4%, respectively. The upper bound after an abbreviated soybean clean-out, 17.7%, was greater than the upper bound for no clean-out, 11.0%. Residual soybeans in the bottom of the uncleaned unloading auger exiting in the first bushel of subsequent grain harvest may have been responsible for these high values.

After 700 L (20 bu) were harvested, commingled percentage for the full clean-out remained below 0.1%. Upper limits of confidence intervals for abbreviated and no clean-outs continued to be similar over a range from about 0.3% to near 0.7% commingling, with values from abbreviated clean-out ranging a bit lower than values for no clean-out, as might be expected.

After 3500 L (100 bu) were harvested, commingled percentage from full clean-outs of both crops and abbreviated clean-out of corn was less than 0.01%. Abbreviated clean-out of soybeans had a slightly greater upper limit just under 0.02%. Commingled percentage from no clean-out had greater variability and thus a wider confidence range, but still less than 0.05%.

After harvest of 11,300 L (320 bu), no commingled grain was present in the six observed samples after a full clean-out (resulting in 0% average commingled percentage) and expected upper bounds of 0.003% and 0.004% after corn and soybeans, respectively. Observed commingled percentages from the abbreviated clean-out slightly increased from the levels at 3500 L (100 bu), resulting in significant overlap of the confidence intervals of abbreviated and no clean-outs, but with all upper values less than 0.035%.

Average concentrations of commingled grain and the upper 95% limit of the confidence interval of commingled grain concentration after harvesting a specific amount of grain through the combine are shown for each combination of clean-out technique and previous crop harvested in figures 1 and 2, respectively.

The percentage commingled grain data suggest that if either no grain or only a small quantity such as 700 L (20 bu) or less can afford to be flushed through the combine, a full clean-out is necessary to obtain a commingled percentage in the range of small fractions of a percentage point. If tolerance for commingled grain is in the range of 0.5% to 1.0% and approximately 700 to 1800 L (20 to 50 bu) of grain can be flushed through the system, an abbreviated or even no clean-out might be considered [assuming at least a self-cleaning is accomplished with combine operation and access doors open (no bystanders)]. If commingled tolerance is not

Table 7. Concentration (%) of commingled grain in sample following cleaning and harvesting specific amounts of grain.

Crop	Clean-out	Harvested Amount		Commingled Grain (%)			
					95% Confidence Interval[a]		
		L	Bu	Average	Low	High	Upper Prediction[b]
Corn	Full	35	1	0.058	0.026	0.111	0.176
		700	20	0.056	0.018	0.079	0.126
		3500	100	0.003	0.000	0.007	0.013
		11,300	320	0.000	0.000	0.003	0.007
	Abbreviated	35	1	0.666	0.336	1.306	2.053
		700	20	0.275	0.126	0.497	0.783
		3500	100	0.003	0.000	0.009	0.016
		11,300	320	0.009	0.001	0.015	0.025
	No	35	1	1.731	0.878	3.404	5.348
		700	20	0.376	0.178	0.696	1.094
		3500	100	0.002	0.000	0.006	0.012
		11,300	320	0.000	0.000	0.003	0.007
Soybean	Full	35	1	0.037	0.016	0.070	0.112
		700	20	0.012	0.004	0.025	0.041
		3500	100	0.003	0.000	0.007	0.013
		11,300	320	0.000	0.000	0.004	0.008
	Abbreviated	35	1	9.731	4.575	17.693	27.787
		700	20	0.179	0.079	0.315	0.497
		3500	100	0.008	0.002	0.018	0.029
		11,300	320	0.016	0.006	0.034	0.055
	No	35	1	6.320	2.835	10.970	17.228
		700	20	0.306	0.153	0.602	0.948
		3500	100	0.027	0.008	0.041	0.066
		11,300	320	0.017	0.006	0.032	0.053

[a] 95% confidence interval around the median percentage commingled grain concentration of a particular treatment (crop, clean-out method, and bushels flushed).

[b] Commingled grain percentage that is above 95% of all predicted observations after cleaning with a particular treatment (crop, clean-out method, and L/bu flushed).

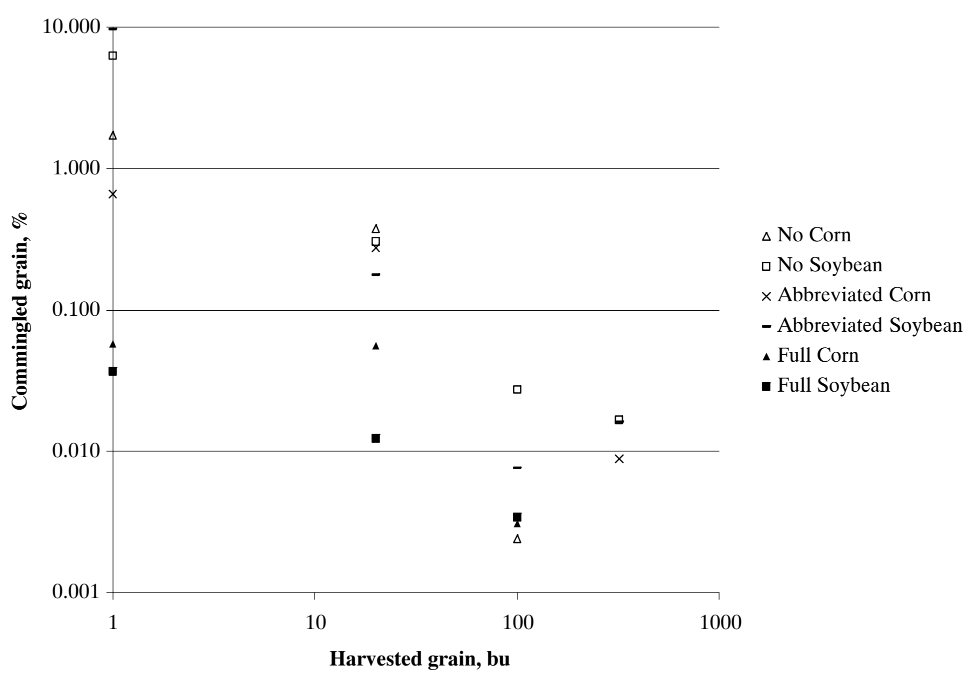

Figure 1. Average percentage of commingled corn or soybeans following no, abbreviated, or full clean-out procedure after a specified amount of subsequent crop has been harvested and unloaded.

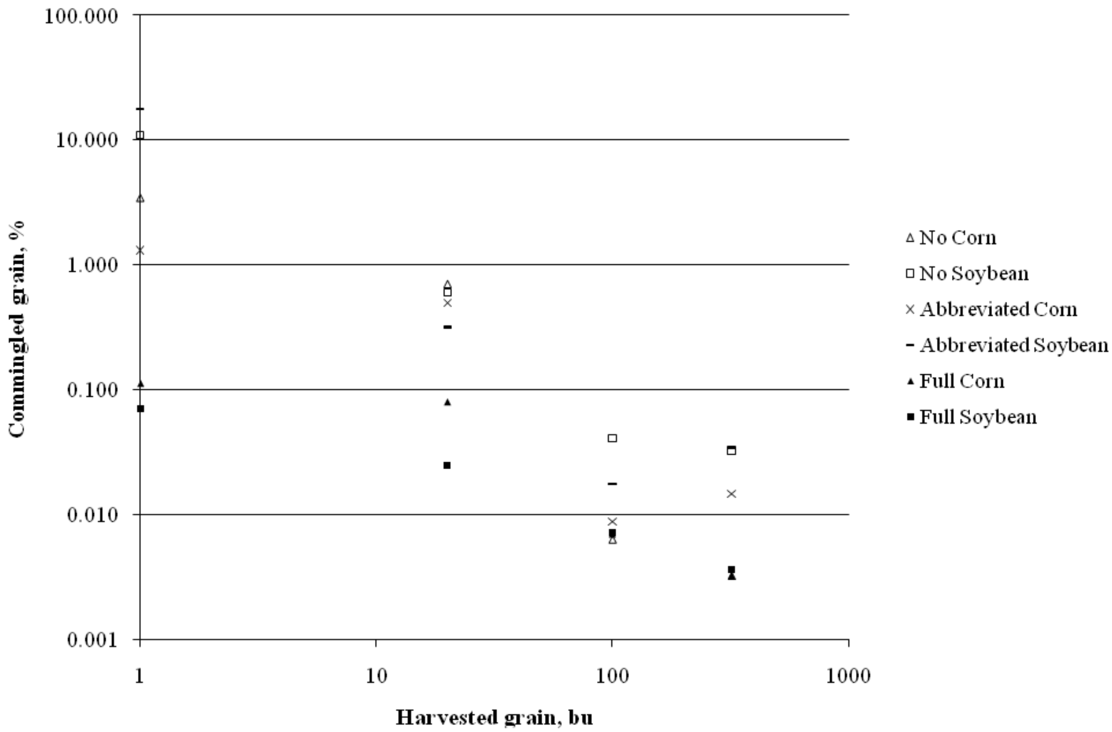

Figure 2. Upper limit of 95% confidence interval above the median percentage of commingled corn or soybeans following no, abbreviated, or full clean-out procedure after a specified amount of subsequent crop has been harvested and unloaded.

"zero," but less than 0.1% and the first grain tank can be sacrificed in a flush, an abbreviated or no clean-out may be sufficient (again still completing at least self-cleaning). If commingled tolerance is "zero," a full clean-out should be done along with flushing some sacrificed grain through the combine.

It should be noted that although heads (corn head, grain platform) were cleaned, crop contamination from the head using the methods of this project was not able to be evaluated. Also as stated with statistical methods, confidence intervals are for the mean value of a treatment combination of clean-out technique, flushing level, and crop. The predicted 95% probability upper limit of commingled grain concentration after any single clean-out (values in last column of table 7) is somewhat greater than that of the overall treatment average (values in next to last column of table 7). Thus combine operators are urged to be conservative in interpretation of these results.

Implications for Combine and Grain Harvest Industry

Measurements suggest the combine industry is striving to minimize catchment in the grain tank. The rock trap opening seemed to help release material during the self pre-cleaning. Accessibility for rotor cleaning is good, however structural horizontal flange edges that may have been reduced in the grain tank have the capacity to catch material. Moving material through the gathering head without allowing unnecessary areas to catch and hold material is beneficial.

Grain and seed industry buyers should consider closely what, if any, commingled grain level is acceptable from harvest operations. Results suggest decisions on clean-out technique and flushing with grain differ depending on acceptable levels of 1.0%, 0.1%, or 0.01% of commingled grain.

Conclusions

Within the range of conditions observed for this combine (Case IH 7010) in alternating clean-outs of corn and soybeans:

Commingled Grain

Using the upper limit of a 95% confidence interval about the median observed value:

- After a full clean-out of all areas of the combine, commingled grain percentage of the previous crop in a subsequent crop harvested was initially 0.1% or less from 0 to 700 L (20 bu) harvested, was below 0.01% after 3500 L (100 bu) were harvested, and below 0.004% after 11,300 L (320 bu) were harvested.
- Abbreviated and no clean-outs had up to 18% commingled grain in the first 35 L (1 bu) harvested and up to 0.7% commingled grain after 700 L (20 bu) were harvested. After 3500 L (100 bu) were harvested, commingled percentage dropped below 0.05% and after 11,300 L (320 bu) harvested below 0.035%. Values generally decreased to low levels, but did not always consistently decrease in the harvested range of 3500 to 11,300 L (100 to 320 bu).

Residual Grain in Combine

- Thirty-one and 33 kg (68 and 73 lb) of total biomaterial were collected from the combine in a full cleanout after harvest of corn and soybeans, respectively (after an initial self-cleaning step). Grain was 56% and 36% of this total for corn and soybeans, respectively.

- Within areas cleaned during both abbreviated and full clean–outs, the head contained the greatest amount of material, feederhouse, grain tank, and rock trap (soybeans) intermediate amounts of material, and the tailings/elevators the least amount of material.
- Within additional areas cleaned during a full clean-out, the rotor contained the most material, the chassis and cleaning shoe intermediate amounts of material, and the unloading auger, chopper, and rear axle, the least amount of material.
- Contrasted with research on earlier combine models (and using self pre-cleaning to assist emptying rock trap and elevator areas), spending a few minutes to remove easily accessed material in the rotor area without removing concaves should be considered for abbreviated clean-outs.

Labor Requirements

- A full clean-out of all areas of the combine required 6.5 person-h. Omitting cleaning the rotor, cleaning shoe, chassis, unloading auger, chopper, and rear axle in an abbreviated clean-out reduced time required to about 2.5 person-h.

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References

Greenlees, W. J., and S. C. Shouse. 2000. Estimating grain contamination from a combine. ASAE Paper No. MC00-103. St. Joseph, Mich.: ASAE.

Hackleman, J. C., and W. O. Scott. 1990. *A History of Seed Certification in the United States.* Raleigh, N.C.: Association of Official Seed Certifying Agencies.

Hanna, H. M., D. H. Jarboe, and G. R. Quick. 2009. Grain residuals and time requirements for combine cleaning. *Applied Eng. in Agric.* 25(6): 851-861.

Hurburgh, C. R., Jr. 1994. Identification and segregation of high-value soybeans at a country elevator. *J. American Oil Chem. Soc.* 71(10): 1073-1078.

Ingles, M. E. A., M. E. Casada, and R. G. Maghirang. 2003. Handling effects on commingling and residual grain in an elevator. *Trans. ASAE* 46(6): 1625-1631.

Ingles, M. E. A., M. E. Casada, R. G. Maghirang, T. J. Herrman, and J. P. Harner III. 2006. Effects of grain-receiving system on commingling in a country elevator. *Applied Eng. in Agric.* 22(5): 713-721.

OECD (Organisation for Economic Co-operation and Development). 2010. *2010 OECD Schemes for the Varietal Certification or the Control of Seed Moving in International Trade.* Paris, France: Organization for Economic Co-operation and Development. Available at: www.oecd.org/dataoecd/30/11/41977674.pdf. Accessed 13 August 2010.

Quick, G. R. 1977. Insect infestation in export grain may start at the combine. In *Proc. of the Intl. Grain and Forage Harvesting Conf.,* 76-81. St. Joseph, Mich.: ASAE.

Robinson, J. L., and O. A. Knott. 1963. *The Story of the Iowa Crop Improvement Association and Its Predecessors.* Ames, Iowa: Iowa Crop Improvement Association.