Effects of Combine Operating Parameters on Harvest Loss and Quality in Rice


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ABSTRACT. Combine tests were conducted in commercial rice fields near Keiser, Arkansas. Data was collected and analyzed for two long-grain rice varieties, 'Newbonnet' and 'Lemont', over a period of two harvest seasons. The test system used allowed for the collection of the clean grain auger discharge, shoe discharge, and rotor discharge separately and simultaneously. Independent variables tested were field speed (feedrate), material-other-than-grain to grain (MOG/G) ratio, moisture content, rotor speed, and concave clearance. Feedrate was the most important factor affecting combine harvest loss. Material-other-than-grain to grain ratio was the second most important factor affecting loss rates. Moisture content, by itself, was significant only in the 'Newbonnet' variety but affected loss rate in the 'Lemont' variety by influencing feedrate and MOG/G ratio. Rotor speed also influenced loss rates but affected each of the varieties differently. Concave setting was significant in both varieties but to a lesser degree in 'Newbonnet'. Head rice yields from combine-harvested samples and hand-harvested samples followed similar trends. Less than two percentage points of reduction in head rice yield were found in the combine-harvested samples when compared to hand-harvested samples.

Keywords. Rice, Harvest loss, Combine, Axial-flow.

Little research has been conducted on rice harvesting losses induced by combine harvesting parameters. With improved combine harvesters and new rice varieties, this limited research is obsolete. In addition, quantitative relationships concerning the effects of combine harvesting parameters on the quality of harvested rice are almost nonexistent.

Automatic monitoring of combine functions has increased and operators can more easily control a greater number of operating parameters. With developments in combine designs such as the axial, or rotary type combine and the introduction of new rice varieties, there is an increased need for determining the optimum settings for operating parameters under different field and crop conditions. This is evidenced by data from a survey, conducted during 1987, indicating harvest losses in rice ranging from 0.2 to 2.3 m³/ha (2 to 26 bushels/acre) (Willcut, 1990).

Several researchers have conducted tests on the effects of combine adjustment on harvest losses. McNeal (1948) measured harvest losses of combines in rice and reported that there were four types of losses caused by the combine during harvest; cutterbar, cylinder, rack, and shoe losses. McNeal (1950) went on to determine that high cylinder and rack losses resulted from forcing too much straw and grain through the combine per unit time. Of the four losses measured in his study, shoe loss was found to be the least. McNeal attributed the hulling and breakage of rice during the combining process to five factors; variety, condition of the grain, cylinder speed, concave clearance, and condition of cylinder and concaves. He concluded that it was necessary to use the proper cylinder speed and concave clearance for the variety and stage of crop maturity in order to obtain the highest grain yield and head rice yield (HRY) possible. Head rice yield is the weight percentage of rough rice that remains as whole kernels throughout the milling process.

Dilday (1989) studied the effects of grain moisture content (MC) and cylinder speed on the milling quality of rice. Data showed that HRY of grain collected at a cylinder speed of 600 rpm was significantly greater than that of grain collected at a cylinder speed of 1000 rpm. Dilday also stated that HRY generally decreased significantly as grain MC at harvest decreased, within a MC range from 12 to 26%.

Nyborg (1964) measured harvest losses of conventional combines in wheat and reported that cylinder adjustments must be closely controlled to maintain minimum harvest losses as MC changed during the day. Mailander et al. (1983) measured combine harvest losses in corn, soybeans and wheat using an axial-flow combine. Material feedrate was determined to be the factor that most affected loss rates. Fairbanks et al. (1979) reported that grain MC, cylinder speed, and cylinder concave adjustment significantly affected combine harvesting losses in grain sorghum.
Haffar et al. (1991) tested several combine settings in two chickpea varieties. Forward speed was a highly significant contributor to variations in harvest losses. Haffar also suggested that the contribution of forward speed and variety was not significant in the amount of broken grain, whereas concave clearance and cleaning fan capacity played a more significant role. Also, concave clearance and fan speed had no significant effect on threshing losses.

Harrison (1991) conducted a study to determine the rotor power and grain losses of an axial-flow combine in barley. He determined that losses were affected by rotor speed, vane angle, and feedrate, and to a lesser extent by MC and concave clearance.

Although there have been extensive combine tests performed in other grains, there has been little work in measuring combine losses in rice. While loss rates are important when combining rice, the quality of rice is also a major concern. In order to produce the highest quality and quantity of rice possible, the effects of combine operating parameters over the entire range of rice conditions required investigation.

OBJECTIVES
The main objective of this study was to quantify the performance of an axial-flow combine in rice under varying crop conditions. Specific objectives were to:

- Determine the effects of feedrate, rotor speed, and concave clearance on harvest loss rate and quality of rice.
- Determine optimum settings for each operating parameter in the above objective over a range of harvest MCs for two long-grain rice varieties.

GENERAL DESCRIPTION OF COMBINE
A 1990 Case IH, model 1680 axial-flow, self-propelled combine was used for testing. The combine had a single, closed tube specialty crop rotor mounted in an axial flow configuration with two impeller blades. The rotor was constructed with a series of short rasp bars evenly spaced around the rotor. The threshing concaves were of bar and wire construction, and the separating grates were made of 9.5 mm (3/8 in.) square steel bar. The discharge beater was a three blade wing type beater. The single cleaning fan was a six blade paddle fan and the adjustable lip chaffer sieve and cleaning sieve moved in an oscillating motion.

The combine was equipped with a 175 kW (235 hp) turbo charged diesel engine, a 6.1 m (20 ft) Case IH, model 1010 rigid grain header, and Case IH’s short cleaning system, which comprises a total cleaning area of 4.14 m² (44.6 ft²). Component speeds were monitored from the cab and the monitoring system was equipped with an alarm and lighted display, which were activated when component speeds reached set maximum or minimum speeds.

EXPERIMENTAL DESIGN
A test system, detailed by Andrews et al. (1992a), was installed on the 1680 combine. The test system allowed material to be collected from the shoe discharge, rotor discharge, and the clean grain auger. For tests conducted in 1990, field speeds of 1.6, 3.2, 4.8, and 6.4 km/h (1, 2, 3, and 4 mph) were chosen. This range of speeds encompasses the normal operating speeds of combines in rice. However, when the rice was above approximately 20% MC, a speed of 6.4 km/h (4 mph) could not be achieved without overloading and possibly plugging the combine. Rotor speeds of 700, 800, and 900 rpm, and concave settings of 2 and 4 were chosen. Concave settings of 2 and 4 correspond to concave clearances of approximately 2.2 and 4 cm, respectively. These settings encompass the recommended settings for rice (Case IH, 1990) and the recommendations made by personnel from Case IH. There were 24 experimental combinations (four field speeds x three rotor speeds x two concave settings) used for each test day. In addition, four randomly selected test combinations for each day were replicated, which yielded 28 test runs per day.

For tests conducted in 1991, the experimental design was modified based on the 1990 results. Field speeds of 1.6, 3.2, and 4.8 km/h (1, 2, and 3 mph) were chosen. A field speed of 6.4 km/h (4 mph) resulted in losses exceeding acceptable loss rates and thus was not included in the experimental design. In an effort to amplify the effects of rotor speed, rotor speeds of 700, 850, and 1000 rpm were chosen. In order to more thoroughly measure the effects of concave setting, it was necessary to expand the concave settings to 1, 3, and 5. The experimental settings for 1991 yielded a total of 27 combinations per day (three field speeds x three rotor speeds x three concave settings). The centroid of the experimental design (field speed of 3.2 km/h, rotor speed of 850 rpm, and concave setting of three) was consecutively replicated three times for each day of testing.

In order to avoid biases due to field variation, all test runs conducted within a given day were completely randomized and conducted within a single bay (area between levees). All randomizations were determined prior to testing by a computer generated randomization.

Operating parameters other than forward speed, rotor speed, and concave setting were maintained at a constant setting which was optimal for rice as recommended by Case IH. The header lift cylinders were blocked to ensure that the header height remained constant throughout the tests. The shoe and chaffer sieves were both set at 14 mm openings. Fan speed was set at 700 rpm and the reel speed was automatically synchronized to ground speed.

PROCEDURE
FIELD TESTS
Combine tests were conducted in laser-leveled, commercial fields near Keiser, Arkansas, in ‘Newbonnet’ rice, a short-statured, long-grain variety and ‘Lemont’ rice, a semi-dwarf, long-grain variety. In 1990, tests were conducted in ‘Newbonnet’ on four days over a nine-day period and the four daily average grain MCs were 22.8, 19.6, 19.1, and 17.1%. Only one day of testing was conducted in ‘Lemont’ during the 1990 harvest and the average MC was 15.4%. For the 1991 harvest, tests were again conducted in ‘Newbonnet’ on four days over an eight day period and the average MCs were 21.9, 21.6, 19.9, and 15.5%. Tests were also conducted in ‘Lemont’ on four days over a 13-day period and the average MCs were 20.5,
18.9, 16.9, and 15.5%. At the beginning of each test day, a minimum of 7 m³ (200 bushels) of rice was harvested as a warm-up for the combine. A test run comprised an initialization period, a test period, and a shut down period. The initialization period consisted of operating the combine in a test strip for at least 10 s. This allowed the operator to obtain the desired field speed and allowed the combine to reach steady state operation. After steady state conditions had been reached, the collection devices were activated by a central control switch (Andrews et al., 1992). Travel of the combine between the initialization period and the test period was constant. Collection of material continued for approximately 6.1 m (20 ft) at which time the collection devices were deactivated. However, the forward motion of the combine continued for at least another 1.5 m (5 ft). After the test run was completed, the forward motion of the combine was stopped but the cleaning system was allowed to operate until the system was empty.

For the 1990 tests, the shoe and rotor discharge were collected separately and at the end of each test run, the collection bags were replaced with empty bags. A representative sample from each shoe and rotor discharge bag was placed in a ziplock bag to be used in determining material other than grain (MOG) MC. For the 1991 tests, the shoe and rotor discharge were collected together in a single discharge bag. The MOG samples in the ziplock bags were refrigerated until subsequent oven drying at 103°C for 24 h (ASAE, 1990b) to determine MOG MC of each discharge bag.

When the collection devices were activated, grain was routed from the discharge of the clean grain auger in the grain tank into a storage column located outside the grain tank on the side of the combine. When the test run was completed, grain was emptied from this storage column into a burlap bag, which was later weighed to determine the amount of grain harvested in a test run. While the grain was being emptied into the burlap bag, a smaller bag was used to collect a representative sample of approximately 5 kg from the storage column. The grain sample bag was used for subsequent grain quality analysis.

When the collection devices were activated to initiate a test period, a weight with a spike extending from it was dropped from an electromagnet mounted to the rear axle of the combine. When the collection devices were deactivated, a second weight was dropped. The distance from the first weight to the second was recorded as the distance traveled during the test period. The time elapsed during the test period was also monitored with a stop watch and recorded as the time over which material was collected.

Field testing began shortly after 1:00 P.M. and took approximately 4 h to complete. The entire set of experimental combinations was tested for each day of testing. However, the order of testing the experimental combinations followed a different randomization schedule for each day.

In addition to the combine harvested samples, hand harvested samples were collected for each day of testing. The hand harvested samples were obtained by cutting stalks with a gas-powered hedge trimmer adjacent to the test run of the combine. Panicles from the stalks were manually removed from the stalks and placed in burlap bags. The rice was allowed to dry for several weeks and the kernels were then manually stripped from the panicles. This procedure was used to obtain samples for determining the HRY of rice that had received minimal mechanical damage for comparison to those harvested with the combine. For the 1990 tests, hand-harvested samples from 10 randomly selected test runs were collected for each test day. For the 1991 tests, a hand-harvested sample was collected for each test run of the combine.

**Rethreshing Tests and Weighing**

All material that had been collected during a test day was transported to a warehouse where the contents of the discharge bags were weighed. The MC of rice from each grain sample bag was determined by a Shizuoka Sieki model CTR 800A individual kernel moisture meter. In 1990, approximately 2 kg of rice was taken from the grain sample bag using a Boerner divider, placed in a ziplock bag, and stored in a refrigerator until HRY determinations could be performed. The remainder of the sample was returned to the grain sample bag to be used later for dockage testing. Head rice yields from 1990 exhibited large variations and showed no consistent trends. It was speculated that HRY damage may have occurred to some of the samples during storage. Thus, for 1991, 1 kg of rice was taken from the sample bag, immediately placed on a screen tray, and dried with ambient air to approximately 15% MC. After the rice had been dried, it was then placed in a ziplock bag and stored in a walk-in cooler.

To determine shoe loss for the 1990 tests, the shoe discharge was partially cleaned in a Swanson thresher/cleaner Model B1 in which the thresher was bypassed. The partially cleaned grain samples were subsequently cleaned at the Rice Processing Laboratory at the University of Arkansas to determine the amount of clean rice discharged from the shoe.

To determine rotor loss for the 1990 tests, the rotor discharge was threshed with a conventional threshing cylinder in line with a cleaning system extracted from a combine. The rotor discharge was threshed twice to ensure that all kernels were removed from the panicles. The recovered grain was weighed and placed in cloth bags until further cleaning was done.

Since the shoe discharge and the rotor discharge were collected together in the 1991 tests, the Swanson thresher/cleaner was not used. All material was threshed twice using the large threshing and cleaning unit.

**Lab Tests**

Grain samples from the grain tank, shoe discharge, and rotor discharge were cleaned using a Carter-Day dockage tester. Clean grain was that which passed through a No. 28 sieve and over a No. 22 sieve. Loss rates were calculated by dividing the amount of clean grain discharged from the rear of the combine by the total amount of clean grain discharged from all discharge points of the combine.

At the time of milling, all samples were dried to approximately 12.5% MC and were milled using a McGill No. 2 rice miller in accordance with the procedure outlined by the United States Department of Agriculture (USDA, 1982).
RESULTS AND DISCUSSION

Table 1 shows the average crop conditions for each day of testing. In general, as grain MC decreased so did the MOG/G ratio, indicating that the crop would be easier to separate at lower MCs, as suggested by PAMI (1990). Straw MC decreased with time but did not necessarily correspond to grain MC. The dockage percentage decreased as straw MC decreased. Head rice yields from the hand-harvested samples were nearly constant throughout the harvest for each year in the ‘Newbonnet’ variety. However, in the ‘Lemont’ variety, HRYs tended to decrease at lower grain MCs.

STATISTICAL ANALYSIS ON HARVEST LOSS

The two years of data were pooled and a model was fitted using RSREG of SAS (SAS, 1987) to determine the relationship of loss to feedrate, MC, rotor speed, concave setting, MOG/G ratio, and variety. Due to variations in MC from one test run to the next within a bay, the individual MC of each test run was used in the analysis instead of the average MC for a given day.

The model showed varietal effects; thus, separate models were fitted for each variety using REG of SAS. The final model for the ‘Newbonnet’ variety was based on two years of testing. Although tests were conducted in ‘Lemont’ variety in 1990 and 1991, the first year of testing included only one day in ‘Lemont’, in which the field was extremely wet. Also, the rice was non-uniform in yield across the field and was weedy. The ‘Lemont’ rice tested in 1991 was more uniform, fairly free of weeds, and field conditions were generally dry. Because of the dramatic differences in the crop and field conditions between the two years, the 1990 test day in the ‘Lemont’ variety was not included in the model.

The influence of each variable on total loss rate for both varieties, as indicated by sum of squares, is shown in figure 1. In both varieties feedrate and MOG/G ratio were the most influential factors affecting loss rates. In ‘Newbonnet’, feedrate accounted for 61.5% of the change in loss and MOG/G ratio accounted for 17.7%. In ‘Lemont’, feedrate and MOG/G ratio accounted for 44.9 and 44.5%, respectively, of the change in loss. Moisture content accounted for 13.8% of the change in loss in ‘Newbonnet’. Although MC by itself was not significant in the ‘Lemont’ variety, MC does affect MOG/G ratio and feedrate, both of which are very important. In ‘Newbonnet’, concave setting and rotor speed accounted for only 7% of the change in loss, with concave setting being the least significant and accounting for 1.3% of the total. However, in ‘Lemont’, the effect of concave setting showed to be more significant than rotor speed; concave setting accounted for 7.4% and rotor speed for 3.2% of the change in loss. This varietal difference may be attributed to several factors, one of which is the difference in the kernel size. In an earlier study by Andrews et al. (1992), 100 kernels from both ‘Lemont’ and ‘Newbonnet’ varieties were measured. The average length, width, and thickness for the ‘Lemont’ variety was 7.08, 2.35, and 1.73 mm, respectively. The average length, width, and thickness for the ‘Newbonnet’ variety was 6.82, 2.06, and 1.59 mm, respectively. A T-test showed differences at the 5% significance level between corresponding dimensions of the two varieties. Since the kernels of the ‘Lemont’ variety tend to be larger than those of ‘Newbonnet’, it is possible for the concave setting to have more influence in determining loss rates in ‘Lemont’ than ‘Newbonnet’.

Table 1. Average crop conditions for each day of testing

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Variety</th>
<th>Straw (%)</th>
<th>Grain (%)</th>
<th>Yield† (t/ha)</th>
<th>MOG/G Ratio</th>
<th>HRY‡ (%)</th>
<th>Dockage§ (%)</th>
</tr>
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<tbody>
<tr>
<td>9-19-90</td>
<td>‘Newbonnet’75.30</td>
<td>22.8</td>
<td>13.22</td>
<td>0.929</td>
<td>61.0</td>
<td>5.6</td>
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<tr>
<td>9-24-90</td>
<td>‘Newbonnet’71.03</td>
<td>19.6</td>
<td>10.02</td>
<td>0.744</td>
<td>61.3</td>
<td>4.2</td>
<td></td>
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<tr>
<td>9-25-90</td>
<td>‘Newbonnet’68.69</td>
<td>19.1</td>
<td>9.60</td>
<td>0.658</td>
<td>61.5</td>
<td>3.1</td>
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</tr>
<tr>
<td>9-28-90</td>
<td>‘Newbonnet’66.69</td>
<td>17.1</td>
<td>10.01</td>
<td>0.551</td>
<td>60.1</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>10-2-90</td>
<td>‘Lemont’     68.02</td>
<td>15.4</td>
<td>7.54</td>
<td>0.850</td>
<td>63.3</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>9-7-91</td>
<td>‘Newbonnet’68.08</td>
<td>21.6</td>
<td>9.44</td>
<td>0.890</td>
<td>64.2</td>
<td>3.1</td>
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</tr>
<tr>
<td>9-8-91</td>
<td>‘Newbonnet’67.05</td>
<td>21.9</td>
<td>9.54</td>
<td>0.871</td>
<td>64.4</td>
<td>2.4</td>
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<tr>
<td>9-12-91</td>
<td>‘Newbonnet’65.23</td>
<td>19.9</td>
<td>11.35</td>
<td>0.640</td>
<td>64.3</td>
<td>2.5</td>
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<tr>
<td>9-14-91</td>
<td>‘Newbonnet’61.34</td>
<td>15.5</td>
<td>8.83</td>
<td>0.611</td>
<td>63.7</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>9-1-91</td>
<td>‘Lemont’     66.53</td>
<td>20.5</td>
<td>9.47</td>
<td>0.890</td>
<td>66.2</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>9-2-91</td>
<td>‘Lemont’     64.27</td>
<td>16.9</td>
<td>9.39</td>
<td>0.712</td>
<td>65.3</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>9-9-91</td>
<td>‘Lemont’     63.56</td>
<td>18.9</td>
<td>9.01</td>
<td>0.932</td>
<td>65.0</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>9-13-91</td>
<td>‘Lemont’     61.88</td>
<td>15.5</td>
<td>8.00</td>
<td>0.753</td>
<td>61.8</td>
<td>2.4</td>
<td></td>
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</tbody>
</table>

* The values shown for each day of testing are the means of 28 observations in 1990 and 29 observations in 1991
† Grain yield is reported as ‘green’ weight and has not been adjusted for moisture content.
‡ Head rice yields are the average of hand-harvested samples from each test day.
§ Dockage was the weight percent of material collected in the grain tank other than clean grain. Clean grain was that which passed through a No. 28 sieve and over a No. 22 sieve in a Carter-Day dockage tester.

TRANSACTIONS OF THE ASAE
Another possible factor in explaining the difference between the two models and why the effects of MC and feedrate are more evident in 'Newbonnet' than in 'Lemont', is that the majority of the 'Newbonnet' tests were conducted when the grain MC was above 19%, while only one day of testing was conducted in the 'Lemont' when the grain MC was above 19%.

**Newbonnet' Variety**

In the 'Newbonnet' variety, the quadratic effects of MOG/G ratio, feedrate and concave setting were significant. There were significant interactions between rotor speed and feedrate, rotor speed and MOG/G ratio, feedrate and MOG/G ratio, and between feedrate and MC. There was also a significant 'year' effect, and when year was retained in the analysis, the R-square was 92% and the mean squared error was 0.75. However, the year term was excluded from the analysis in order to produce a more general model for the two years. The final model explained 85% of the variability associated with loss with a mean squared error of 1.08. The model is shown below and contains those terms significant at the 5% probability level.

\[
\% \text{Loss} = -1.256 - 13.955 (\text{MG}) - 0.161 (\text{FR}) \\
+ 0.103 (\text{MC}) + 0.0104 (\text{RS}) - 0.986 (\text{CS}) \\
+ 16.193 (\text{MG}^2) + 0.019 (\text{FR}^2) + 0.164 (\text{CS}^2) \\
+ 0.506 (\text{FR} \times \text{MG}) + 0.021 (\text{FR} \times \text{MC}) \\
- 0.00066 (\text{FR} \times \text{RS}) - 0.0116 (\text{MG} \times \text{RS}) \tag{1}
\]

where
- MG = MOG/G ratio
- FR = feedrate (kg/s)
- MC = moisture content (% w.b.)
- RS = rotor speed (rpm)
- CS = concave setting

Figure 2 shows a response surface characterizing the effects of feedrate and MOG/G ratio on loss. The figure indicates that as feedrate and MOG/G ratio increased, losses increased. At high MOG/G ratios the effects of feedrate were greater than at low MOG/G ratios. The effect of MOG/G ratio followed a similar trend in that at high feedrates the effect of MOG/G ratio was greater than at low feedrates. Figure 2 also indicates that losses were minimized when rice was harvested at feedrates below approximately 4 kg/s and at MOG/G ratios below approximately 0.8. The combine operator can control the MOG/G ratio to some extent by raising the header to minimize the amount of MOG entering the combine. By minimizing the amount of MOG being harvested, feedrate is also reduced, thus, the forward speed of the combine can be increased without increasing loss rates.

Figure 3 illustrates the effects of MC on loss rates. The figure indicates that as MC increased, loss rates also increased at a given feedrate. The figure also shows that minimum losses occurred at feedrates as high as 8 kg/s when harvesting at an MC of 16%. However, at higher MCs, feedrates had to be reduced to maintain the same minimum loss rate. The same trend as to the effect of MC was present throughout the entire range of rotor speeds and concave settings tested.

Figure 4 shows a typical response surface illustrating the effects of rotor speed on loss rates. At feedrates below approximately 5 kg/s, rotor speed did not influence loss rates. However, at feedrates above 5 kg/s, increasing rotor speed progressively lowered loss rates.

Figure 5 shows the effect of concave setting on loss rate. The figure indicates that there were no differences between loss rates produced from concave settings of 1 and 5 at any feedrate. However, a concave setting of 3 produced approximately 0.6 percentage points lower loss than a concave setting of 1 or 5 at a given feedrate. The trend for
concave setting was consistent for all levels of MC, rotor speed, and MOG/G ratio tested in 'Newbonnet'.

'LEMONT' VARIETY

Feedrate, rotor speed, concave setting, and MOG/G ratio significantly affected loss in the 'Lemont' variety. The quadratic effects of feedrate, rotor speed and concave setting were significant. Interactions between feedrate and MOG/G ratio and between feedrate and concave setting were also significant. The model explained 86% of the variability associated with loss with a mean squared error of 3.20. The model is shown below and contains those terms significant at the 5% probability level.

\[
\%\text{ Loss} = 25.076 - 4.219 \text{ (MG)} - 1.170 \text{ (FR)} \\
- 0.0506 \text{ (RS)} - 1.049 \text{ (CS)} + 0.0770 \text{ (FR}^2) \\
+ 0.320 \text{ (CS}^2) + 0.00003 \text{ (RS}^2) \\
+ 1.228 \text{ (FR}\times\text{MG}) - 0.116 \text{ (FR}\times\text{CS})
\]

where
\[
\text{MG} = \text{ MOG/G ratio} \\
\text{FR} = \text{ feedrate (kg/s)} \\
\text{RS} = \text{ rotor speed (rpm)} \\
\text{CS} = \text{ concave setting}
\]

Figure 6 shows the response surface illustrating the effects of feedrate and MOG/G ratio in the 'Lemont' variety. The figure indicates that in general, loss rates increased as feedrate increased, much like that of 'Newbonnet'. The figure also shows that when rice was harvested above a feedrate of approximately 5 kg/s, as MOG/G ratios increased, loss rates also increased. At feedrates above 10 kg/s, loss rates experienced at an MOG/G ratio of 1 were more than 4 percentage points greater than loss rates experienced at an MOG/G ratio of 0.5. Also as feedrate increased, the influence of MOG/G ratio on loss rate increased.

The effect of concave setting on loss rate is illustrated in figure 7. In general, the effect of concave setting in 'Lemont' was similar to that of 'Newbonnet'. However, at feedrates above approximately 8 kg/s, loss rate in the 'Lemont' was greater than that of 'Newbonnet'. The figure shows that when harvesting at feedrates above approximately 8 kg/s, a concave setting of 1 produced higher loss rates than concave settings of 3 or 5. However, at feedrates below approximately 8 kg/s, a concave setting of 5 produced higher loss rates than concave settings of 1 or 3. This trend may be attributed to the threshing action inside the rotor cage. When operating at feedrates below 8 kg/s and a wide concave clearance, the clearance between
the rotor and the concaves is large enough that the crop is not thoroughly threshed. When operating at feedrates above 8 kg/s and a narrow concave clearance, the clearance between the rotor and the concave is such that the crop flows through the rotor cage too quickly to be thoroughly threshed. Within the range of variables tested, a concave setting of 3 tended to produce the lowest losses.

Figure 8 shows a response surface illustrating the effects of rotor speed. The difference in loss rates between rotor speeds of 700 and 1000 rpm was minimal. However, a rotor speed of 850 rpm tended to produce losses of one percentage point less than either the 700 or 1000 rpm rotor speeds. The same trend in rotor speed was present for all levels of concave setting and MOG/G ratio that were tested.

in the ‘Lemont’ variety. However, this trend in rotor speed was different from the linear response in ‘Newbonnet’.

**HEAD RICE YIELD**

**‘NEWBONNET’ VARIETY**

Head rice yields from the hand-harvested samples and combine-harvested samples from the ‘Newbonnet’ variety in 1991 are shown in figure 9. The figure shows that HRY followed similar trends for both the hand-harvested and the combine-harvested samples. However, when MC was regressed against the HRYs of the hand-harvested samples, the HRYs were found to be constant with a mean of 64.0% and a standard deviation of 1.35. Moisture content was significant when regressed against the HRYs of the combine-harvested samples. The figure indicates the maximum HRY from the combine occurred when rice was harvested between 18 and 20% MC. The reduction in HRY caused by the combine was calculated by subtracting the HRY of the combine-harvested sample from the mean HRY of the hand-harvested samples. Statistical analysis showed that MOG/G ratio and rotor speed significantly affected the reduction in HRY. However, the R-square of the model was only 20% with a mean squared error of 2.03. Approximately 80% of the variability associated with HRY reduction was not accounted for by the model, and may be explained by the variability of HRYs found in the field. Thus, for the ‘Newbonnet’ variety, the variability in HRYs throughout the field overshadowed any definite trends in HRY reduction due to combine settings.

**‘LEMONT’ VARIETY**

Figure 10 shows the comparison of HRYs from hand harvested samples to that of the combine-harvested samples from ‘Lemont’ in 1991. Similar trends are shown for HRYs from the hand-harvested samples and HRYs from the combine-harvested samples. In both cases, maximum HRYs occurred when rice was harvested at approximately 20% MC. The downward trend of HRY at MCs above 20% can be explained by the presence of immature kernels, which generally break during milling. At MCs less than approximately 16%, the downward trend
in HRY can be attributed to re-wetting in the field (Siebenmorgen et al., 1992). Statistical analysis showed that the difference between HRYs of hand-harvested samples and HRYs of combine-harvested was significant. In general, HRYs from the hand-harvested samples were approximately 0.8 percentage points higher than those of the combine-harvested samples. Head rice yield reduction was minimized over an MC range of 17 to 21% and was least at approximately 19% MC. As MC increased or decreased from 19%, the amount of reduction in HRY due to the combine increased. Statistical analysis showed that MC, MOG/G ratio, feedrate, and rotor speed significantly affected HRY reduction. However, the model only explained 23% of the variability associated with HRY reduction and had a mean squared error of 5.03. Like the HRYs in ‘Newbonnet’, the low R-square value may be partially explained by the variability of HRY found in the field. Although any definite trends in HRY reduction due to combine settings is overshadowed by field variability, there is some indication that the combine slightly reduced HRY.

SUMMARY AND CONCLUSIONS

Feedrate was the most important factor affecting combine harvest loss. In general, loss rates increased as feedrate increased. MOG/G ratio was second most important factor affecting loss rates. In general, higher MOG/G ratios resulted in higher loss rates. However, at low feedrates, MOG/G ratio has less influence on loss rates than at high feedrates. MOG/G ratio had more influence in the ‘Lemont’ variety than in ‘Newbonnet’. Moisture content had a direct influence on loss rate only in the ‘Newbonnet’ variety, and indirectly affected loss rate in the ‘Lemont’ variety through feedrate and MOG/G ratio. As MC increased, loss rates also increased at a given feedrate. Rotor speed was also a significant factor affecting loss rate. In the ‘Newbonnet’ variety as rotor speed increased, loss rates steadily decreased over a range of 700 to 1000 rpm. In the ‘Lemont’ variety, a quadratic relationship was found in that a rotor speed of 850 rpm produced less loss than either the 700 or 1000 rpm speeds.

There were no significant differences between the 700 and 1000 rpm rotor speeds in the ‘Lemont’ variety.

Concave setting was significant in both varieties but to a lesser degree in ‘Newbonnet’. Overall, a concave setting of 3 tended to produce lower loss rates than a concave setting of 1 or 5. However, in the ‘Lemont’ variety, at feedrates above approximately 12 kg/s, there were no significant differences in the concave settings of 3 and 5.

Head rice yields from combine-harvested samples and hand-harvested samples followed similar trends. Although there was a slight reduction in HRY from combine harvested samples when compared to hand harvested samples, any trends present in the HRY reduction due to combine settings were overshadowed by field variability. However, maximum HRYs were obtained when rice was harvested from 19 to 20% MC.

Overall, loss rates were minimized at lower feedrates and lower MOG/G ratios in both varieties. A concave setting of 3 tended to minimize loss rates in both varieties. In the ‘Lemont’ variety, a rotor speed of 850 rpm produced the lowest losses. In the ‘Newbonnet’ variety, a rotor speed of 1000 rpm produced the lowest losses. It is speculated that the differences in the effects of the variables tested in the two varieties on loss rates were due to differences in the size of the kernels and the differences in the average MCs at which the two varieties were tested.

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