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Original Article

Prediction equations for header losses of combine harvesters when harvesting Thai Hom Mali rice

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Abstract

The objective of this study was to predict header losses of a combine harvester when harvesting Thai Hom Mali rice. The results of the study indicate that grain moisture content (M), reel index (RI), cutter bar speed (V), service life of cutterbar (Y), tine spacing (R), tine clearance over cutter bar (C), stem length (H), product of M and Y (M*Y), product of M and V (M*V), product of RI and R (RI*R), product of V and C (V*C), product of V and H (V*H), V^2 and RI^2 were the major parameters affecting the losses. The prediction equations had R^2 = 0.75. The average percentage header losses given by the estimation equation differed from the measurement by only 0.25.

Keywords: rice combine harvester, header loss, prediction equations

1. Introduction

Thai rice is of high quality and most essential to the economic, social and political conditions of Thailand (Chinsuwan *et al.*, 2002). Harvesting rice is a very important process which affects the quality and quantity of the rice. Nowadays, rice combine harvesters are playing a more important role in harvesting and are being more widely used. Their role has also increased as rice cropping spreads throughout Thailand. It is estimated that there are about 4,000 rice combine harvesters being used. Almost all of them are Thai-designed rice combine harvesters and at present are hired out for field harvesting in Thailand. (Chinsuwan *et al.*, 2004).

Thai Hom Mali rice is a native rice variety, the total planting area of which covers about 16 million rai (~2.5 million ha 6.25 rai = 1 ha). It is a very important staple for the nation's economy (LDD, 2004). Studies of the header losses when using rice combine harvesters with Hom Mali rice showed losses between 2.00-3.43 % (Chinsuwan *et al.*, 1999) equivalent to a monetary value of around a billion baht per year (~$30 million per year). Most of the losses were from the high variance caused by improper adjustment of the machines with respect to crop conditions or from increasing the machine speeds. Generally, the operators modified the threshing units without realizing their capability or the losses from working conditions (Chinsuwan *et al.*, 2004).

Research studies reveal that there are two main factors that cause header losses, i.e. the crops themselves and the conditions of the machines including the cutter bar speed (Hummel and Nave, 1979), reel index (Chinsuwan *et al.*, 2004), tine clearance over the cutter bar (Quick, 1999), tine spacing (Mohammed and Abdoun, 1978), service life of the cutter bar (Klenin *et al.*, 1986) and stem length (Siebenmorgen *et al.*, 1994). Crop condition factors are related to the rice varieties (Chinsuwan *et al.*, 2002), grain moisture content (Chinsuwan *et al.*, 1997) and other ambient factors such as rice plant density (Yore *et al.*, 2002). Losses are also indicated by a high variance of improper machine adjustment to the crop conditions as mentioned above.

Andrews *et al.* (1993) studied the effects of the operating parameters of combine harvesters on harvest losses

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of rice by forming a process equation and calculating their losses from the rice combine harvesters by using a second-order response surface model. The findings indicate that the feed rate, ratio of grain to material other than grain, moisture content, rotor speed and concave clearance affected threshing losses.

Chuan-udom and Chinsuwan (2009) conducted a study on the threshing unit loss prediction for thai axial flow rice combine harvesters. They derived prediction equations with an R^2 value of 0.92 and an average value of 0.10% error.

The header losses of a rice combine machine are a major problem in the harvesting process (Chinsuwan *et al.*, 2004). Thus, the objective of this study was to obtain a prediction equation for header losses of combine harvesters when harvesting Thai Hom Mali rice. This should enable a prediction of the losses from the combine harvesters and help farmers make appropriate decisions in their use, hence minimizing losses in the harvesting process.

2. Methodology

Step 1: The study of parameters that affect header losses

The equipment used in this study was a Thai rice combine harvester (Figure 1), 3.20 m in width where the distance from the center of the reel to the tine edge was 0.78 m. The cutter bar speed, reel speed, tine bar, cutter bar unit and spacing tine clearance over cutter bar could all be adjusted. The engine power was 157 kw (210 hp).

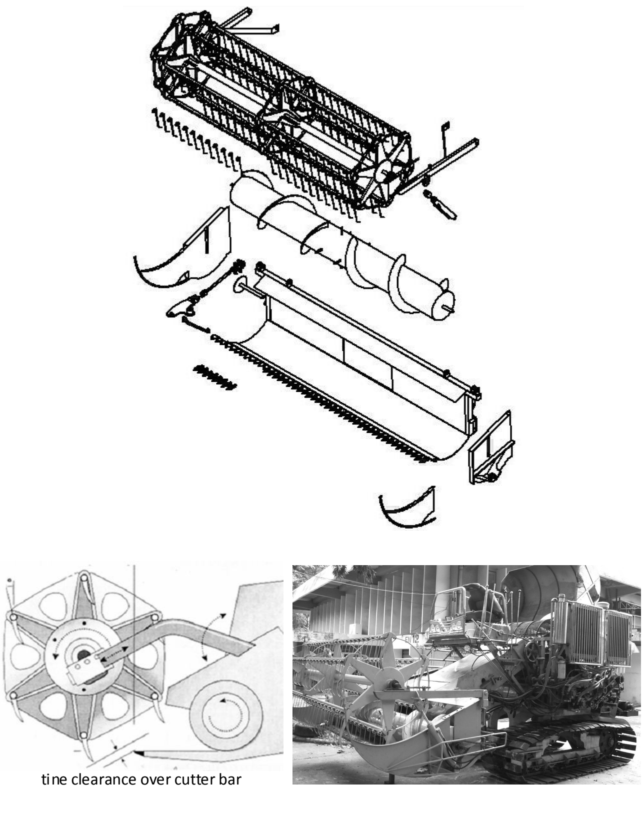

Figure 1. The rice combine harvester used for testing and its header unit.

The study of parameters was based on 7 factors: grain moisture content (M), and factors related to machine conditions including the cutter bar speed (V), reel index (RI), tine clearance over the cutter bar (C), tine spacing (R), service life of the cutter bar (Y) and stem length (H). The test was carried out on standing rice stems. The specified incline of the angle of the rice under study was to be more than 60 degrees and applied only to standing rice stems (Manalili *et al.*, 1981).

Appropriate and current values of the factors studied were as follow: 3 levels of service life of the cutter bar for: 50, 500 and 1,000 rai, 3 levels of tine spacing: 8, 12 and 16 cm, 8 levels of tine clearance over the cutter bar: 10, 15, 20, 25, 30, 35, 40 and 45 mm. The stem length, the cutter bar speed and reel index used in each test had 4 different levels: stem length varied from 30-80 cm, the cutter bar speeds were 0.15-0.70 m/s, reel index was 1.5 to 5.5, and the grain moisture content each day was within 15.34-25.10 % wb. The design of this experiment used random sampling to cover all equation surfaces.

The data obtained were used to find out how the parameters affected the header losses by using a second-order model or the relation of the squared arch regression equation as shown in equation 1, which depicts the relations of cofactors and shows the linear relations, squared arch and interrelations (Berger and Maurer, 2002). A regression equation was developed from the obtained model, by having the second-degree terms in the regression equation that had the least effect on the dependent variables eliminated. Then, another regression equation was formulated until the second-degree parameters in the equation had a reliability value affecting the losses of not less than 95%. Next, the first-degree parameter was taken into consideration; when interrelated with the second-degree parameters at a reliability value greater than 95%, then the first-degree parameter which least affected the dependent variables was omitted, and a new regression equation formed. The first-degree parameter least affecting the dependent variables was repeatedly eliminated until it did not have any interrelation with the second-degree parameter at a 95% reliability level.

$$Y = \beta_0 + \Sigma_{(i=1,k)} \beta_i x_i + \Sigma_{(i=1,k)} \beta_{ii} x_i^2 + \Sigma\Sigma_{(i<j)} \beta_{ij} x_i x_j \quad (1)$$

where Y = dependent variable
x_i, x_j = independent variables
β_0, β_i, β_{ii}, β_{ij} = constants

Step 2: Formulation of the prediction equations for header losses

There are many brands of rice combine harvesters in Thailand, each being different from the others in its header set designs. The formulation of the prediction equation to cover all working conditions for each brand was based on

Step 1 above. In this research, data related to 22 machines from 12 brands of rice combine harvesters were collected randomly in the Thung Kula Ronghai (Roi Et and Surin province) field area in November 2006. Losses from the headers were recorded by collecting falling seeds from each machine by hand within an area of 2 m^2. There were three replications of seed collection, and the data of losses of randomly selected machines were used to design a new regression equation.

Step 3: Assessment of the prediction equations

The prediction equation obtained was used as a basis for the assessment of header losses from 23 machines of 12 brands of rice combine harvesters in the Thung Kula Ronghai field area in November 2007. Steps were repeated in order to confirm the previous prediction equation and assess the equation's applicability.

3. Results and Discussion

Step 1: The Parameters That Affected Headers Losses

Table 1 shows the factors that affected the header losses of Hom Mali rice from the study having reel indexes between 1.53 and 5.10 with the cutter bar speeds between 0.17 and 0.67 m/s¸ service life of the cutter bars (Y) for 50 to 1,000 rai, the tine spacings between 8 and 16 cm, tine clearances over the cutter bar between 10 and 45 mm, stem lengths between 32.61 and 77.85 cm and grain moisture contents between 15.34 and 25.10 % wb.

The regression equations indicate that there were 14 overall parameters of the rice combine harvester machines' performance that affected header losses (HL), namely grain moisture content (M), reel index (RI), cutter bar speed (V), service life of the cutter bar (Y), tine spacing (R), tine clearance over the cutter bar (C), stem length (H), product of M and Y (M*Y), product of M and V (M*V), product of RI and R (RI*R), product of V and C (V*C), product of V and H (V*H), cutter bar speed squared (V^2) and reel index squared (RI^2) (Equation 2). The service life of the cutter bar (Y), tine spacing (R), tine clearance over the cutter bar (C), stem length (H) and grain moisture content (M) affected the header losses in straight lines, whereas the reel index (RI) and the cutter bar speed (V) affected the header losses in square arches.

$$HL = f\{M, Y, R, C, V, RI, H, M*Y, M*V, RI*R, V*C, V*H, V^2, RI^2\} \quad (2)$$

The parameters of the rice combine harvester performance affecting header losses of Hom Mali rice can be used in constructing equations to predict losses so that users can make decisions on an appropriate technique for rice harvesting with minimal header losses.

Step 2: Formulation of the prediction equations for header losses

Data in Table 2 together with parameters from Step 1 were used in constructing the regression equation to predict the header losses as given by Equation 3, which had the decision coefficient (R^2) of 0.75 .

$$\begin{aligned} HL = {} & 13.674 - 0.531\,(M) + 0.003\,(Y) - 0.164\,(R) - 0.074\,(C) - 14.189\,(V) - 1.913\,(RI) + 0.062\,(H) - 0.0001\,(M*Y) \\ & + 0.684\,(M*V) + 0.026\,(RI*R) + 0.106\,(V*C) - 0.059\,(V*H) + 2.456\,(V^2) + 0.392\,(RI^2) \end{aligned} \quad (3)$$

The prediction equation was used to indicate the relations of all factors affecting header losses using the normal values of a harvesting reel index of 2, cutter bar speed of 0.5 m/s, tine spacing of 12 cm, tine clearance over the cutter bar of 25 mm, grain moisture content of 22 % wb, stem length of 50 cm and service life of cutter bar for 50 rai with the blades still remaining sharp. The results were as follows.

That the grain moisture content affects the header losses (Figure 2) indicated that header loss had a tendency to decrease with increasing moisture. This conforms to the study of Chinsuwan *et al.* (1997) that high-moisture content or fresh paddy tend to cling to the head firmly and their rate of falling was less than low-moisture or dry grains (Chinsuwan *et al.*, 1997).

That the reel index affects the header loss (Figure 3) shows that the loss was less when the reel index was between 1.5 and 3.0. However, when the reel index was lower than 1.5 or higher than 3.0, there was a tendency for the header loss to be greater. This was because when the reel index moved too slowly the tine failed to sweep all the rice towards the header. On the other hand, when the reel index was high or moved too quickly, the tine would beat the head violently resulting in greater loss (Chinsuwan *et al.*, 1997).

That the cutter bar speed affects the header loss (Figure 4) indicates that the cutter bar speed increases with increasing header loss. When the cutter bar speed was 0.5 m/s, the loss was minimal; with speeds lower than 0.5 m/s, it was too difficult to cut the stem. In contrast, when the cutter bar had a very high speed, violent vibration at the header had a severe impact on the stems and caused grain loss.

That the service life of the cutter bar affects header loss (Figure 5) indicates that when the service life of the cutter bar increased from 50 to 1,000 rai, there was more loss due to blunting of the blades.

That the stem length affects header loss (Figure 6) indicates that when the length of the cut stems increased, header loss also increased. In rice fields, cutting rice stems shorter than 40 cm results in grain falling. A 40-50 cm length of cut rice stems causes less loss. Cutting long stems is difficult and causes greater loss due to cutting the stems at wider diameters, and also a higher feedrate and density, which

Table 1. Factors affecting the header losses of Hom Mali rice

M (% wb.)	Y (rai*)	R (cm)	C (mm)	V (m/s)	RI	H (cm)	Loss (%)
25.10	50	12	10	0.20	2.05	37.76	7.43
			20	0.37	2.65	45.18	2.15
			30	0.45	4.96	56.30	2.54
22.53	500	8	35	0.25	2.37	47.31	4.73
			15	0.17	1.78	34.42	7.34
			45	0.42	2.16	56.51	4.15
			25	0.58	2.92	60.27	4.27
23.30	1,000	12	15	0.25	1.58	32.61	3.34
			25	0.58	2.17	58.79	2.58
			35	0.42	2.30	45.63	2.04
			45	0.35	1.97	53.43	2.45
19.19	50	8	25	0.33	2.91	46.67	5.15
			15	0.42	3.35	56.88	11.16
			35	0.17	1.64	58.80	21.53
			45	0.58	1.99	72.57	6.02
18.50	1,000	8	10	0.33	2.50	69.58	6.67
			30	0.58	2.55	51.85	7.16
			20	0.50	2.27	77.85	9.79
			40	0.20	2.11	85.65	15.23
19.50	500	12	30	0.33	2.60	58.06	3.29
			20	0.25	5.10	41.33	9.64
			40	0.50	2.44	58.41	5.92
			10	0.67	2.01	72.87	12.38
15.34	50	16	25	0.63	1.53	44.71	32.01
			35	0.50	1.75	34.86	13.26
			45	0.25	2.06	49.19	12.67
			15	0.42	2.73	56.55	9.78
17.83	500	16	35	0.42	3.48	38.98	18.19
			15	0.33	2.42	26.38	12.54
			45	0.58	2.22	48.46	11.25
			25	0.25	1.69	64.21	27.84
20.12	1,000	12	10	0.25	2.92	38.31	10.21
			20	0.58	2.42	43.53	22.95
			30	0.42	2.61	49.02	5.39
			40	0.50	1.78	58.52	9.81
22.01	500	16	10	0.42	2.31	52.00	5.01
			20	0.33	1.91	58.67	4.26
			30	0.58	1.83	65.39	6.03
			40	0.25	1.78	44.96	6.87
21.41	1,000	16	15	0.50	3.49	43.86	3.09
			35	0.58	2.49	35.55	4.69
			25	0.42	4.93	67.89	6.06
			45	0.25	1.77	52.35	18.02
24.39	50	12	15	0.62	1.58	32.61	3.33
			25	0.25	2.17	58.79	2.57
			35	0.50	2.30	45.63	2.04
			45	0.33	1.97	53.43	2.45

* 6.25 rai = 1 ha

Remark: Data were collected daily for 4 tests except on the first day, when data for only 3 tests were collected due to limited time.

Table 2. Parameters used for constructing prediction equations from the header losses

Brand	No.	M (% wb.)	Y (rai*)	R (cm)	C (mm)	V (m/s)	RI	H (cm)	Loss (%)
A	1	22.84	150	12.37	24.11	0.53	2.18	74.69	1.78
	2	17.58	50	12.40	49.39	0.58	2.26	47.06	1.18
	3	25.06	1500	9.13	29.78	0.78	2.09	60.39	2.56
B	1	21.71	100	12.10	37.50	0.68	2.09	68.36	1.07
	2	22.81	1000	13.10	37.00	0.57	2.35	44.48	0.40
	3	26.30	500	12.00	13.75	0.64	1.85	50.10	1.00
C	1	24.45	200	11.15	29.50	0.68	1.86	61.80	0.55
	2	25.17	400	12.10	15.47	0.59	2.68	63.56	0.41
	3	24.82	350	11.27	23.00	0.65	2.01	63.35	1.22
D	1	26.05	1100	12.77	19.94	0.74	2.00	47.19	0.41
	2	17.63	100	12.00	50.00	0.54	2.09	52.93	1.04
E	1	25.81	350	10.21	19.40	0.68	2.09	52.66	2.23
	2	26.14	800	12.36	5.00	0.62	2.42	65.29	1.03
F	1	22.95	300	20.83	21.20	0.64	2.52	63.79	1.08
	2	24.56	1200	10.30	21.33	0.68	2.57	64.92	1.91
G	1	27.87	1000	10.13	63.44	0.78	2.71	63.92	2.20
	2	24.98	300	13.00	12.13	0.58	3.31	68.79	1.07
H	1	23.78	50	10.33	28.50	0.72	3.47	66.32	2.89
I	1	28.06	1000	11.81	50.67	0.86	2.11	74.62	2.84
J	1	29.76	450	9.28	31.83	0.58	2.51	70.74	0.53
K	1	22.96	500	12.46	35.88	0.71	4.38	54.52	3.66
L	1	27.71	300	11.20	14.78	0.78	2.46	64.94	1.55

*6.25 rai = 1 ha

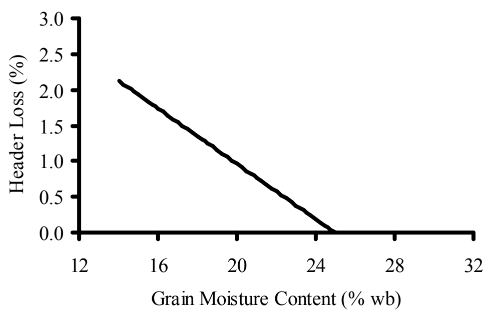

Figure 2. The effect of grain moisture content on header loss predicted by equation 3, when using RI = 2, V = 0.5 m/s, Y = 50 rai, R = 12 cm, C = 25 mm and H = 50 cm .

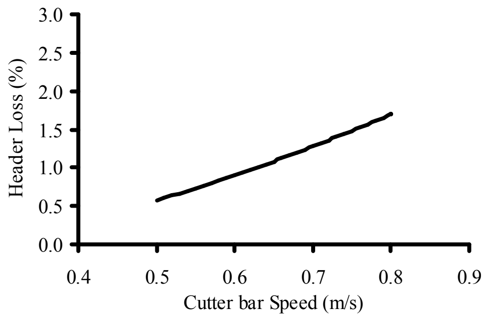

Figure 4. The effect of cutter bar speed on header loss predicted by equation 3, when using M = 22 %wb, RI = 2, Y = 50 rai, R = 12 cm, C = 25 mm and H = 50 cm .

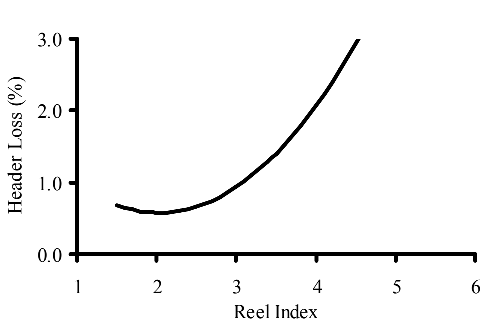

Figure 3. The effect of the reel index on header loss predicted by equation 3, when using M = 22 %wb, V = 0.5 m/s, Y = 50 rai, R = 12 cm, C = 25 mm and H = 50 cm .

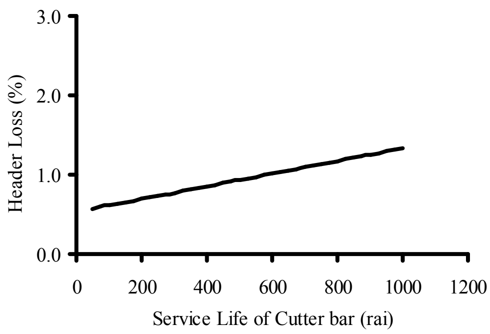

Figure 5. The effect of service life of the cutter bar on header loss predicted by equation 3, when using M = 22 %wb, RI = 2, V = 0.5 m/s, R = 12 cm, C = 25 mm and H = 50 cm .

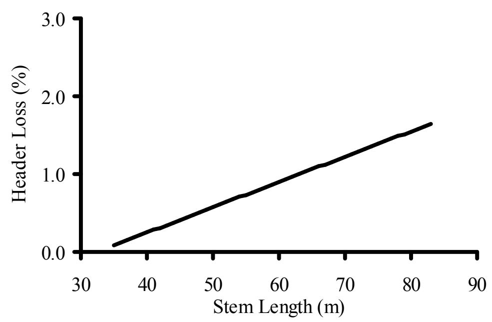

Figure 6. The effect of stem length on header loss predicted by equation 3, when using M = 22 %wb, RI = 2, V = 0.5 m/s, Y = 50 rai, R = 12 cm and C = 25 mm.

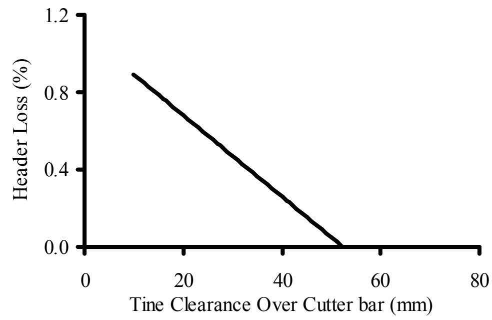

Figure 7. The effect of tine clearance over the cutter bar on header loss predicted by equation 3, when using M = 22 %wb, RI = 2, V = 0.5 m/s, Y = 50 rai, R = 12 cm and H = 50 cm.

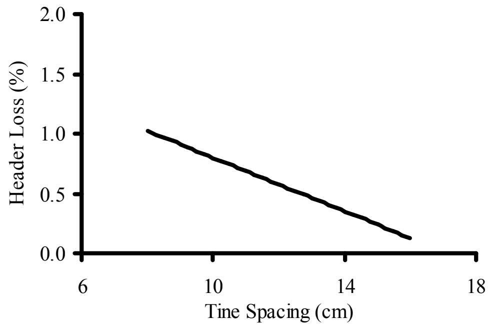

Figure 8. The effect of tine spacing of the cutter bar on header loss predicted by equation 3, when using M = 22 %wb, RI = 2, V = 0.5 m/s, Y = 50 rai, C = 25 mm and H = 50 cm.

makes packing of rice stems for transport more difficult.

That the tine clearance over the cutter bar affects header loss (Figure 7) shows that when the tine clearance over the cutter bar increased, header loss tended to decrease. When the tine clearance over the cutter bar was between the range of 40 to 50 mm, the header loss was the least. When the clearance was below 40 mm, the rice stems became attached to the reel unit resulting in header loss. In cases where the clearance was higher it was more difficult for the rice stems to bend towards the cutters of the header set, resulting in a reduction of the effective cutting of the whole rice stems.

That the tine spacing affects header loss (Figure 8) reveals that when the tine spacing increased the hook set had a tendency to decrease. If the tine spacing was around 16 cm, the loss was minimal. For lower tine spacing, the loss increased due to the fact that the number of tines was higher, which increased the chance of these tines beating the rice ears. On the other hand, when the tine spacing was larger the number of tines was not sufficient to bend down the rice stems for cutting.

In conclusion, when employing the combine harvester to minimize header losses of Hom Mali rice using prediction equations the following header factors should be used: cutter bar speeds between 0.50 and 0.60 m/s, reel indexes between 1.5 and 3.0, stem lengths between 40 and 50 cm, tine spaces between 12 and 16 cm and tine clearances over the cutter bars between 40 and 50 mm, which was the most practical adjustable width. For a longer service life the cutter bar should be regularly sharpened.

Step 3: Assessment of the prediction equations

Table 3 shows the assessment of the prediction equations for header losses. It can be seen that the predicted results differed from the experimental results in the range of 0.01 to 1.10%, with an average of 0.25%. Hence, the prediction or anticipation of losses using rice combine harvesters constructed in Thailand for harvesting Hom Mali rice should use Equation 3 for determining header losses.

4. Conclusions

The prediction equations for header losses of combine harvesters when harvesting Thai Hom Mali rice indicate that the following parameters influence the losses: grain moisture content (M), reel index (RI), cutter bar speed (V), service life of the cutter bar (Y), tine spacing (R), tine clearance over the cutter bar (C), stem length (H), product of M and Y (M*Y), product of M and V (M*V), product of RI and R (RI*R), product of V and C (V*C), product of V and H (V*H), V^2 and RI^2 are the major parameters affecting the

Table 3. Assessment of the prediction equations for the header losses

Brand	No.	M (%wb.)	Y (rai*)	R (cm)	C (mm)	V (m/s)	RI (cm)	H	% Loss		
									Measurement	Prediction	Errors
A	1	26.39	300	11.17	27.00	0.69	2.83	57.42	1.60	1.53	0.07
	2	25.47	300	13.11	43.00	0.81	3.49	61.13	3.10	3.02	0.08
	3	26.73	250	11.39	35.33	0.70	3.19	62.64	1.87	1.89	0.02
B	1	26.99	400	13.94	34.72	0.74	1.88	39.94	1.75	1.01	0.74
	2	28.39	500	11.89	37.50	0.76	2.60	59.15	2.20	1.89	0.31
	3	27.89	500	9.61	19.67	0.80	2.03	48.62	2.06	2.02	0.04
C	1	27.08	300	11.67	19.06	0.69	1.58	57.43	1.51	1.28	0.23
	2	24.72	600	10.94	9.67	0.63	2.06	43.78	1.03	1.09	0.06
	3	28.23	500	13.00	32.39	0.72	2.06	54.79	1.76	1.19	0.57
D	1	20.69	200	11.17	34.56	0.71	1.92	43.82	1.14	1.50	0.36
	2	25.31	150	12.83	40.72	0.78	2.37	50.85	1.83	1.79	0.04
	3	28.92	500	9.39	53.44	0.74	1.86	46.73	2.44	1.66	0.78
E	1	25.80	200	12.83	30.00	0.75	2.66	62.81	2.18	1.78	0.40
	2	27.25	300	13.44	13.83	0.66	2.38	44.12	0.68	0.52	0.16
F	1	25.94	200	11.28	15.00	0.76	1.63	48.98	1.54	1.60	0.06
	2	21.89	300	12.89	22.89	0.66	2.35	53.86	1.68	1.38	0.30
G	1	25.59	300	11.00	18.89	0.76	1.39	41.32	1.62	1.65	0.03
	2	21.01	1000	10.94	40.61	0.63	3.10	45.24	2.29	2.26	0.03
H	1	23.10	500	13.67	81.83	0.84	2.69	57.15	3.12	3.22	0.10
I	1	19.74	1000	10.89	26.50	0.79	1.85	60.86	2.77	2.94	0.17
J	1	26.31	400	11.78	9.22	0.84	2.25	60.03	2.10	2.11	0.01
K	1	24.42	500	10.33	29.50	0.87	2.26	65.00	2.88	2.83	0.05
L	1	27.95	800	10.72	36.94	0.80	1.82	39.09	0.96	2.06	1.10

Average 0.25
*6.25 rai = 1 ha

losses. The prediction equations had $R^2 = 0.75$. The average header losses given by the estimation equation had an absolute difference of 0.25%.

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