DETERMINATION OF HARVESTING LOSSES, FIELD CAPACITY AND ENERGY CONSUMPTION FOR DIFFERENT RICE COMBINE HARVESTERS

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ABSTRACT

According to the type and specification of each combine harvester, losses, field capacities and energy required may vary. Hence, studying different parameters which may cause losses and affect combine performance are important. So, field evaluation to measure combine losses, fuel consumption and field capacity was conducted at International Rice Research Institute, Los Baños, Philippines during dry season 2014. Four different rice combine harvesters with different threshing systems and configurations including one head-feed combine (Kubota ER 232) and three whole-crop combines [Wintersteiger, CLAAS Crop Tiger: axial-tangential flow (TAF) and Thai combine] were assessed on split-split two level randomized block design with four replications. Each combine operated under two levels of forward speeds (lower and higher) to harvest two different rice varieties (NSIC RC222 and NSIC RC238). Measurements for each combine included major components of losses [shattering losses, blower/screen losses (rear-end losses) and unstrapped losses] and field capacity. Fuel consumption was recorded for Kubota and CLAAS combine. All combine Harvesters run under same harvesting condition. Results revealed that average values of shattering and unstrapped losses ranged from 1 to 24.11 and from 0.12 to 7.22 % of yield respectively. All combine harvesters lead up to cause higher shattering losses when operated at lower speeds compared to higher speeds. Maximum blower/screen losses (rear-end losses) recorded was 2.26 % of yield by using CLAAS to harvest NSIC RC238, while minimum value was 0.24 % of yield and obtained when Kubota harvested NSIC RC238 variety. The maximum averages of blower/screen losses (rear-end losses) value recorded with Wintersteiger and Thai combines were 1.04 and 1.58 % of yield respectively. Average harvesting capacity were 0.473, 0.424, 0.400 and 0.380 ha h^{-1} for Kubota, Thai, Wintersteiger and Class

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combine respectively when operated at higher forward speed to harvest both varieties. For CLAAS combine, fuel consumption varied from 52.481 to 100.191 l ha^{-1}, while for Kubota, fuel consumption varied from 7.396 to 29.586 l ha^{-1}. Minimum engine power required to run Kubota and its consumed energy were 7.94 hp and 23.37 kW.h ha^{-1} respectively when harvested NSIC RC238, maximum engine power required was 23.66 when Kubota used to harvest NSIC RC222 with 93.49 kW.h ha^{-1} consumed energy. For CLAAS, minimum engine power required was 27.66 hp to harvest NSIC RC238 at higher speed with 165.84 kW.h ha^{-1} consumed energy, while the maximum engine power required was 45.32 hp to harvest NSIC RC222 at lower speed with 316.6 kW.h ha^{-1} consumed energy.

Keywords: Combine harvesters, harvesting losses, rice crop, field capacity, energy required.

INTRODUCTION

Rice is the world's most important food staple and 90% of the rice-producing area is located in Asia. It is a major source of livelihood for farmers, especially in low-income and lower-middle-income countries ***(Dawe et al. 2010; Pandey et al. 2010)***. Rice combine harvesters are playing a more important role in harvesting and are being widely used. Now the sales and use of combine harvesters are expanding very rapidly in the Asian region, e.g number of combine harvesters increased from 947 in 2010 to 2935 units in 2012 in Cambodia ***(Saruth, 2011; MAFF, 2013)***. Number of combine harvesters recorded in Bangladesh was 100 in 2011 compared to 30 units in 2008 ***(Abdul-Wohab, 2011; Ahmed and Matin, 2008)***, Number of combine harvesters being used in Thailand is around 41143 and 600 is the yearly local production (***NSO, 2010)***. The percentage of rice harvested by combine reached 15 % in Vietnam and 10% in Philippines ***(Viet, 2012; Mariano et al., 2012)***. In Egypt, number of combine harvesters being used in 2008 was 3161 units according to Food and Agriculture Organization of the United Nations (FAO) ***(FAO, 2014)***. For countries which has higher mechanization index like Japan, Korea, China and India, the number of combine harvesters and the percentage of rice harvested area by them is higher. Different combine harvesters have been introduced with different specification, threshing and cleaning systems. Japan developed and introduced small head feed rice combines which are designed to harvest Japonica varieties and they were widely used in Japan, Taiwan, Korea and many countries ***(Chang, 1986)***. Thailand introduced a big axial flow thresher based combines with 130-190 hp diesel engine and uses cutterbar system of Western combines in its harvesting unit which considered big compared to other combines ***(Kalsirisilp and Singh, 1998)***. IRRI has been using it in its experimental farm in Los Baños, Philippines since mid-1990s ***(Gummert and Hien, 2013).*** CLAAS introduced different combine harvesters including small, medium and multi-purpose combine harvester e.g Crop Tiger to be operated in smaller size rice farms in Asia, and powered by 58-86 hp 4-cylinder diesel engines with different mobility systems (***CLAAS Vision, 1998)***. However, the major design concepts and use of all combine harvesters remain to minimize crop losses that occur while using the machine.

For losses tracking under different conditions, ***El-Nakib et al. (2003)*** used Kubota combine as a mechanical harvester of rice crop ***(Sakha 102)***. They found that header, threshing, separating and shoe losses increased with the increase of the forward speed and the decrease of grain moisture content. And also they found that optimum operating parameters for harvesting rice crop were, combine forward speed of 4.5 km h^{-1} and grain moisture content of 16.5 %. ***Badr (2005)*** indicated that increasing the forward speed from 1.0 to 4.0 km h^{-1} at a constant moisture content of 22 %, increased field capacity from 0.31 to 1.14 fed h^{-1} while decreased field efficiency from 89.3 to 82.7 % with using Yanmar combine. ***El-Sharabasy (2006)*** indicated that increasing machine forward speed from 1.5 to 3.0 km/h increased effective field capacity from 0.277 to 0.452; 0.251 to 0.382; 0.208 to 0.349 and 0.181 to 0.296 fed h^{-1} at different grain moisture contents of 21.45, 22.20, 23.12 and 24.60 %, respectively. ***Abdelmotaleb et al. (2009)*** showed that the increase of combine forward speed form 0.8 to 2.5 km h^{-1} leads to decrease the field efficiency from 84.96 to 62.35% at cutting height of 0.2 m using the combine without control system. The other cutting heights and combine systems had the same above mention trend. Other researchers examined field performance of different combine harvesters. ***Kalsirislip and Singh (1999)*** reported that in a combine equipped with a 3m width head stripper, field capacity and field efficiency were 0.66 ha h^{-1} and 74% for standing crop and 0.3 ha h^{-1} and 72% for lodged crop, respectively. ***Fouad et al. (1990)*** studied a self-propelled rice combine harvester and reported that raising travel speed from 0.8 to 2.9 kmh^{-1} increased grain losses but decreased field efficiency of the combine.

So, the main objective of this study was to evaluate different combine harvesters in rice field to track losses and variables may affect them, the evaluation included recoding the percentage of losses for different four combine harvesters and observing energy required for two whole-crop and head-feed combine harvesters.

MATERIALS AND METHODS

1. Site, Soil Specification and Harvesting Conditions

Field evaluation to measure combine losses, fuel consumption and field capacity was conducted at experimental farm within the Experimental Station of the International Rice Research Institute (IRRI) in Los Baños, Laguna, Philippines. The site has a slope of 1% with northeasterly aspect, and an elevation of 27 m above sea level. The soils are Lithic Haplustept ***(Soil Survey Staff, 2010)*** varying in texture from loam to clay and over-lying volcanic tuff evident at 0.3 m to 1.2 m depth. At harvesting time, wind speed was 2.7 m s^{-1} with direction to NNW. Mean temperature was 28.7 $^{\circ}$C with radiation of 21.8 MJ m^{-2} and 87.1 relative humidity (Climate Unit, Crop and Environmental Science Division, International Rice Research Institute).

The field was prepared and mechanically transplanted with two varieties of rice NSIC RC222 (a semi-dwarf, high yielding shattering lowland irrigated variety) and NSIC RC 238 with flood irrigation system along with the season. The site was historically cropped with paddy rice prior to the experiment. 50–60 kg seed ha^{-1} rate has been used to raise seedlings and planting on 18 December in 2013. Fertilizers were applied basally at 40 kg N ha^{-1}, 17 kg P ha^{-1}, and 33 kg K ha^{-1} as granular fertilizers, additional urea fertilizer was with totaling 150 kg N ha^{-1}.

Four different rice combine harvesters with different threshing systems and were operated to measure losses component which are shattering loss, blower/screen losses and unstrapped loss. Specifications of each combine used in the study are listed below in table 1:

Table1 1: Combines used in experiments and their specifications

Combine	Kubota	Wintersteiger	CLAAS	Thai combine
Type	head-feed	whole-crop	whole-crop	whole-crop (axial flow combine harvester)
Model	ER 323	Delta Plot combine	Crop Tiger 30 Terra Trac	KPH-22T
Total length, mm	3470	6000	5855	6300
All width, mm	1690	2200	2620	3200
Overall height, mm	1980	2750	2905	3470
Mass, kg	2800	3500	4270	9000
Engine	67 HP at 2700 rpm 3 cylinder vertical water cooled engine	84 HP 3.31 capacity turbo water cooled Perkins engine	86 HP BS-III emissions standard-cylinder water cooled engine	207 HP water cooled 6 cylinders, 24 valve engine
Fuel	Diesel			
Year in service	2	1	2	5
Threshing and cleaning systems	Threshing principle: Head feed with rasp bars Threshing cylinder: 550 mm-1760 mm re-thresher:195 mm-900 mm, Cleaner: chaffer sieve + fan (front blowing and rear suction) + two times vibrate	Threshing principle Concave :10 concave bars, threshing drum diameter: 350 mm, threshing drum width: 780 mm, speed adjustment: electrically adjustable, variator: 330 - 1900 rpm stepless beater bars 6 units, Shakers Area: 1.8 m^2, 2 drop stages, including suspended guide plates, cleaning blower hydraulically driven	Threshing principle: Tangential axial flow (TAF) With Pegteeth Cleaning system: forced air-cleaning fan, 2 speeds, 1200 and 1500 rpm, controlled by fan shutter, cleaning area: 1.24 m^2 (upper and lower sieves)	Threshing principle: axial flow Upper threshing tank :1615 mm, Paddy thresher diameter 560 mm, upper threshing tank can be separated

2. Losses Measurement

Losses measurements done for all combine harvesters when operated with advance low and high velocity selected by the operator using a speed selection lever and also measurable during operation by recording the time required for the harvester in a given distance.

To determine harvesting losses, catching frames made of sackcloth with 300 x 300 mm^2 to be placed between the rows of plants before harvesting the field. After harvesting, all the grains found on the frames are collected and weighed, this amount of grains represent the shattering losses (header losses) and in which rear-end losses are prevented from falling onto the ground in the wake of the harvester. Rear-end losses (blower/screen losses) were determined by collected all discharged straw by using a net carried by two people who followed the harvester and walking behind/beside the machine (Figure 1). The collected grain cleaned by hand to separate the grains that were blown over and its amount calculated. For third type of losses, rice grain that remained on standing straw after field harvesting were observed and collected to be the unstrapped loss.

Rear-end losses (blower/screen losses) **Shattering loss**

Figure 1: Two type of harvesting losses; rear-end losses and shattering losses

3. Experimental Design

Split-split two level randomized block design with four replications was used. Area of 36 x 100 m^2 was divided into two sub-plots 48 x 36 m^2 each, each sub-plot divided into 32 sub-sub-plots with 4.5 x 12 m^2 each. Combine harvester operated under two levels of forward speeds (lower and higher) to harvest two different rice varieties (NSIC RC222 and NSIC RC238) as the two study variables. All combine Harvesters run under same harvesting condition and components of combines kept constant including the reel rotational velocity, cutter bar speed, reel index, feed rate etc. Yield component sampling at maturity stage done for 0.3 x 2 rows area in four locations, while grain yield sampling done in 32 sub-sub-plots within 9 rows x 2.5 m area.

Fuel consumption of Kubota and CLAAS combine harvester was recorded using flow meter sensors attached to the engine. An electronic board was used to receive and save digital pulses sent by the flow meter sensors. One of the sensors was installed where fuel enters the injector pump; another flow meter was located where fuel returns to the tank. All fuel data recorded on the device memory and also manually recorded.

Power/energy requirement was identically based on fuel consumed. To estimate the engine power, the following formula was used (***Hunt, 1983***).

$$EP = Fc \times (\frac{1}{60 \times 60})PE \times L.C.V \times 427 \times \frac{1}{75} \times \frac{1}{1.36}\eta_{th}\eta_{m}$$

Where:

Fc: Fuel consumption, l/h.

PE: Density of diesel fuel kg/l (for Gas oil = 0.85 and Gasoline = 0.72)

L.C.V: the lower calorific value of fuel, (11000 k.cal/kg).

427: Thermo-mechanical equivalent, (kg.m/k.cal).

η_{thb}: Thermal efficiency of the engine (35 % for Diesel)

η_{m}: Mechanical efficiency of the engine (80 % for Diesel)

The consumed energy can be calculated as following:

$\text{Engine power} = 3.16\ Fc$, kW

Field capacity was calculated after recording harvesting time in specific area with speed and width. The experimental data was analyzed statistically by analysis of variance (ANOVA) method, critical difference at 1 and 5 per cent level of significance observed for testing significance of difference between the different treatments.

RESULTS AND DISCUSSION

1. Harvesting Losses

1.1.Shattering Losses

All combine harvesters tended to cause shattering losses under the two rice varieties and within the two ranges of forward speeds. Average value of shattering losses varied from 1 up to 24.11% of yield as minimum and maximum average value respectively. Higher shattering losses observed when all combine harvesters operated at lower speeds compared to higher speeds except for Thai combine (Figure 2a). This matching with the recommendation to adopt proper harvesting speed because when travel speeds are too slow may increase header loss due to an inconsistent flow of material or repeated working cycles at the header.

Using Thai combine, Kubota, Wintersteiger and CLAAS gave average of 22.44, 7.37, 6.88 and 6.33 % losses of yield as shattering losses respectively under different combines' forward speeds for NSIC RC222. While using same combines gave 17.43, 7.93, 4.36 and 9.16 % losses of yield as shattering losses respectively for NSIC RC238 (Figure 2b). It was clear from data that average values of NSIC RC238 shattering losses were less than NSIC RC222 when harvested by Thai and Wintersteiger combine, but with using both CLAAS and Kubota combines, the shattering losses in NSIC RC238 increased by 44.7% and 7.6 % respectively compared to rice variety NSIC RC222. That is may be because of lower grain moisture content at harvesting time for both verities which was 22.1 % in average.

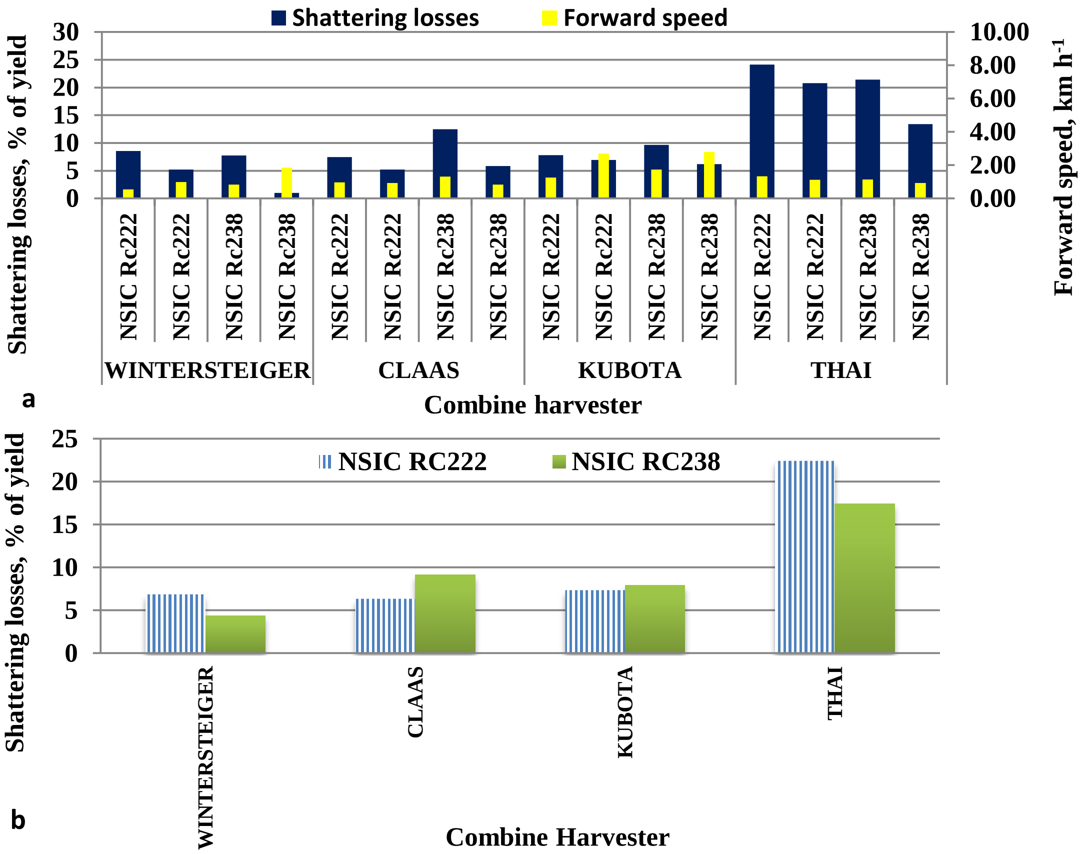

Figure 2: Effect of using different combines with their forward speeds on shattering losses (a) and for two rice varieties (b)

Analysis of variance (ANOVA), multiple comparison tests and model analysis (Type III SS) for shuttering losses showed that the standard deviation value was 7.687 with 0.736 coefficient of determination. Both combine harvester and harvesting speed had significant effect on shuttering losses, while verities have no significant effect on shuttering losses. For Comparison tests, the three combines; Wintersteiger, Kubota and CLAAS had significant differences to reduce shattering losses values against Thai combine but not with each other. There was significant differences too when they are operated in two different speed ranges, while the differences in shattering values was not significant within both varieties (Table 2).

Table 2: Multiple comparison tests for the variables: Tukey (HSD) / Fisher (LSD) analysis of the differences between groups with a confidence range of 95 % for shattering loss

Variable	R (coefficient of correlation)	R^2 (coefficient of determination)	R^2adj. (adjusted coefficient of determination)	Mean	Standard deviation
Shattering loss	0.858	0.736	0.654	10.212	7.687
Comparison tests for the variable: Harvester					
Categories	Difference	Standardized difference	Critical value HSD/Fisher (LSD)	Pr. > Diff Tukey (HSD) /Fisher (LSD)	Significant
Thai * Wintersteiger	13.152	8.224	2.661/2.011	< 0.0001	Yes
Thai * Kubota	11.658	7.289	2.661/2.011	< 0.0001	Yes
Thai * CLAAS	11.560	7.228	2.661/2.011	< 0.0001	Yes
CLAAS * Wintersteiger	1.592	0.996	2.661/2.011	0.753/0.324	No
CLAAS * Kubota	0.098	0.061	2.661/2.011	1.000/0.951	No
Kubota * Wintersteiger	1.495	0.934	2.661/2.011	0.787/0.355	No
Comparison tests for the variable: variety, Tukey (HSD) and Fisher (LSD)					
NSIC RC238 * NSIC RC222	0.988	0.874	2.011	0.387	No
Multiple comparison tests for the variable: Speed, Tukey (HSD) and Fisher (LSD)					
S1* S2	6.346	5.612	2.011	< 0.0001	Yes

1.2.Rear-end and Unstrapped Losses

For both rear-end losses and unstrapped losses, there was no clear trend for losses variation with the forward speed, as rear-end losses depend more on the threshing and cleaning systems and their components. Data showed that maximum rear-end losses recorded was 2.26 % of yield by using CLASS to harvest NSIC RC238, while minimum value was 0.24 % of yield and obtained when Kubota harvested NSIC RC238. The maximum averages rear-end losses value recorded with Wintersteiger and Thai combines were 1.04 and 1.58 % of yield respectively (Table 3).

Although, the unstrapped losses not correlated to combines entire components, considerable amount of losses recorded and even higher than rear-end losses in some plots, 4.19 % of yield unstrapped losses observed with harvesting NSIC RC238 by Thai combine. Grand averages of unstrapped losses values under all combines for both varieties were 2.71, 2.35, 1.21 and 1.01 for Thai, Wintersteiger, Kubota and CLAAS respectively (Table 3 and Figure 3). A trend of increasing unstrapped losses appeared when NSIC RC222 got harvested at higher speed by Thai, Wintersteiger and Kubota, which could be related to unfavorable high harvesting speed, but still cannot be a general trend, same time unstrapped losses observed in-between harvesting width as well as in both sides of each combine, that is may a reason to involve the drivers and their abilities to control the harvesting path.

Table 3: Rear-end and unstrapped losses for different combine harvesters

Combine types	Rice Varieties	Average Speed, km h^{-1}	Average Rear-end losses, %	Average Unstrapped Losses, %
Wintersteiger	NSIC RC222	0.55	1.00	2.12
	NSIC RC222	0.99	0.93	2.96
	NSIC RC238	0.84	1.04	3.03
	NSIC RC238	1.85	0.85	1.30
Claas	NSIC RC222	0.96	1.76	2.09
	NSIC RC222	0.93	0.50	0.16
	NSIC RC238	1.31	2.26	1.29
	NSIC RC238	0.84	1.49	0.48
Kubota	NSIC RC222	1.25	1.03	0.82
	NSIC RC222	2.71	1.15	2.35
	NSIC RC238	1.74	0.24	0.77
	NSIC RC238	2.81	1.05	0.90
Thai	NSIC RC222	1.33	0.59	2.40
	NSIC RC222	1.12	1.23	2.97
	NSIC RC238	1.14	1.14	4.19
	NSIC RC238	0.94	1.58	1.30

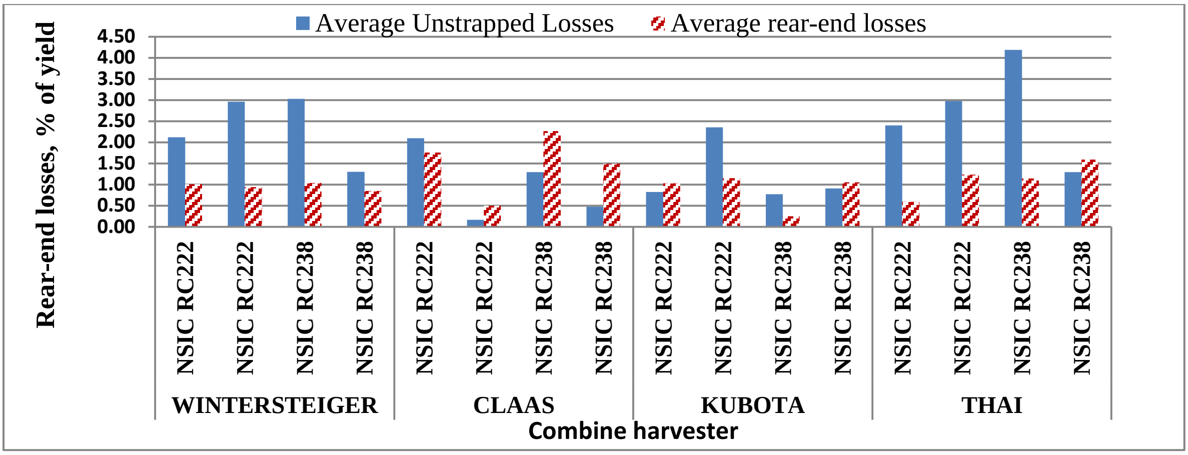

Figure 3: Rear-end and unstrapped losses for different combine harvesters

Model analysis for rear-end losses showed no significant effects for the the variables, the standard deviation value was 0.718 with 0.558 coefficient of determination. Comparison tests (LSD) showed no trend for significant differences in rear-end losses values within the combine, also there was no significant differences in the value of rear-end losses either with the two speed ranges or varaieties (Table 4).

Table 4: Multiple comparison tests for the variables: Tukey (HSD) / Fisher (LSD) analysis of the differences between groups with a confidence range of 95 % for Rear-end loss (Threshing loss)

Variable	R (coefficient of correlation)	R^2 (coefficient of determination)	R^2adj. (adjusted coefficient of determination)	Mean	Standard deviation
Rear-end loss (Threshing loss)	0.747	0.558	0.419	1.162	0.718
Comparison tests for the variable: Harvester					
Categories	Difference	Standardized difference	Critical value HSD/Fisher (LSD)	Pr. > Diff Tukey (HSD) /Fisher (LSD)	Significant (HSD)/Fisher (LSD)
CLAAS * Kubota	0.631	3.263	2.661/2.011	0.011/0.002	Yes
CLAAS * Wintersteiger	0.500	2.584	2.661/2.011	0.060/0.013	No/yes
CLAAS * Thai	0.220	1.137	2.661/2.011	0.668/0.261	No
Thai * Kubota	0.411	2.125	2.661/2.011	0.160/0.039	No/ yes
Thai * Wintersteiger	0.280	1.446	2.661/2.011	0.478/0.155	No
Wintersteiger * Kubota	0.131	0.679	2.661/2.011	0.904/0.500	No
Comparison tests for the variable: variety, Tukey (HSD) and Fisher (LSD)					
NSIC RC238 * NSIC RC222	0.099	0.725	2.011	0.472	No
Multiple comparison tests for the variable: Speed, Tukey (HSD) and Fisher (LSD)					
S1 * S2	0.049	0.358	2.011	0.722	No

For unstrapped losses, the standard deviation value was 3.119 with 0.305 coefficient of determination. No significant effect observed with varaiables same as no significant differences. Except that (LSD) Comparison tests showed advanges of using both CLAAS and kubota to reduce unstarrped losses compared to Thai combine (Table 5).

Table 5: Multiple comparison tests for the variables: Tukey (HSD) / Fisher (LSD) analysis of the differences between groups with a confidence range of 95 % for unstrapped loss.

Variable	R (coefficient of correlation)	R^2 (coefficient of determination)	R^2adj. (adjusted coefficient of determination)	Mean	Standard deviation
Unstrapped loss	0.552	0.305	0.083	2.163	3.119
Comparison tests for the variable: Harvester					
Categories	Difference	Standardized difference	Critical value HSD/Fisher (LSD)	Pr. > Diff Tukey (HSD)/Fisher (LSD)	Significant (HSD)/Fisher (LSD)
Thai * CLAAS	2.590	2.413	2.663/2.012	0.088/0.020	No/yes
Thai * Kubota	2.441	2.312	2.663/2.012	0.110/0.025	No/yes
Thai * Wintersteiger	0.996	0.943	2.663/2.012	0.782/0.350	No
Wintersteiger * CLAAS	1.594	1.486	2.663/2.012	0.454/0.144	No
Wintersteiger * Kubota	1.445	1.369	2.663/2.012	0.525/0.178	No
Kubota * CLAAS	0.149	0.139	2.663/2.012	0.999/0.890	No
Comparison tests for the variable: variety, Tukey (HSD) and Fisher (LSD)					
NSIC RC222 * NSIC RC238	0.216	0.287	2.012	0.776	No
Multiple comparison tests for the variable: Speed, Tukey (HSD) and Fisher (LSD)					
S1 * S2	0.664	0.882	2.012	0.382	No

2. Harvesting Capacity

Average harvesting capacities (ha h^{-1}) have been recorded for all combine harvesters. Maximum harvesting capacity recorded was 0.473 ha h^{-1} for Kubota when harvesting NSIC RC238 variety with higher forward speed, because of faster forward speed (2.4 km h^{-1}) compared any other combine. Minimum value of average harvesting capacity was 0.104 ha h^{-1} and recorded with using Wintersteiger for harvesting NSIC RC238 with low forward speed (Figure 4). All harvesting capacities tended to logic trend with speed and width, but in some cases, CLAAS combine had plugging in the feeder house due to overfeeding when speed increased in some plots, that's the reason that harvesting capacity in case of higher speed appeared to be lower than its harvesting capacity with lower forward speed due the additional time needed for re-adjusting.

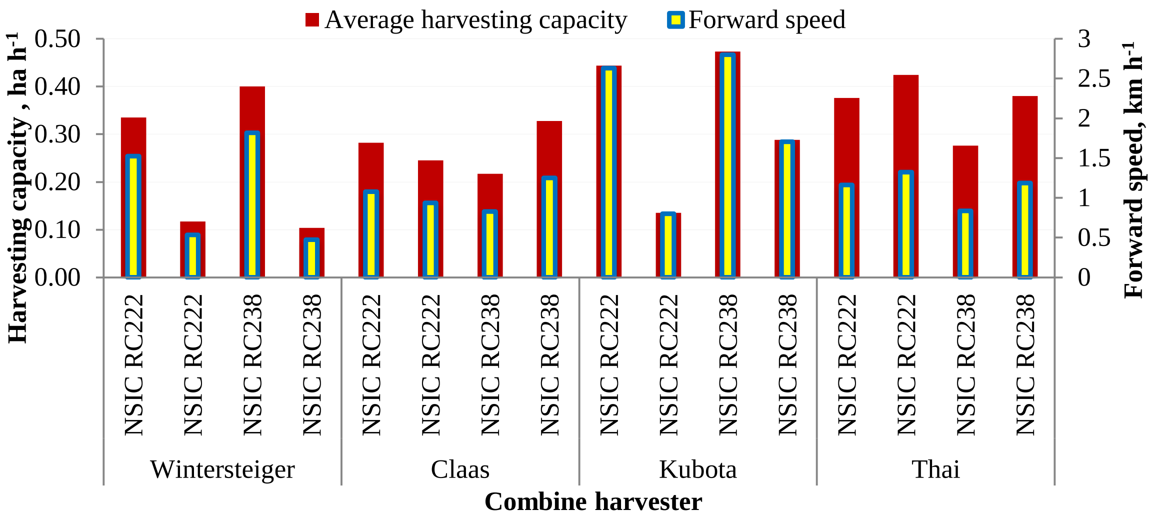

Figure 4: Average values of harvesting capacities for different combine harvesters

Analysis of variance (ANOVA), multiple comparison tests and model analysis (Type III SS) for harvesting capacity showed that the standard deviation value was 0.116 with 0.871 coefficient of determination. Both combine harvester and harvesting speed had significant effect on harvesting capacity, while varieties have no significant effect on harvesting capacity. Even comparison tests showed significant differences in harvesting capacity values with both varieties, but there was no significant effect from ANOVA. Also, there was significant differences in harvesting capacity values with two harvesting speed ranges. Kubota Combine showed significant differences and advance for higher harvesting capacity compared to Wintersteiger and CLAAS combines, while Wintersteiger and CLAAS showed significant differences with better harvesting capacity compared to Thai (Table 6).

3. Fuel Consumption, Engine Power and Consumed Energy

Grand average of fuel consumption rate by CLAAS combine was 65.012 l ha^{-1}, which is more than average fuel consumption rate for Kubota by 71.6 % under different forward speeds and varieties. Generally, there are no significant differences in CLAAS fuel consumption either its running under high/ low forward speeds, but in Kubota fuel consumption data showed lower fuel consumption with higher speed compared to lower speeds (Figure 5).

Table 6: Multiple comparison tests for the variables: Tukey (HSD) / Fisher (LSD) analysis of the differences between groups with a confidence range of 95 % for harvesting capacity

Variable	R (coefficient of correlation)	R^2 (coefficient of determination)	R^2adj. (adjusted coefficient of determination)	Mean	Standard deviation
Harvesting capacity	0.933	0.871	0.831	0.303	0.116
Comparison tests for the variable: Harvester					
Categories	Difference	Standardized difference	Critical value HSD/Fisher (LSD)	Pr. > Diff Tukey (HSD) /Fisher (LSD)	Significant (HSD)/Fisher (LSD)
Kubota * Wintersteiger	0.117	6.943	2.661/2.011	< 0.0001	Yes
Kubota * CLAAS	0.094	5.610	2.661/2.011	< 0.0001	Yes
Kubota * Thai	0.013	0.745	2.661/2.011	0.878/0.460	No
Thai * Wintersteiger	0.104	6.198	2.661/2.011	< 0.0001	Yes
Thai * CLAAS	0.082	4.865	2.661/2.011	< 0.0001	Yes
CLAAS * Wintersteiger	0.022	1.333	2.661/2.011	0.547/0.189	No
Comparison tests for the variable: variety, Tukey (HSD) and Fisher (LSD)					
NSIC RC238 * NSIC RC222	0.026	2.189	2.011	0.034	Yes
Multiple comparison tests for the variable: Speed, Tukey (HSD) and Fisher (LSD)					
S1 * S2	0.072	6.086	2.011	< 0.0001	Yes

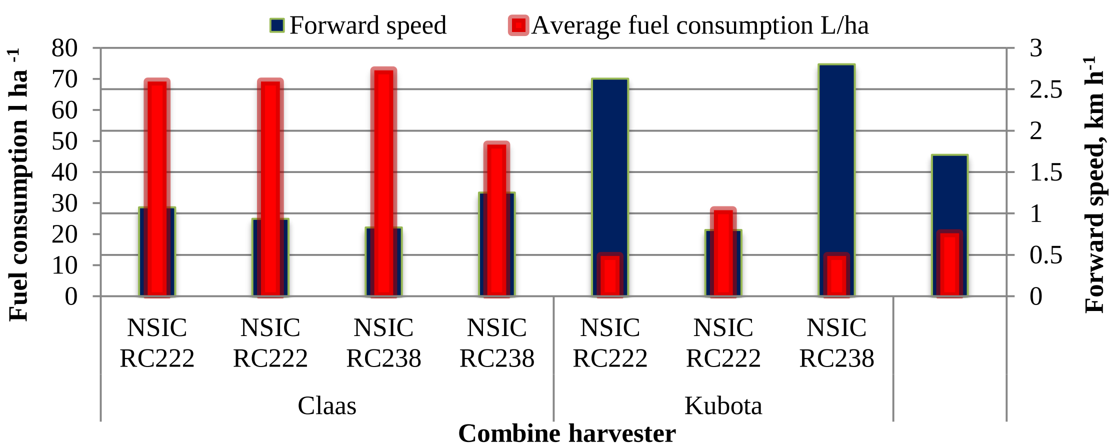

Figure 5: Fuel consumption

As the fuel consumed by CLAAS was higher, the required engine power and consumed energy were higher too, the minimum engine power required to run Kubota and consumed energy were 14.27 hp 23.37 kW.h ha^{-1} respectively when harvested NSIC RC238 and maximum engine power required was 42.55 hp when Kubota used to harvest NSIC RC222 with 93.49 kW.h ha^{-1} consumed energy. Kubota' lower and higher values of engine power and consumed energy obtained at higher harvesting speed. For CLAAS, minimum engine power required was 49.74 hp to harvest NSIC RC238 at higher speed with 165.84 kW.h ha^{-1} consumed energy, while the maximum engine power required was 81.50 hp to harvest NSIC RC222 at lower speed with 316.6 kW.h ha^{-1} consumed energy. Average engine power and consumed energy for both combine harvesters needed to harvest two varieties under two ranges of forward speed presented as in Figure 6 and Table 7.

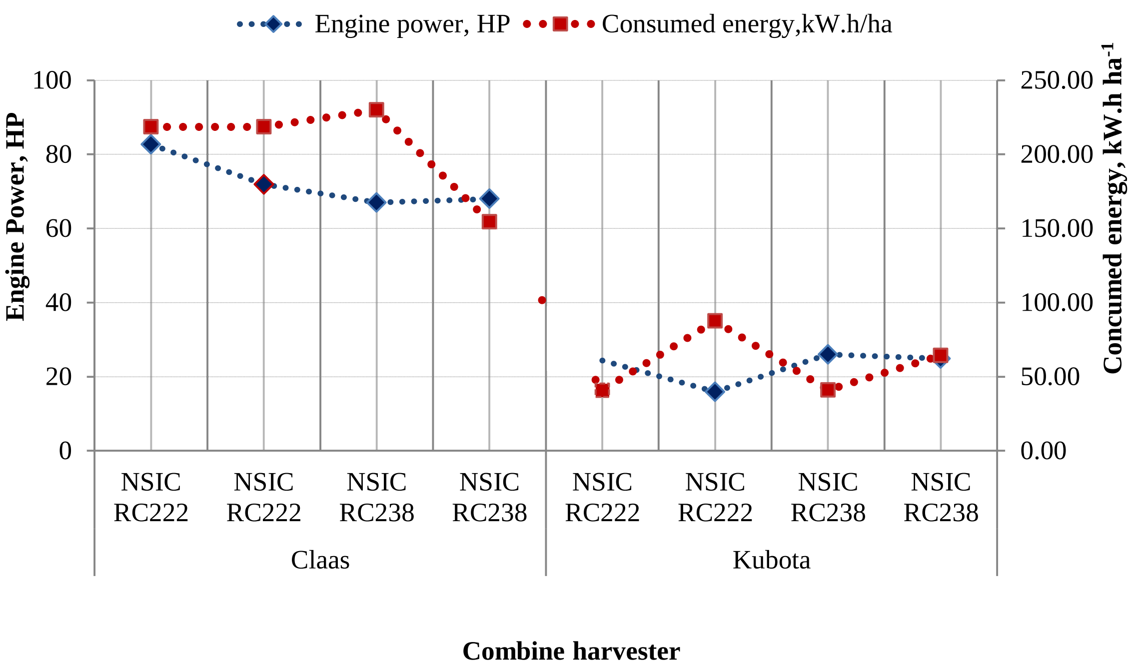

Figure 6: Engine power and consumed energy

Table 7: Average engine power and consumed energy for both combine harvesters needed to harvest two varieties under two ranges of forward speed

Combine	Average Speed (km h^{-1})	Rice varieties	Average fuel consumption, L h^{-1}	Average Engine power, hp (kW)	Average Consumed energy, kW.h ha^{-1}
CLAAS	**s1 (1.08)**	**RC 222**	19.50	82.64 (61.62)	218.61
	s2 (0.94)	**RC 222**	16.96	71.88 (53.60)	218.61
	s1(0.83)	**RC 238**	15.81	66.99 (49.96)	229.91
	s2 (1.25)	**RC 238**	16.03	67.95 (50.67)	154.53
Kubota	**s1 (2.63)**	**RC 222**	5.75	24.38 (18.18)	40.90
	s2 (0.80)	**RC 222**	3.75	15.90 (11.86)	87.65
	s1 (2.80)	**RC 238**	6.13	25.96 (19.36)	40.90
	s2 (1.71)	**RC 238**	5.87	24.86 (18.54)	64.28

s1: high forward speed   s2: low forward speed

ANOVA showed highly significant effect of the harvester as the data of fuel consumption are varying between the two combines with no significant effect for harvesting speed and varieties. Standard deviation value was 27.208 with 0.842 coefficient of determination. Same trend obtained with comparison tests (Table 8).

Table 8: Multiple comparison tests for the variables: Tukey (HSD) / Fisher (LSD) analysis of the differences between groups with a confidence range of 95 % for fuel consumption.

Variable		R (coefficient of correlation)	R^2 (coefficient of determination)	R^2adj. (adjusted coefficient of determination)	Mean	Standard deviation
Fuel consumption		0.918	0.842	0.796	41.748	27.208
Comparison tests for the variable: Harvester						
Categories		Difference	Standardized difference	Critical value HSD/Fisher (LSD)	Pr. > Diff Tukey (HSD) /Fisher (LSD)	Significant (HSD)/Fisher (LSD)
CLAAS * Kubota		46.514	10.709	2.064	< 0.0001	Yes
Comparison tests for the variable: variety, Tukey (HSD) and Fisher (LSD)						
NSIC RC 222 * NSIC RC 238	6.024		1.387	2.064	0.178	No
Multiple comparison tests for the variable: Speed, Tukey (HSD) and Fisher (LSD)						
S1 * S2	0.416		0.096	2.064	0.924	No

CONCLUSIONS

Both combine harvester type and harvesting speed had significant effect on shattering losses, while both used varieties have no significant effect on shattering losses. Even with Thai combine, the differences in shattering losses for both varieties were higher than the other combines but without significance. For both rear-end losses and unstrapped losses, there was no clear trend for losses variation with the forward speed, as rear-end losses depend more on the threshing and cleaning systems and their components. All harvesting capacities tended to have its logic trend with the speed and width, but in some cases were varied due to field operational problems. With CLAAS combine, fuel consumption was higher than the amount consumed by Kubota, so, minimum engine power required to run Kubota and its consumed energy were lower too.

This study gave moderate understanding of combine's operating parameters in actual conditions to be considered to minimize losses. Determination of combine's fuel efficiency and field capacity is important for saving energy and avoidance of GHG emissions while giving farmers the ability to choose between different combine harvesters according to their conditions and needs. However, the combines were taken as used by operators and their settings were not optimized with respect to maximizing capacity and minimizing losses before the trials, in addition to unskilled operators, improper maintenance, and in-field drawbacks, so it is highly recommended to conduct more trials to track these different issues.

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الملخص العربي

تحديد فواقد الحصاد والكفاءه الحقلية والطاقه المطلوبه لآلات الحصاد المجمعه لمحصول الأرز

د. رشاد عزيز حجازي*

الهدف الرئيسي للبحث هو تحديد نسب الفاقد من الأنتاجية لآلات الحصاد المجمعه (كومباين) لمحصول الأرز والتي تتكون من ثلاث فواقد هما بعثره الحبوب (النثر) وفواقد الحبوب الناتجه مع قش الأرز خلف الكومباين والفواقد الناتجه من بقايا الحبوب داخل السنابل دون حصاد. كذلك اشتملت الدراسة علي تحديد السعه الحقليه النظريه لكل آله حصاد مع حساب استهلاك الوقود لنوعين فقط من آلات الحصاد هما كوبوتا وكلاس. وتم اجراء التجارب في المزرعه البحثيه للمركز الدولي لبحوث الأرز في الفلبين.

وتم دراسة تـأثير كل من أربع ألات حصاد (كوبوتا، كلاس، وينترشتيجار، وآله الحصاد التايلاندية) وسرعه تقدم كل آله كمدي للسرعات المنخضه والعاليه وصنف محصول الأرز المنزرع (صنفين NSIC RC 222 و NSIC RC 238) علي نسبه الفواقد والسعه النظريه والطاقه المطلوبه للحصاد. وتم تشغيل كل اللآلات في نفس اليوم وتحت نفس الظروف ومتوسط محتوي رطوبي واحد عند الحصاد (٢٢,١ %).

<u>وقد أوضحت النتائج ان:</u>

كل آلات الحصاد أعطت نسب فواقد لبعثره الحبوب (النثر) من الأنتاجيه الكليه لكلا الصنفين (NSIC RC 222 و NSIC RC238) وعند سرعات مختلفه . متوسط فواقد البعثره كانت ما بين ١ الي ٢٤,١١ % من الأنتاجيه كاقل قيمه واعلي قيمه علي الترتيب. النسب العليا من الفواقد لوحظت مع السرعات الأقل ما عدا بعض القياسات لآله الحصاد التايلانديه. استخدام كلا من آله الحصاد التايلاندية، كوبوتا، وينترشتيجار، وكلاس أعطي متوسط نسبه فواقد ٢٢,٤٤ و ٧,٣٧ و ٦,٨٨ و ٦,٣٣ % علي الترتيب عند حصاد الأرز صنف NSIC RC 222 تحت سرعات مختلفه بينما متوسط نسب الفواقد لصنف الأرز الأخر لنفس الآلات كانت ١٧,٤٣ و ٧,٩٣ و ٤,٣٦ و ٩,١٦ % علي الترتيب. كلا من نوع آله الحصاد والسرعات كان لهما تاثير معنوي علي الفواقد بعكس صنفي الأرز.

لم يكن هناك اتجاه معين لكلا من فواقد الحبوب الناتجه مع قش الأرز خلف الكومباين والفواقد الناتجه من بقايا الحبوب داخل السنابل دون حصاد مع تغير السرعات. حيث ان الفواقد المجمعه من خلف الكومباين تعتمد اكثر علي كفاءه اجهزه الفصل والتنقيه. النتائج ظهرت ان اعلي قيمه

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لفواقد فواقد الحبوب الناتجه مع قش الأرز كانت ٢,٢٦% عند حصاد صنف الأرز NSIC RC238 بكومباين كلاس بينما اقل قيمه كانت ٠,٢٤ % عند استخدام كوبوتا لحصاد نفس الصنف.

الفواقد الناتجه من بقايا الحبوب داخل السنابل دون حصاد أظهرت قيماً اعلي في بعض الاحيان من حتي من فواقد الحبوب الناتجه مع قش الأرز خلف الكومباين. فمثلا عند استخدام آله الحصاد التايلانديه مع صنف NSIC RC238 كانت تلك الفواقد ٤,١٩ % من الانتاجية. متوسط الفواقد الناتجه من بقايا الحبوب داخل السنابل دون حصاد للأربع آلات حصاد المستخدمه كانت ٢,١٧ و ٢,٣٥ و ١,٢١ و ١,٠١ لأله الحصاد التايلانديه، وينترشتيجار، كوبوتا ، وكلاس علي الترتيب. أعلي سعه حقليه للحصاد كانت ٠,٤٣٧ هكتار/ساعة عند استخدام كوبوتا لحصاد صنف الأرز NSIC RC238وذلك للسرعه العاليه للكومباين (٢,٤ كم/ساعه) مقارنه باآلات الأخري. وفي المقابل اقل سعه حقليه للحصاد كانت ٠,١٠٤ هكتار/ساعة للسرعه المخفضه لكومباين وينترشتيجار عند حصاد نفس صنف االأرز. المتوسط العام لاستهلاك الوقود لكومباين كلاس كان ٦٥,٠١٢ لتر/هكتار عند السرعات المختلفه ولصنفي الأرز. ولآله الحصاد كوبوتا كان استهلا الوقود اقل بمقدار ٧١,٦ % عن كلاس وكذلك كانت القدره المطوبة للمحرك والطاقه المستخدمة اقل.