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Performance of Mid-Size Combine Harvester of Grain Corn on the Field Efficiency and Energy Consumption at the Northern Johor of Malaysia

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ABSTRACT

A mid-size combine harvester with 2.76 m reaping width and 103.53 hp engine output has been employed in grain corn production, especially by small-scale grain corn farmers. This study attempted to determine field performances of a typical mid-size combine harvester by measuring its effective field capacity (EFC), field efficiency (FE), fuel consumption (FC) and field machine index (FMI). Different types of energy inputs such as fuel, machinery, human, included direct, indirect, renewable and non-renewable energy involved in grain corn harvesting were also measured. The field measurements were carried out in 3 ha of grain corn farm, under similar field conditions using a typical mid-size combine harvester. The average values of EFC, FE, FC and FMI for the mid-size combine harvester were found to be 0.23 ha/h, 34.97%, 37.25 lit/ha and 0.91, respectively. The average equivalent energy values of fuel, machinery and human energy were 1780.70 MJ/ha, 587.73 MJ/ha and 8.53 MJ/ha, respectively. The average values of the direct and indirect energy were 1789.23 MJ/ha and 587.73 MJ/ha, respectively. The average values of renewable and non-renewable energy were recorded at 8.53 MJ/ha and 2368.42 MJ/ha, respectively. The mid-size combine

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harvester investigated in this study exhibited good field performance characteristic using a reasonable amount of energy consumption as compared to harvesting operation for other grain crops. From the results, it can be concluded that good practice in harvesting operation could improve field performance, and minimise operational costs and energy consumption.

Keywords: Crop, farm, fuel consumption, machinery, speed, working width

INTRODUCTION

Corn or maize (*Zea mays* L.) is the third largest agricultural crop grown in the world after wheat and rice (Nor et al., 2019). In Southeast Asia, among the main producing countries for grain corn is Indonesia, Philippine, Thailand and Vietnam with the production values of 11.9, 8.2, 5.3 and 3.95 million tons, respectively (USDA, 2018). In Malaysia, however, there is no commercial corn production for feed that has been established. In 2017, Malaysia imported around 3.7 million tons of grain corn valued about RM3 billion (US$ 737 million) (UNC, 2019). In 2016, Malaysia imported 4.1 million tons of grain corn from Thailand, India, Australia, Brazil, Argentina, Paraguay and the United States of America (UNC, 2019). Due to this huge amount of the import value, the Malaysian government has taken initiatives to encourage local production of 30% grain corn to fulfil the demand for domestic consumption (Nor et al., 2019).

One of the strategies to increase the production of field corn is by utilizing a proper information, management, technology and mechanization system (Aribe et al., 2019). Mechanization technology in agriculture which is economical and suitable to local physical and climatic conditions could potentially offer a long-term sustainable production for field corn, especially in dealing with labour shortage (Hamid et al., 2018). A proper mechanization package is also important to ensure grain corn can be harvested in a timely manner, avoiding grain losses due to unfavourable weather condition at a farm (Busato et al., 2007). Hence, the usage of a mid-size combine harvester by farmers could be considered as a good step to overcome labour shortage and improve operational time of machine in the corn fields (Hamid et al., 2018).

The analysis and prediction of agricultural machinery performance are essential in machinery management. The field performance and energy consumption are two important parameters in determining the efficiency and field capacity of a combine harvester (Busato et al., 2007). The working time required to perform any agricultural operation mostly depends on the design and technological parameters of the machinery used. For example, an increase in machine's working width and speed could increase the field efficiency and reduce the working time (Sarauskis et al., 2014). The working pattern during harvesting also has a great influence on the total time of some additional activities that are computed in the field (Busato et al., 2007). Although some of the non-productive activities are unavoidable, optimising field performance is intended to minimise the sum of these non-productive activities (Henrichsmeyer & Ohls, 1995). Minimisation of the non-productive time, fuel consumption, in-field travelled distance, or the excessive wheeling of the field, may result in significant economic and environmental benefit (Bochtis et al., 2007).

Energy efficiency in machinery management is also one of the significant factors in agricultural production (Canakci et al., 2005). Efficient use of energy may increase productivity, profitability, sustainability and competitiveness of agricultural sector (Singh et al., 2002). Total physical energy input consists of human power, animal power, machinery power, electricity and fuel consumptions. In general, energy requirements in agriculture can be divided into two groups: direct and indirect energy (Ozkan et al., 2004a). Direct energy is consumed in the farm, in the form of energy products, such as fuel, lubricants and labour. Whereas, indirect energy is consumed outside the farm boundaries to produce any input used in the farm such as machinery and chemicals (Gemtos et al., 2013). The ability to identify and quantify different form of energies involved in field corn harvesting may help farmers to increase energy efficiency, thus minimise the production cost.

However, there are insufficient scientific researches that have been accomplished to quantify field performances and energy consumption for a mid-size combine harvester for harvesting grain corn in Malaysia. Therefore, the goal of this research is to evaluate the field performances and energy consumption for a typical mid-size combine harvester utilized for grain corn harvesting under Malaysian farm condition. The specific objective is to measure effective field capacity, field efficiency, human, fuel and machinery energy.

MATERIALS AND METHODS

Study Area

This research was conducted at a private field corn located in Labis, Johor, Malaysia (2^o21’39” N – 102^o 56’ 13” E). From the entire farm area (approximately 10 ha), 3 ha of the farm area which consisted of four plots were randomly selected for data collection during two consecutive dry harvesting seasons. The area of each plot was 0.75 ha consisting of three subplots (0.25 ha), which divided according to CRD (completely randomized design) method. All harvested plots were adjacent to each other in the same location and subjected to the same weather (sunny day) and terrain slopes ranging from 0^o to 30^o during harvest. The principal soil type in terms of soil texture found in this area was sandy loam. The area for each subplot was measured using measuring tape (Smith et al., 1994).

Combine Harvester

A mid-size combine harvester selected in this study (2.76 m reaping width and 103.53 hp engine output) was manufactured by Kubota (DC 105X) (Figure 1 & 2). This model was predominantly used by Malaysian Department of Agriculture (DOA) and National Farmers’

Association (NAFAS) for grain corn harvesting in their trial plots. The specification of the mid-size combine harvester is shown in Table 1.

Figure 1. Mid-size combine harvester in operation (model Kubota DC 105X)

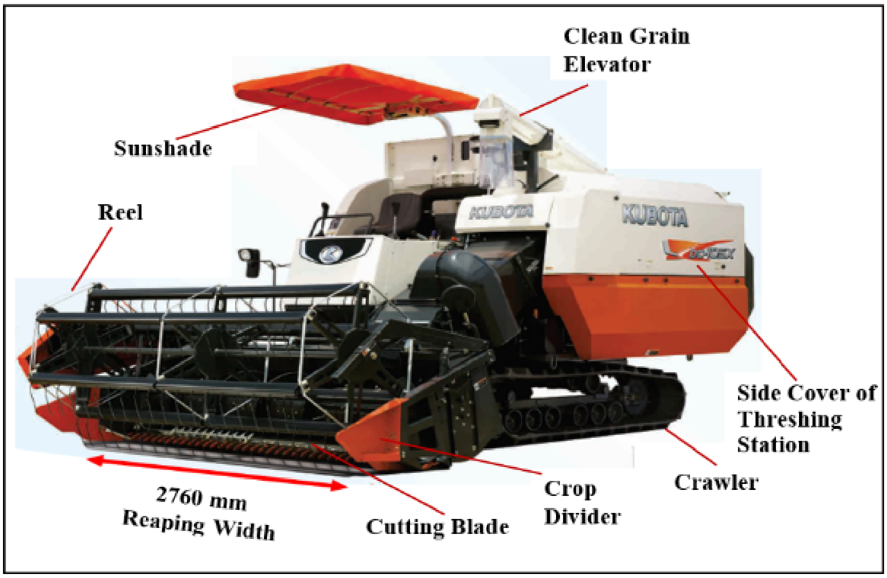

Figure 2. Typical parts of mid-size combine harvester (model Kubota DC 105X) (Sime Kubota Sdn Bhd, 2019)

Table 1
Specification of mid-size combine harvester for grain corn harvesting

Specification	Value
Brand	Kubota
Model	DC 105X-V3800DI-TIE2-CT
Overall length, mm	5460
Overall width, mm	3045
Overall height, mm	3040
Minimum ground clearance, mm	325 to 425
Weight, kg	4630
Total displacement, cc	3769
Engine output, kW	77.2
Rotation speed, rpm	2600
Fuel	Diesel
Fuel tank capacity, lit	105
Reaping width, mm	2760
Blade width, mm	2667
Grain tank capacity, lit	2350
Operator	1 person

Measurement of Operational Times

The time taken for each task involved during harvest operation were recorded manually using a stopwatch. These tasks included the harvesting time (time spent in performing the actual harvesting operation by cutting the plant), cornering and reversing time (time spent in turning and by the combine harvester without cutting the plant), unloading time (time spent in unloading the grain tank of the combine harvester and going to or from corn conveying trucks) and others (time taken in refuelling, adjusting or setting the machine). The total field time represents the time spent when a combine harvester engine was turned on, run and turned off once the job was completed (Olt et al., 2019). The data were used to compute the field performances which included forward speed (FS), effective field capacity (EFC), field efficiency (FE) and field machine index (FMI). FS of the combine harvester was obtained by recording the time taken to travel at a measured distance. The distance was measured with a measuring tape and the time was counted using a stopwatch. Such procedure was carried out in 12 repetitions to have the average theoretical speed by dividing the summation of total value of speed for all rows by the number of rows (Smith et al., 1994).

Determination of Fuel Consumption

The fuel consumption for the mid-size combine harvester was determined by measuring the difference of the fuel inside the fuel tank before and after the operation. The measurement of fuel consumption was conducted by refilling the fuel tank back to its full capacity after the harvesting operation using a measuring cylinder for each harvesting replications (Amponsah et al., 2017). The fuel consumption for each subplot was measured and the data characterizing fuel consumption were compared in lit/ha. The comparison of fuel consumption in lit/ha was a simple and cost-effective way to measure the fuel consumption of agricultural machinery (Jokiniemi et al., 2012).

Determination of Field Efficiency

Field efficiency (FE) is defined as the percentage of the time when the machine is operated at its full rated speed and width in the field under actual working condition (Nasri et al., 2016). FE describes how effective the time is spent to do the work and it becomes the ratio between the harvester's productivity under actual working conditions and the theoretical maximum possible productivity (Grisso et al., 2004). The FE is calculated based on the effective field capacity (EFC) and theoretical field capacity (TFC). EFC means the ability of a combine harvester to harvest crop under the actual field condition while TFC is a theoretical field capacity which was obtained from the width of machine and multiplied with the average forward speed (FS) during the field work (Zhou, 2012). The FE, TFC and EFC are calculated using Equation 1-3 (ASABE, 2005).

$$\mathrm{FE} = \frac{\mathrm{EFC}}{\mathrm{TFC}} \qquad [1]$$

Where FE is field efficiency (%), EFC is an effective field capacity (ha/h) and TFC is a theoretical field capacity (ha/h).

$$\mathrm{TFC} = \frac{\mathrm{W} * \mathrm{S}}{10} \qquad [2]$$

Where W is width of machine (m) and S is speed of machine (km/h).

$$\mathrm{EFC} = \frac{\mathrm{A}}{\mathrm{T}} \qquad [3]$$

Where A is the harvested area (ha) and T is working time (h) which represents time spent in performing the operation from the beginning to the end which includes harvesting, turning, unloading and others for instance like machine setting, adjustment and refuelling.

Determination of Field Machine Index

Field machine index (FMI) is the index indicating the turning effectiveness of a combine harvester (Equation 4) (Wagiman et al., 2019).

$$\mathrm{FMI} = \frac{\mathrm{EOT}}{(\mathrm{EOT} + \text{Turning time})} \qquad [4]$$

Where EOT is effective operating time which means harvesting (h). Turning time includes cornering and reversing time is non-productive time (h).

Energy Sources of Field Corn Harvesting

Energy Conversion Coefficient. The recorded farm inputs namely machinery, fuel and human utilized during the harvesting operation were converted into equivalent energy values in MJ/ha by using specific conversion coefficients. Energy conversion coefficient is a value which expresses the energy input expended in the production and distribution of a unit physical material (Elsoragaby et al., 2019a). The equivalent energy sources of the harvesting operation in grain corn production were estimated by classical mathematical Equation 5-8.

Machinery Energy. Machinery energy is an indirect energy assumed to be embodied in a piece of equipment during manufacturing (Elsoragaby et al., 2019a). To compute the machinery energy, the total useful life and EFC of the machine were taken into consideration (Muazu et al., 2014a). The weight of the machine was included by equally distributing its weight over the total economic life of it. The general expression used to compute machinery energy is given in Equation 5 (Gezer et al., 2003).

$$\mathrm{ME} = \frac{\mathrm{Cf} * \mathrm{W}}{\mathrm{EFC} * \mathrm{L}} \qquad [5]$$

Where ME is machinery energy (MJ/ha), Cf is the energy conversion coefficient for the combine harvester, W is the weight of the combine harvester (kg), EFC is the effective field capacity (ha/h) and L is the economic life of the combine harvester (h). The 3000 hours of useful life for self-propelled combine harvester is adopted from ASABE Standard, ASAE D497.7 (ASABE, 2011). The machinery energy conversion factor used for the combine harvester was 87.63 MJ/kg (Muazu et al., 2014a).

Fuel Energy. Fuel energy per unit area is a function of the type and quantity of fuel consumed by the machinery used by the farmers. The quantity of fuel consumed by the machinery used to power engines in performing various operations in crop cultivation system was multiplied by an energy conversion factor for the fuel. Thus, the general expression used to compute fuel energy is given as follows (Equation 6) (Muazu et al., 2014a):

$$FE = \frac{Fcon * Fc}{A} \quad [6]$$

Where FE is fuel energy (MJ/ha), Fcon is the quantity of fuel consumed (lit), Fc is the fuel energy conversion coefficient (MJ/lit) and A is the farm area covered (ha). The fuel energy conversion factor used for the combine harvester is 47.80 MJ/kg (Canakci et al., 2005).

Human Energy. Human energy expenditure in harvesting operation was evaluated based on the number of farm workers engaged in harvesting operation per unit area and the time spent in performing the operations multiplied by an energy conversion coefficient. The general expression used to compute human energy is given in Equation 7 (Muazu et al., 2014a).

$$HE = \frac{n * H * lc}{A} \quad [7]$$

Where HE is human energy (MJ/ha), n is the number of workers engaged in an operation, H is the duration of operation (h), lc is the energy conversion coefficient for human labour and A is the farm area covered (ha). The human energy conversion factor used for the combine harvester is 1.96 MJ/kg (Canakci et al., 2005).

Total Energy Input. Total energy input in harvesting operation per hectare was determined as the summation of energy from all the sources which is as follows (Equation 8) (Elsoragaby et al., 2019a):

$$TEI = ME + FE + HE \quad [8]$$

Where TEI is total energy input of harvesting operation (MJ/ha) and ME, FE, HE, are as previously defined.

Energy Forms

Direct and Indirect Energy. There were two types of energy inputs in agricultural productions namely the direct and indirect energy. Direct energy refers to the energy which was directly used in the field while indirect energy refers to the energy which was not directly used in the field (Ozkan et al., 2004b). In harvesting operation, direct energy was obtained through the summation of fuel and human energy while indirect energy was obtained from the machinery energy (Gemtos et al., 2013).

Renewable and Non-renewable Energy. Energy inputs in crop production can also be grouped into renewable and non-renewable energy. The renewable energy sources can be replenished over time while non-renewable energy sources are depleted with time. In harvesting operation, the human energy is considered as renewable energy while the fuel and machinery energies are considered as non-renewable energy (Mohammadi et al., 2010).

Statistical Analysis

Statistical analysis was carried out using SAS v.9.1 software (SAS Institute Inc., Cary, NC). The variables were assessed for normal distribution and were log-transformed to fit a normal distribution. The one-way analysis of variance (ANOVA) was conducted using SAS GLM procedure and the mean results were compared for P-value with 95% confidence and 5% significance level ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Field Performance Analysis

Field performance measurement is a very critical requirement in order to evaluate the effectiveness of the mid-size combine harvester employed during harvest in a field corn. Table 2 states that there are no significant differences for each parameter in the field performance of grain corn harvesting at 5% significance level ($P \leq 0.05$) between harvesting plots.

Effective Field Capacity and Field Efficiency

Table 2 illustrates EFC and FE of the mid-size combine harvester employed for grain corn harvesting in this study. There were no major mechanical or operational problems observed during harvesting which could affect either EFC or FE. Table 2 indicates that the mid-size combine harvester with 2.67 m working width had 0.23 ha/h and 34.97% of average EFC and FE, respectively. Previous research from Malaysian Agricultural Research and Development Institute (MARDI) showed that the mid-size combine harvester (Kubota DC 70G) with 1.98 m working width had EFC and FE of 0.32 ha/h and 62.79%, respectively (Hamid et al., 2018). Recently, the field performance of the mid-size combine harvester (WS 7.0Plus) with 2.2 m working width utilised in a paddy field was studied, and the EFC and FE for the machine were found to be 0.53 ha/h and 72% respectively (Elsoragaby et al., 2019a). In a similar study on wheat production, a mid-size combine harvester with 1.10 m working width had a 60% of mean FE and 0.86 ha/h of mean EFC (Chegini & Mirnezami, 2016).

Lower average values for FE and EFC were found in this study as compared to the previous studies due to lower FS (2.55 km/h) applied in this study to avoid over loading of the feeding rate, and thus reducing grain losses. Unsuitable FS poses high possibility in reducing the grain yield due to uncontrollable losses. Plot 4 with mean FS of 2.56 km/h had 9.09% greater mean EFC than plot 1 with 2.37 km/h of mean FS (Table 2). Plot 4 also showed that the harvesting operation resulted in a higher number of acres covered per hour than plot 1. Hamid et al. (2018) found that the highest harvesting speed (4.73 km/h) of the mid-size combine harvester (Kubota DC 70G Plus) contributed to a lower yield (5814.22 kg/ha). The highest yield (7002.36 kg/ha) was obtained at a harvesting speed of 2.25 km/h for the same variety of grain corn. The study revealed that the difference in harvesting speed of 2.48 km/h between these 2 plots resulted in 16.97% (1188.14 kg/ha) of yield loss (Hamid et al., 2018). Zubko et al. (2018) reported that the productivity of winter wheat grain yield increased by 49% when FS increased from 3 to 6 km/h. Thus, it is concluded that the productivity would increase when FS increases without exceeding its optimum speed to minimize the grain losses.

Table 2

Field performance of the mid-size combine harvester for different plots

Field Performance	Plot 1 (Mean ± SD)	Plot 2 (Mean ± SD)	Plot 3 (Mean ± SD)	Plot 4 (Mean ± SD)	Average (Mean ± SD)	P- Value
FS, km/h	2.37 ± 0.19	2.72 ± 0.37	2.54 ± 0.15	2.56 ± 0.03	2.55 ± 0.23	0.36
EFC, ha/h	0.22 ± 0.02	0.23 ± 0.01	0.23 ± 0.02	0.24 ± 0.01	0.23 ± 0.01	0.70
FE, %	33.84 ± 3.15	35.35 ± 0.87	34.85 ± 2.63	35.86 ± 0.87	34.97 ± 1.99	0.70
FC, lit/ha	40.20 ± 2.80	34.97 ± 3.88	37.58 ± 2.54	36.27 ± 0.34	37.25 ± 3.07	0.19
FMI	0.91 ± 0.02	0.91 ± 0.01	0.90 ± 0.02	0.93 ± 0.01	0.91 ± 0.01	0.19

The P-values of experimental parameters at 95% confidence level (n=12). There were no significant differences of experimental parameters at $\alpha \leq 0.05$.

Fuel Consumption

Table 2 shows that the average value of FC for the mid-size combine harvester is 37.25 lit/ha. This amount is higher when compared to previous research on wheat and barley harvesting, using the combine harvester (Caterpillar C6.6), which consumed 29.03 and 17.28 lit/ha of diesel, respectively (Spokas et al., 2016). Table 2 which represents the comparison of the fuel consumption for all plots shows that the greater FE was associated with lesser FC and *vice versa*. For instance, in plot 1, FE at 33.84% consumed about 40.20 lit/ha of fuel which was 15.03% greater than FC for plot 2 with FE of 35.35%. Similar study was carried out using two combine harvesters at different capacities in paddy field

(Elsoragaby et al., 2019a). The conventional combine harvester (Clayson 8080) with a lower FE (64%) consumed 21.13 lit/ha of fuel, which was 14.46% greater than the fuel consumed by the mid-size combine harvester (WS 7.0Plus) with a FE of 72%.

Field Machine Index

The turning effectiveness of the mid-size combine harvester in terms of FMI is also shown in Table 2. The average value of FMI for the mid-size combine harvester is 0.91. This value is almost similar to the FMI value of 0.87 reported by previous study which employed the mid-size combine harvester (DC 95M) in a paddy field (Wagiman et al., 2019). According to Shamsiri et al. (2013), the value of FMI would be greater when the turning time of the combine harvester is lesser. A higher FMI value from both respective machineries in grain corn and paddy field as recently mentioned indicated the need for exclusion of unproductive movement such as cornering and reversing in carrying out the harvesting operation.

Field Time Distribution in Harvesting Operation

The field time distribution of the mid-size combine harvester for harvesting different plots considered several tasks which included productive (harvesting) and non-productive (cornering and reversing, machine setting and adjustment and unloading). Field time distribution is very important to be analysed for effective time management in farm machinery operation. Table 3 shows that there were no significant differences at 5% significant level ($P \leq 0.05$) of each task between harvesting for each plot.

Table 3

Field time distribution of the mid-size combine harvester for different plots

Task	Plot 1 (Mean ± SD)	Plot 2 (Mean ± SD)	Plot 3 (Mean ± SD)	Plot 4 (Mean ± SD)	Average (Mean ± SD)	P-Value
Harvesting, h/ha	2.87 ± 0.24	2.53 ± 0.32	2.67 ± 0.14	2.65 ± 0.03	2.68 ± 0.22	0.33
Turning, h/ha	0.30 ± 0.06	0.23 ± 0.02	0.29 ± 0.07	0.21 ± 0.01	0.26 ± 0.05	0.11
Machine Setting and Adjustment, h/ha	0.18 ± 0.06	0.22 ± 0.04	0.17 ± 0.03	0.14 ± 0.03	0.18 ± 0.05	0.22
Unloading, h/ha	1.16 ± 0.23	1.29 ± 0.13	1.30 ± 0.17	1.19 ± 0.02	1.24 ± 0.15	0.60
Total, h/ha	4.51 ± 0.49	4.27 ± 0.16	4.43 ± 0.34	4.20 ± 0.04	4.35 ± 0.29	0.61

The P-values of experimental parameters at 95% confidence level (n=12). There were no significant differences of experimental parameters at $\alpha \leq 0.05$.

Harvesting Time

The average harvesting time was computed for all plots as illustrated in Table 3. The mid-size combine harvester spent 61.58% of the total field time for harvesting task which is equivalent to 2.68 h/ha. Elsoragaby et al. (2019a) highlighted that the mid-size combine harvester (WS 7.0 Plus) spent 71.69% (1.36 h/ha) from the total field time in paddy field. In another study, Busato et al. (2007) reported that the wheat harvesting with 9 m working width combine harvester spent 61.76% of the total field time which was equivalent to 0.12 h/ha.

The differences of harvesting time between the combine harvesters as previously stated are dependent on machinery specification, terrain condition, types and varieties of grain crops. For instance, the mid-size combine harvester had recommended FS by the manufacturer which would be really suitable for specific grain corn harvesting to avoid losses of unrecovered corn from the cobs which are left behind due to excessive FS.

Turning Time

Generally, turning time which consists of cornering and reversing in harvesting consumed about 5.91% (0.26 h/ha) of the total field time (Table 3). For paddy and wheat harvesting, the turning time consumed 8.84% (0.17 h/ha) and 23.61% (0.05 h/ha), respectively of the total field time (Elsoragaby et al., 2019a; Busato et al., 2007). These studies showed that the turning time of the combine harvester for wheat harvesting was 80.77% lower than that of the rice harvesting. Lower mean value of turning time in wheat harvesting might due to less frequent turning of larger size combine harvester with the larger working width (5 m) as compared to the mid-size combine harvester employed in rice harvesting which had a smaller working width (2.67 m). It was mentioned by Elsoragaby et al. (2019a) that the advantage of having large working width made the conventional combine harvester to have greater EFC thus reducing the time loss in unproductive movement during turning.

Unloading time

The mid-size combine harvester spent about 28.41% (1.24 h/ha) of the total field time to unload the grain corn from the grain tank into the truck (Table 3). In comparison to paddy harvesting, earlier research finding showed that 18.95% (0.36 h/ha) of the total field time was spent for grain unloading (Elsoragaby et al., 2019a). Busato et al. (2007) revealed that for wheat harvesting, 12.22% (0.02 h/ha) of the total field time was spent to unload the grain. A relatively higher unloading time for the mid-size combine harvester as shown in Table 3 was justified by frequent grain unloading due to the small size of grain tank as compared to conventional combine harvester which generally has a larger size of grain tank.

Machine Setting and Adjustment

Table 3 presents the remaining time spent for other tasks such as machine setting and adjustment which consumed about 4.10% (0.18 h/ha) of the total field time in grain corn harvesting. A series of recent studies indicated that the remaining time for other tasks consumed 0.52% (0.01 h/ha) and 2.41% (0.01 h/ha) of the total field time in paddy and wheat harvesting, respectively (Elsoragaby et al., 2019a; Busato et al., 2007). The remaining time consumed for other tasks as previously discussed, is dependent on soil condition, effectiveness of the machine performance and the skills of operators. The extra unproductive time consumed in the corn field is due to frequent machine setting and adjustment in order to optimize the field performance and increase the harvesting efficiency.

Total Field Time

Table 3 indicates that the total harvesting field time in corn field is 4.35 h/ha. Similar research on the mid-size combine harvester (Kubota DC 70G Plus) conducted by MARDI revealed that the total field time are 3.13, 2.56 and 2.44 h/ha for 3 different varieties of grain corn at the same harvesting plot (Hamid et al., 2018). Elsoragaby et al. (2019a) stated that the total field time was 1.9 h/ha for paddy harvesting by the mid-size combine harvester (WS 7.0Plus). Chegini and Mirnezami (2016) presented the average total field time was 1.90 h/ha for wheat harvesting by John Deere 955 combine harvester. The higher total harvesting time in the current study as compared to the previous studies is due to a higher time consumed on unproductive task especially during grain corn unloading which accounts for 28.41% from the total average field time (Table 3).

Energy Consumption

Energy consumption is one of the most important factors required to be monitored and observed during field operation. Energy losses should be minimized in order to save cost of operation especially during harvesting. Table 4 shows that there are no significant differences of energy input between harvesting sub plots at 5% significance level ($P \leq 0.05$).

Fuel Energy

The fuel energy contributed 74.93% (1780.70 MJ/ha) of the total energy input in grain corn harvesting as shown in Table 4. Muazu et al. (2014a) reported that for wet land paddy harvesting, the self-propelled combine harvester consumed 853.54 MJ/ha of fuel energy which was equivalent to 73.59% of the total energy input. For other crops such as rapeseed, sunflower and sweet sorghum, the combine harvester with 7000 kg weight and 3.8 m working width consumed 1116 MJ/ha of fuel energy (Gemtos et al., 2013). The difference in fuel energy consumption between combine harvesters as previously mentioned is due to different in machinery specification, work load and duration of working time.

Table 3 and 4 show that a higher fuel energy corresponds to a higher total field time and *vice versa*. For instance, the mean fuel energy in plot 1 (1921.40 MJ/ha) with mean total field time of 4.51 h/ha was 14.94% greater in fuel energy than in plot 2 (1671.70 MJ/ha) which has a mean total field time of 4.27 h/ha. Similar findings could be seen between plot 3 and 4 where the mean fuel energy in plot 3 (1796.13 MJ/ha) with a mean total field time of 4.43 h/ha was 3.61% greater in fuel energy than plot 4 (1733.55 MJ/ha) which had a mean total field time of 4.20 h/ha. Chegini and Mirnezami (2016) found that 18 minutes and 33 minutes of total harvesting time resulted in 11.36 and 17.06 lit/ha of diesel fuel consumption, respectively in wheat harvesting.

Table 4

Energy input of grain corn harvesting for different plots

Energy Input	Plot 1 (Mean ± SD)	Plot 2 (Mean ± SD)	Plot 3 (Mean ± SD)	Plot 4 (Mean ± SD)	Average (Mean ± SD)	P-Value
Fuel Energy, MJ/ha	1921.40 ± 134.33	1671.70 ± 185.85	1796.13 ± 121.44	1733.55 ± 16.17	1780.70 ± 146.97	0.19
Machinery Energy, MJ/ha	609.24 ± 59.27	579.84 ± 14.15	590.15 ± 42.59	571.68 ± 14.15	587.73 ± 35.45	0.66
Human Energy, MJ/ha	8.85 ± 0.95	8.36 ± 0.33	8.70 ± 0.67	8.22 ± 0.08	8.53 ± 0.58	0.58
Total Energy, MJ/ha	2539.50 ± 193.56	2259.91 ± 200.24	2394.97 ± 164.58	2313.45 ± 17.76	2376.96 ± 176.68	0.24

The P-values of experimental parameters at 95% confidence level (n=12). There were no significant differences of experimental parameters at $\alpha \leq 0.05$.

Machinery Energy

Machinery energy was determined by considering weight, EFC and estimated working life. Table 4 represents the average value of machinery energy of 587.73 MJ/ha which is equivalent to 24.77% of energy distribution in the total energy input. Muazu et al. (2014b) pointed that the self-propelled combine harvester with 3000 hrs of estimated working life contributed 303.53 MJ/ha of machinery energy which was equivalent to 26.17% of energy distribution in the total energy input in paddy harvesting. Gemtos et al. (2013) stated that the harvesting of rapeseed, sunflower and sweet sorghum in 1 ha/h required 417.8 MJ/ha of machinery energy, where the combine harvester used had 7000 kg of weight and 2000 hrs estimated working life. In fact, the same model of the combine harvesters with the same specification used on the same crop can have different mean value of machinery energy due to difference in EFC. For instance, plot 1 with 0.22 ha/h of EFC had 609.24 MJ/ha of machinery energy while plot 4 with 0.24 ha/h of EFC had 571.68 MJ/ha of machinery energy. The harvesting operation with lower EFC values has greater machinery energy than the harvesting operation with higher EFC values.

Human Energy

Table 4 also presents the average value of human energy consumed in corn field which is about 8.53 MJ/ha, equivalent to 0.36% of energy distribution in the total energy input. Muazu et al. (2014b) reported that the human energy in wet land paddy harvesting was 2.72 MJ/ha which was equivalent to 0.23% of energy distribution in the total energy input. Table 2 and 4 show that the lesser mean of EFC in plot 3 (0.23 ha/h) had 5.84% greater mean human energy (8.7 MJ/ha) than plot 4 which had 0.24 ha/h of mean EFC and 8.22 MJ/ha of the mean human energy. This study explained that greater human energy was consumed per hectare due to lesser harvested area per working hour. An additional working time per harvested area contributes to a lesser EFC.

Total Energy Input

Table 4 reveals that the average value of the total energy input of grain corn harvesting is 2376.96 MJ/ha. Muazu et al. (2014b) highlighted that the total energy input for wet land paddy harvesting by self-propelled combine harvester was 1159.79 MJ/ha. The average value of the total energy input or total operating energy for sunflower and sweet sorghum harvesting with a combine harvester of 7000 kg mass are 1585MJ/ha and 406 MJ/ha, respectively (Gemtos et al., 2013).

Table 2 and 4 represent plot 4 with mean FE (35.86%) and a mean total energy input (2313.45 MJ/ha) has 8.90% less value of mean total energy input than plot 1 which has a mean FE of 33.84%. Elsoragaby et al. (2019a) mentioned that the mid-size combine harvester (WS 7.0Plus) with mean FE of 72% had 19.77% lesser value of total energy input than the conventional combine harvester (Clayson 8080) which had a mean FE of 64%. Overall, the total energy input decreases when FE increases.

Energy Classification

From the result presented in Figure 3, the average value of direct and indirect energy distribution from the total energy input in grain corn harvesting were 75.23 and 24.77%, respectively. Elsoragaby et al. (2019b) reported that the average values of direct and indirect energies from the total energy input in paddy harvesting were 76.25 and 23.75%, respectively. For sweet sorghum, rapeseed and sunflower harvesting, the direct and indirect energy were 72.76 and 27.33%, respectively (Gemtos et al., 2013). Thus, it can be concluded that all studies reported that direct energy is greater than indirect energy for all the crops under investigation.

Figure 4 shows that the average value of renewable and non-renewable energy in grain corn harvesting are 0.36% and 99.64%, respectively. Recent research in paddy harvesting showed that the renewable and non-renewable energy are 0.17 and 99.83%, respectively (Elsoragaby et al., 2019b). Similar research conducted by Muazu et al. (2014b) in wet land paddy harvesting revealed that the renewable and non-renewable energy were 0.23% and 99.76%, respectively. These reports illustrate that the consumption of non-renewable energy is greater than the renewable energy in harvesting operation especially for grain crop like paddy and corn.

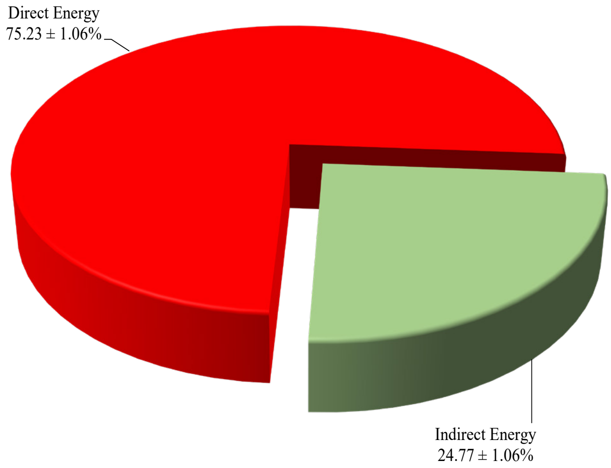

Figure 3. Direct and indirect energy for harvesting operation in grain corn production

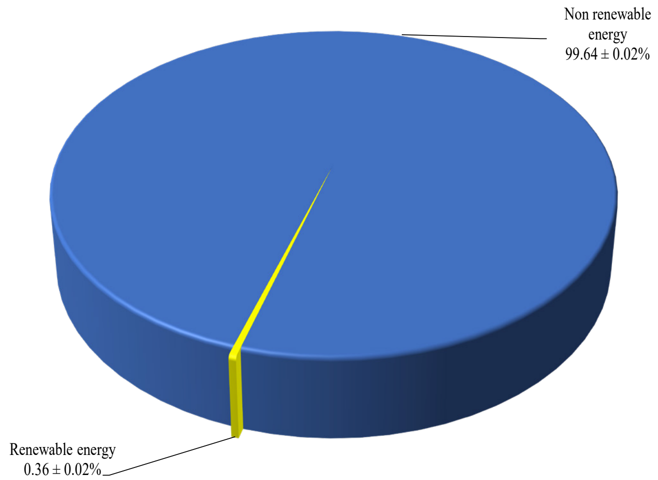

Figure 4. Renewable and non-renewable energy for harvesting operation in grain corn production

CONCLUSION

This study examined various parameters in determining the field performances and energy consumption involved in grain corn production. The average value of FE, EFC and FC were 34.97%, 0.23ha/h and 40.20 lit/ha, respectively. The average value of FS and FMI were 2.55 km/h and 0.91 respectively. Based on the findings, the average value of energy consumption for fuel, machinery and human energy were recorded at 1780.70 MJ/ha, 587.73 MJ/ha and 8.53 MJ/ha, respectively. The fuel, machinery and human energy contributed about 74.93, 24.77 and 0.36% to the total energy consumption, respectively. The share of the direct and indirect energy in the fields by average value from the total energy consumption were 75.23 and 24.77% respectively. While the share of the renewable and non-renewable energy were 0.36 and 99.64%, respectively. This research indicated that the field performance and energy consumption for grain corn harvesting in Labis, Malaysia was consistent with some other grain harvesting operation that were studied in previous scientific researches and are discussed as literature studies in this article. Based on these findings of this study, it is recommended that, when operating a mid-size corn harvester with 2.76 m reaping width and 2.67 m cutting blade, the following operating parameters would yield the most optimal corn productions and minimum energy consumption with forward speeds were between 2.37 to 2.72 km/h, total harvest time of 4.20 to 4.51 h/ha, and sandy loam soils. These parameters achieved an average value of the effective field capacity 0.23 ha/h with maximum value of 0.24 ha/h, the average value of fuel consumption 37.25 lit/ha with minimum value of 34.97 lit/ha, average percentage of field efficiency 34.97% with maximum value of 35.86%, and an average of the field machine index 0.91 with maximum value 0.93, as well as the total energy consumption between 2259.91 and 2539.50 MJ/ha with an average of consumption 2376.96 MJ/ha.

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