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Research article

Comparison between conventional human energy measurement and physical human energy measurement methods in wetland rice production

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ABSTRACT

Measurement of human energy expenditure during crop production helps in the optimization of production operations and costs by identifying steps which that can benefit from the use of appropriate mechanization technologies. This study measures human energy expenditure associated with all 6 major rice (Oryza sativa L.) cultivation operations using two measurement methods-i.e. conventional human energy expenditure method and direct measurement with a Garmin forerunner 35 body media. The aim of this study was to provide a detailed comparison of these two methods and document the human energy costs in a manner that will identify steps to be taken to help optimize agricultural practices. Results (mean + 95%CL) revealed that the total human energy expenditure obtained through the conventional method was 25.5% higher (33.3 ± 1 versus 26.6 ± 1.3) in transplanting and 26.1% higher (30.3 ± 1.9 versus 24.0 ± 2.1) than the human energy expenditure recorded using the Garmin method in broadcast seeding method.

Similarly, during the harvesting operation, the conventional measurement and Garmin measurement methods differed significantly, with the conventional method the human energy expenditure was 89.9% higher (3.2 ± 0.4 versus 1.68 ± 0.2) in the fields using the transplanting and 88.7% higher (3.3 ± 0.5 versus 1.8 ± 0.3) in the fields using the broadcast seeding than the human energy expenditure recorded using the Garmin method. When using Garmin method, the human energy expenditure in the case of using the midsize combine harvester was 13.49% lesser (592.4 ± 67.2 versus 522.0 ± 75.1) than the case of using conventional one.

Results based on heart rate also indicated that operations such as tillage were less intensive (72 ± 3.3 bpm) compared with operations such as chemicals spraying (135 ± 4 bpm). Although we did not have a criterion measure available to determine which method was the most accurate, the Garmin measurement gives an estimate of actual physical human energy expended in performing a specific task with consider all conditions and thus more information to aid in identifying critical operations that could be optimized and mechanized.

1. Introduction

Rice is an important cereal crop and staple food for half of the world's population (Sahu et al., 2018). Malaysia's rice productivity is 4.21 t/ha which is 8.51% lower than the global average. From 1981 to 2018, Malaysia's population increased by 121.4% while the area under rice cultivation increased by only 1.1 (FAOSTAT, 2018). Generally, rice is grown either by direct seeding or by transplanting. Direct seeding refers to the process of producing a rice crop from seeds planted in the field (Hassan, 2011). The transplanting method uses rice seedlings taken from the nursery and grown in the field.

All agricultural operations require energy from human, animal, or mechanical sources (Chamsing et al., 2006). Due to population increase, lack of sufficient land for cultivation, and increased prosperity, energy consumption in agriculture increased. The problem is solved by maximizing production performance, minimizing labor-intensive practices, or both (Hosseinzadeh-Bandbafha, 2018).

The lack of adequate manpower in the rice farming sector is a major concern for both farmers and agricultural policymakers due to its strong impact on production cost and the need to complete agricultural operations promptly to avoid unnecessary agricultural losses. The need for human labor in agriculture decreases with increasing mechanization

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(Baruah and Bora, 2008). Complete information on the level of human capacity is required in each process to effectively assess the state of agricultural mechanization of the rice production system. This information has the potential to discover the critical processes that require mechanization, to enhance the rice yield by completing the processes efficiently and quickly.

Nawi et al. (2012) recommend that critical field operations are those with the highest human energy expenditures. They then concluded that the tasks that lead to the highest energy expenditure can be identified as the tasks with the highest heart rate, these tasks which the industry should focus on when designing new machines or improving existing machines. In doing so, they found that fertilizing and chemical spraying are critical operations in rice production.

Muazu et al. (2015) reported that in Malaysia the human energy and machinery energy were 42 MJ/ha and 478 MJ/ha respectively in rice production. Elsoragaby et al. (2019a) found that different authors adopted different energy coefficients for the human energy such as Bilalis et al. (2013), Muazu et al. (2014b), Ozkan et al. (2004a), Ozkan et al. (2004b), Sartori et al. (2005), Kizilaslan. (2009), Yousefi et al. (2014), Mobtaker et al. (2010), Salami. (2010), and AghaAlikhani et al. (2013).

The study of human energy in crop production helps to use appropriate mechanization technology and reduce the cost of production (Fadavi et al., 2010). Measuring the human energy and heart rate of rice farmers in field operations help to implement an appropriate mechanization plan, achieve worker safety, and increase production efficiency (Nawi et al., 2012).

The novelty of this study, currently there is no detailed study that has been reported on investigating the Garmin method in measuring of human energy in crop production and compare it with the conventional measuring human energy in rice production. The present study was conducted in 62 farms in the real field conditions for two seasons under actual field operations. This study presents an opportunity to document human energy for the agricultural production of rice that can be used across the globe now and used by historians in the future.

The aim of the study is to investigate the conventional human energy measurement and physical human energy measurement methods (Garmin method) and to obtain information to help the implementation of appropriate mechanization, with consideration of workers health and productivity, in wetland rice cultivation.

2. Materials and methods

2.1. Study area

The location of the study area is at 3°29′47″ N and 101º09′56″ E in Sungei Burong, Malaysia. Data were collected from 62 farms in two seasons, main season from June to November 2017, and off-season from January to June 2018. To evaluate the human energy in the main season, 17 farms for transplanting and 13 farms for broadcast seeding were used. While in the off-season, 23 farms were used to evaluate the human energy in transplanting and 9 farms were used to evaluate the human energy broadcast seeding method. The total area cultivated under the transplanting method was 41.3 ha. While the total area cultivated under the broadcast seeding method was 20.8 ha. The variety of rice used in the fields in the two seasons was CL220 for both cultivation methods. The research contains data obtained from participant workers. This is to confirm that informed consent was obtained from all participants for the data collection, and the research conducted, and the collecting of this data was under Universiti Putra Malaysia Rules.

Essentially the main data collection exercise covers six standard wetland rice cultivation operations conducted by farmers in the study area and they include slashing, tillage, planting, fertilizing, chemicals spraying, and harvesting operations. Applicable data regarding the various machinery/implements weight, engine power, and model used by the farmers were also sought. The specifications for the machinery used by the farmers are given. The slashing operation was conducted using four-wheel drive KUBOTA M9540 tractors. A straw cutter with a working width of 1.8 m, was attached to the tractors as an implement to cut the rice straw left standing by the combine harvester. Tillage operation was conducted using four-wheel drive KUBOTA M9540 tractors. Rotary tillers with a working width of 2.7 m, was attached to the tractors as an implement for tilling the soil. The 2.7 m rotavator, is used to break up the virgin soil during the first and second runs. In the third tillage run, a rotary tiller with a working width of 3 m was used as a soil tilling implement. In planting operation, for the transplanting method, the seedlings were transplanted using rice transplanter at a spacing of 20 cm × 30 cm with 6 seedlings per hill. For the broadcast seeding method, the pre-germinated seeds were broadcasted at a seeding rate of 134.5 kg/ha or about 449 seeds/m^2. In the fertilizing operation, the farmers used knapsack HARRY 3WF28 mist duster (2.13 kW petrol engine 12.5 kg) to perform fertilizer applications. In all farms the farmers used power sprayer machines (4.8 Kw petrol engine 140 kg) which manufacture locally were generally used by the farmers in applying pesticides in all pesticides applications except first application they used knapsack HARRY 3WF28 mist duster (2.13 kW petrol engine 12.5 kg) to perform pesticides application on their farms. Harvesting operation was done by using New Holland Corporation, Turin, Italy Clayson 8080, 82 kW at 2500 rpm self-propelled rice combine harvester with 5 m cutting width, and World Star Corporation, China ws7.0, 76.1 kW at 2600 rpm self-propelled rice combine harvester with 2.7 m cutting width.

Figure 1 shows the Garmin satellite picture, represents the location of the study area and field pattern of the field machines for the fertilizing operation and harvesting operation.

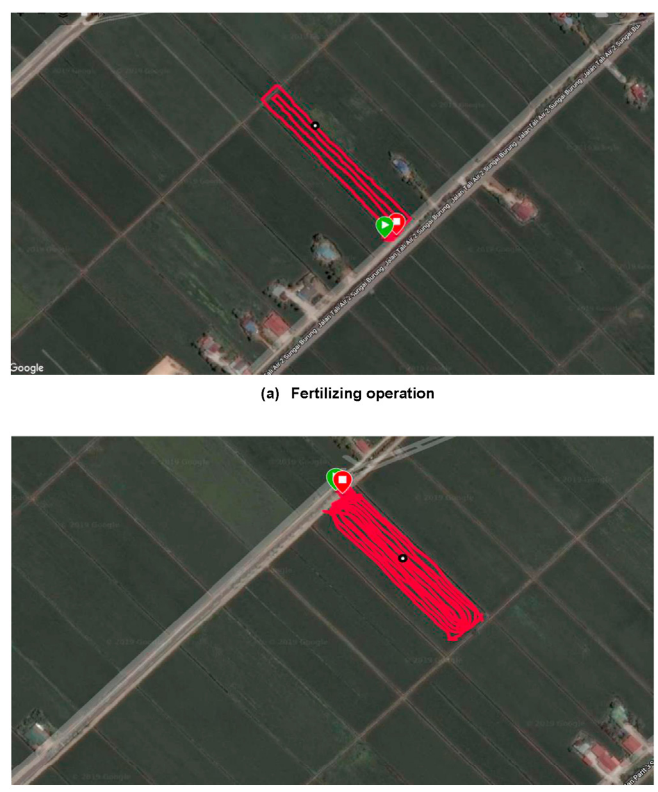


Figure 1. Garmin satellite pictures present the locations and. field pattern of the field machines.

2.2. Conventional versus Garmin measured human energy

Human labor is employed to a varying degree in rice cultivation depending on the mechanization status of the system. In the case of a fully mechanized rice cultivation system, human labor is limited to operating field machinery used in performing cultivation activities. While in the case of topical traditional (manual) system, human labor is used as the overall source of power for the entire cultivation system. Several methods of evaluating human labor in crop production are open for use in analyzing its contribution to the overall energy flow in the production system. The commonly used evaluation method is h/ha. Conventionally, in order to express the human labor in terms of energy values so as to facilitate comparison with other energy sources used in crop production, a conversion factor of 1.96 MJ/h is used. Human energy expenditure in crop production is also evaluated using specialized monitoring instruments such as Garmin forerunner 35 body media Fit. These instruments give an estimation of actual physical human energy expended in performing a specific operation.

Human energy expenditure associated with rice cultivation operations was evaluated in this study based on two methods, conventional human energy expenditure method and physical human energy expenditure method obtained through direct measurement with Garmin forerunner 35 body media. The device measures energy use directly (kcal).

2.2.1. Conventional human energy expenditure

Conventional human energy expenditure was computed depending on the number of labors enrolled in operation per unit area and the time in doing the operation multiplied by the conversion coefficient of the energy. Eq. (1) is used to calculate human energy (Elsoragaby et al., 2019c), (Lubis et al., 2019), (Muazu et al., 2014a), (Nassiri and Singh, 2009), and (Nabavi-Pelesaraei et al., 2018).

Figure 2. The farmworkers in performing various operations in the study area.

$$\text{HEC} = \frac{\text{n} \times \text{H} \times \text{cc}}{\text{A}} \quad (1)$$

Where: HEC is the human energy measured by the conventional method (MJ/ha), n is the number of labors enrolled in the operation, H is the length of time of operation (h), lc is the conversion coefficient of human energy (1.96 MJ/h), and A is the area cultivated (ha).).

2.2.2. Garmin human energy expenditure

Garmin forerunner 35 body media is a wearable instrument that measures calories burned per duration of time. It uses four sensors (accelerometer, heat flux, galvanic skin response, and skin temperature sensors) to capture different data points per minute, from heat and sweat produce to steps made and calories burned by the user. Garmin heart rate watches should be worn by the workers before an activity after the person is allowed 10 min period of rest so the heart rate could be stabilized. The wearable monitor is configured using the personal body parameters such as height, weight, age, handedness, and smoking status of the worker. To record energy expenditure, the farmworker wears the monitor on his arm. The data collected by the sensors together with the personal information of the user are used by the embedded computing algorithms in the monitor to give the amount of energy expended by the user. The monitor when powered on, can be paired with an optional display unit, for the display of the cumulative calories burned in real-time. The display unit receives energy updates from the monitor every minute. By uploading the energy data to the online Activity Manager, a minute by minute account of energy expenditure is assessed on the dashboard via a plotted graph.

The amount of energy expended by the worker is shown in Eq. (2). The human energy for the operation was computed by summation of the human energy for all workers engage in the operation on one farm then the average was taken for all farms. Figure 2 represents the farmworkers in performing operations in the study area.

Table 1. Statistics of farm workers' personal data (Average of main and off-seasons).

Parameter	Measurement
Age, years	23.7 ± 2.3§
Height, m	1.7 ± 0.02
Weight, kg	67.6 ± 5.03
Married	Yes = 13.8%, No = 86.2%
Handedness	Right = 96.6%, Left = 3.4%
Smoking	Yes = 55.2%, No = 44.8%
Nationality	Malaysian = 58.6%, Non-Malaysian = 41.4%
Gender	Male = 100%, Female = 0
Number of workers	29

§ At 95% confidence interval.

$$HEG = EE{*}0.004184/A \quad (2)$$

Where: HEG is Garmin human energy (MJ/ha), EE is the total calorie of the labors enrolled in the operation (kcal), and A is the area cultivated (ha).

2.3. Statistical analysis

The energy expenditures for each operation were compared using t-tests at a 95% confidence interval, assuming unequal variances. In the main season, the mean energy expenditures were calculated from 17 farms using the transplanting and 13 farms using the broadcast seeding method, whereas in the off-season, the mean energy expenditures were calculated from 23 and 9 farms using the transplanting and the broadcast seeding methods, respectively.

3. Results and discussion

3.1. Workers metadata

Data on human energy expenditures were collected from 29 farmworkers in the main and the off-seasons. The summary statistics of the farmworkers' personal data are given in Table 1.

At a 95% confidence interval, the mean age, height, and weight of the workers were 23.72 years, 1.66 m, and 67.59 kg, respectively. Out of the 29 farmworkers that executed the whole rice cultivation activities, 55.2% were smokers. There is no female participated in the rice cultivation activities in the study area. In terms of handedness, about 96.6% of the farmworkers were right-handed. Out of the 29 workers that participated in the wetland rice cultivation activities, 13.8% were married. The study revealed that a high percentage of about 41.4% of the workers that participated in rice production were foreigners. This because low income for the farmers makes the rice production sector less attractive for Malaysians.

3.2. Comparison of conventional versus Garmin measured human energy

In literature, the authors calculated the human energy expenditure by a conventional method like Chaichana et al. (2014) for rice production in Thailand, Elsoragaby et al. (2019b) in Malaysia, Yuan and Peng (2017) in China, Nassiri and Singh (2009) in India, Islam et al. (2001) in Bangladesh, Nabavi-Pelesaraei et al. (2018) in Iran, Truong et al. (2017) in Vietnam, and Soni and Soe (2015) in Myanmar. No study calculated the human energy expenditure by physical method.

Table 2 shows that the mean consumption of human energy in Malaysia rice production is 31.8 MJ/ha which is higher than that of Thailand but lower than that of China, India, Bangladesh, Iran, Vietnam, and Myanmar. Myanmar and Vietnam have a good source of workers in performing the operations.

In this study, in the case of the fields under the transplanting method, the result revealed that the total human energy expenditure obtained through the conventional method was 25.5% higher mean than the

Table 2. Human energy expenditure in rice production from different countries.

Country	Human Energy	References
Thailand	13.1	(Chaichana et al.,. 2014)
Malaysia	31.8	(Elsoragaby et al.,. 2019b)
China	484	(Yuan and Peng, 2017)
India	902	(Nassiri and Singh, 2009)
Bengladesh	1306	(Islam et al.,. 2001)
Iran	1526.1	(Nabavi-Pelesaraei et al., 2018)
Vietnam	1837	(Truong et al., 2017)
Myanmar	2435.0	(Soni and Soe, 2015)

Table 3. Comparison between Conventional and Garmin measurement in transplanting, MJ/ha (Average of main and off-seasons).

Operation	Conventional,	Garmin	p value	Difference%
Slashing	1.9 ± 0.2§	2.6 ± 0.3	0.0014***	-24.9
Tillage	4.8 ± 0.1	4.1 ± 0.3	0.0001***	+17.0
Planting	4.1 ± 0.2	4.2 ± 0.3	0.5122[ns]	-3.1
Fertilizing	8.4 ± 0.5	6.6 ± 0.3	3.09E-20***	+29.1
Spraying	11.0 ± 0.5	7.5 ± 0.5	7.30E-14***	+45.8
Harvesting	3.2 ± 0.4	1.7 ± 0.2	4.36E-09***	+89.9
Total Energy	33.3 ± 1.1	26.6 ± 1.3	3.99E-16***	+25.5

***Significant at α = 0.001 and [ns] not significant at α = 0.05.
§ At 95% confidence interval.

Table 4. Comparison between Conventional and Garmin measurement in broadcast seeding, MJ/ha (Average of main and off-seasons).

Operation	Conventional	Garmin	p value	Difference%
Slashing	1.9 ± 0.3§	3.2 ± 0.4	3.33E-05***	-41.3
Tillage	5.2 ± 0.5	3.8 ± 0.5	0.0003***	+38.3
Planting	1.6 ± 0.1	1.4 ± 0.2	0.0393*	+13.4
Fertilizing	6.8 ± 0. 7	5.6 ± 0.7	0.0298*	+20.2
Spraying	11.5 ± 1.0	8.2 ± 0.9	2.74E-05***	+39.4
Harvesting	3.3 ± 0.5	1.8 ± 0.3	2.88E-06***	+88.7
Total Energy	30.3 ± 1.9	24.0 ± 2.1	4.94E-05***	+26.1

***Significant at α = 0.001 and *Significant at α = 0.05.
§ At 95% confidence interval.

physical human energy expenditure recorded using the Garmin method (33.3 versus 26.6 MJ/ha). Whereas in the case of the fields under broadcast seeding methods, the total human energy expenditure obtained through the conventional method was 26.1% higher mean than the physical human energy expenditure recorded using the Garmin method (30.3 versus 24 MJ/ha).

Both methods provide a measure of total energy expenditure for each agricultural operation. It includes the total energy expenditure of the individual performing the operation of resting metabolic rate plus the expenditure for the physical activity in excess to resting metabolic rate. The human energy expenditure value obtained through the conventional method in the fields under transplanting method was 24.9% lower mean in slashing operation (1.9 versus 2.6 MJ/ha), 17% higher mean in tillage operation (4.8 versus 4.1 MJ/ha), 3.1% lower mean in planting operation (4.1 versus 4.2 MJ/ha), 29.1% higher mean in fertilizing operation (8.4 versus 6.5 MJ/ha), 45.8% higher mean in chemicals spraying operation (11 versus 7.5 MJ/ha), and 89.9% higher mean in harvesting operation (3.2 versus 1.7 MJ/ha) than the recorded value for physical human energy expenditure using Garmin method (Table 3 and Table 4).

The human energy expenditure value obtained through the conventional method in the fields under broadcast seeding method was 41.3% lower mean in slashing operation (1.9 versus 3.2 MJ/ha), 38.3% higher mean in tillage operation (5.2 versus 3.8 MJ/ha), 13.4% higher mean in planting operation (1.6 versus 1.4 MJ/ha), 20.2% higher mean in fertilizing operation (6.8 versus 5.6 MJ/ha), 39.4% higher mean in chemicals spraying operation (11.5 versus 8.2 MJ/ha), and 88.7% higher mean in harvesting operation (3.3 versus 1.8 MJ/ha) than the recorded value for physical human energy expenditure using Garmin method. Figure 3 represents the comparison between Conventional and Garmin

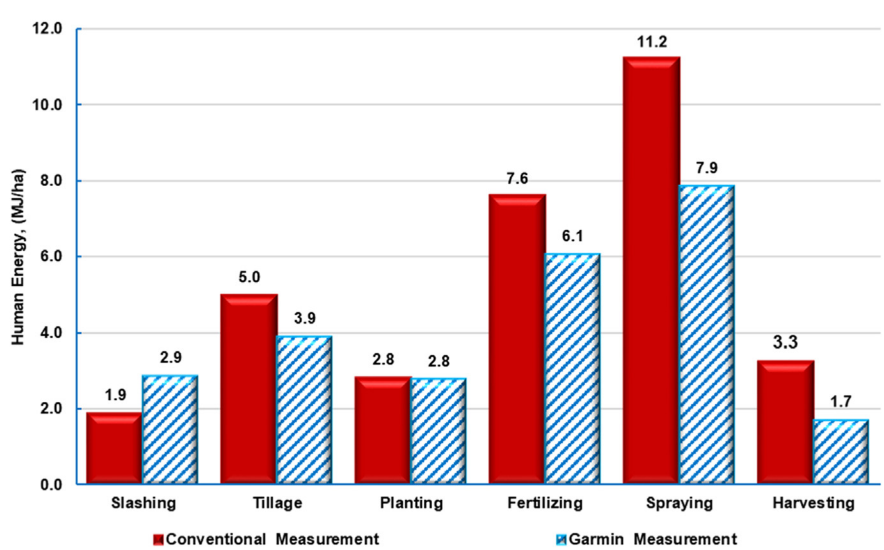
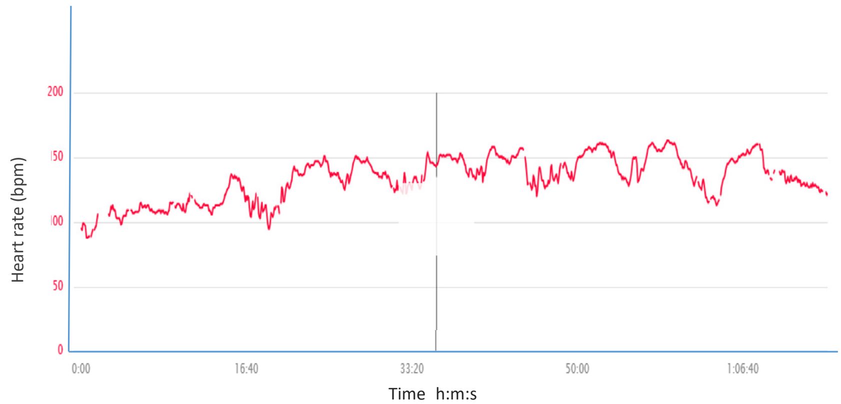
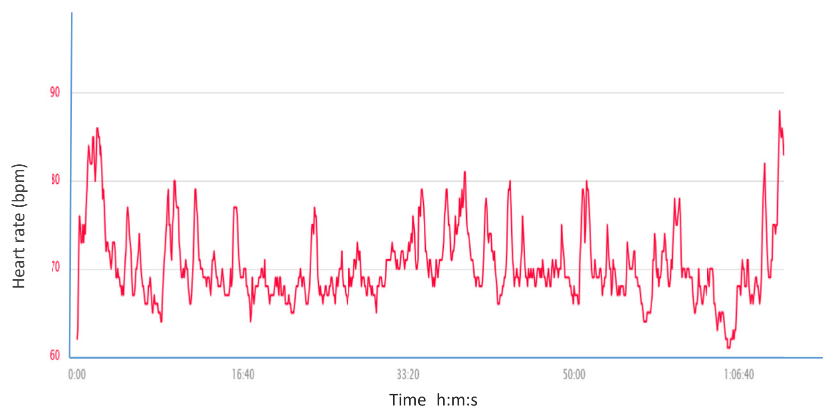


Figure 3. Comparison between Conventional and Garmin measured human energy in average of both cultivation methods and average of main and off seasons.



(a) Chemicals spraying operation



(b) Tillage operation

Figure 4. Heart rate for the workers in performing the operations.

Table 5. Comparison of conventional combine versus mid-size combine in harvesting operation when using conventional and Garmin measured human energy area base, kcal/ha.

Measurement	Conventional Combine	Mid-size Combine	Difference%	p value
Conventional	621.2 ± 48.14§	1162.7 ± 56.8	-46.6	0.00***
Garmin	592.4 ± 67.2	522.0 ± 75.1	+13.5	0.1878 ns

***Significant at α = 0.001 and ns = not significant.
§ At 95% confidence interval.

measured human energy in the average of both cultivation methods and the average of main and off-season.

From the previous, we found that the human energy expenditures estimated from the time based conventional method are significantly different from the recorded values of physical human energy expenditure obtained through direct measurement with Garmin.

The analysis of the results showed that higher values for the human energy expenditures were recorded using the conventional method compared with the Garmin method values in performing the actual field operations such as tillage, planting, fertilizing, chemicals spraying, and harvesting operation in the fields under transplanting and the fields under broadcast seeding methods this because the conventional method of estimating human energy expenditures is based on the time spent by a farm worker in performing the job on a given size of the farm and a constant coefficient. While Garmin method gives an estimate of actual physical human energy expended in performing a specific task.

Table 6. Comparison of conventional combine versus mid-size combine in harvesting operation when using conventional and Garmin measured human energy time base, kcal/min.

Measurement	Conventional Combine	Mid-size Combine	Difference%	p value
Conventional	7.8	7.8	0.0	0.00***
Garmin	7.6 ± 0.91§	3.5 ± 0.5	54.3	2.928E-10***

***Significant at α = 0.001 and ns = not significant.
§ At 95% confidence interval.

3.3. Worker's heart rate

Lower mean heart rate was recorded in not labor-intensive operations such as tillage, harvesting, and slashing operations compared with mean heart rate in the labor-intensive operations such as planting, fertilizing, and chemical spraying operations. Figure 4 represents the heart rate of the workers in performing chemicals spraying and tillage operation. The heart rate of the worker in performing chemicals spraying and tillage operation were 135 bpm and 72 bpm respectively because the worker in performing full mechanized tillage operation using tractor needs lesser physical activities than the worker in performing semi-mechanized chemicals spraying operation using a power sprayer machine.

3.4. Conventional versus Garmin measured human energy in harvesting operation

In the case of harvesting operation, we notice that the difference between conventional measurement and Garmin measurement methods was a highly significant 89.9% in the fields under the transplanting method and 88.7% in the fields under the broadcast seeding method, that why we focus on harvesting operation for this study.

When using the conventional method in the case of using conventional combine the mean recorded value for physical human energy expenditure using the Garmin method being about 4.9% lower than the human energy expenditure value obtained through the conventional method (592.4 and 621.2 kcal/ha). While in the case of using mid-size combine the mean recorded value for Garmin method was 1.2 times lower mean than the value obtained through conventional method (522 and 1162.9 kcal/ha) (Table 5), in this case, we notice that the difference between Garmin method and conventional method values were higher than the case of the conventional combine by 21.2 times, that because the conventional method of estimating human energy expenditures is based on the time spent by a farm worker in performing the job on a given size of the farm and a constant (human energy coefficient 1.96 MJ/h). Therefore, in the conventional method as the field time for accomplishing a harvesting operation increases, the cumulative human energy expenditure increases while the work rate remains constant (7.81 kcal/min) (Table 6) in using of both combines but Garmin gives an estimate of actual physical human energy expended in performing a specific task. Analysis of the results also showed that when using the Garmin method, the human energy expenditure in the case of using the mid-size combine harvester was 13.5% lesser mean than the case of using conventional combine harvester (522 and 592.4 kcal/ha) although the higher time spent in the case of using mid-size combine because it easier to drive and it needs lower physical activities to make turning and reverse and also it has smooth movement than the conventional combine.

4. Conclusion

This study was conducted under actual field operations in the real field conditions for two cultivation seasons and two cultivation methods in 62 farms of wetland rice cultivation in Malaysia. The present study is investigated and compared to the conventional method and the Garmin method for measuring the human energy expenditure in wetland rice cultivation. The rice variety used in the fields over the two seasons was CL220 across both transplanting and broadcasting methods.

Based on the findings of the study the human energy expenditures estimated from the time based conventional method are significantly different from the recorded values of physical human energy expenditure obtained through direct measurement with Garmin. In two cultivation seasons, the total human energy expenditure obtained through the conventional method in the fields under transplanting and the field under broadcast seeding methods were 25.5% and 26.1% higher mean than the physical human energy expenditure recorded using Garmin method.

The difference between conventional measurement and Garmin measurement methods in harvesting operation was highly significant, it was 89.9% in the fields under the transplanting method and 88.7% in the fields under the broadcast seeding method.

Lower mean heart rate was recorded in mechanized operations such as tillage, harvesting, and slashing compared with mean heart rate in semi-mechanized operations such as planting, fertilizing, and spraying operations.

Agricultural policymakers can use the information on the level of machinery utilization in each field operation and develop a comprehensive agricultural mechanization plan for rice cultivation.

The results also showed that when using the Garmin method, the human energy expenditure in the case of using the mid-size combine harvester was 13.5% lesser mean than the case of using conventional combine harvester although the higher time spent in the case of using mid-size combine because the mid-size combine is easier to drive and need lesser physical activities to make turning and reverse and also it has smooth movement than the conventional combine.

Recommendations for future research

- There was an immediate need to carry out such analysis for future steps to be taken for any improvement in agricultural mechanization systems regarding the human energy values of the operations.
- In future works Garmin measurement of estimating human energy must use instead of conventional measurement of estimating human energy in different areas because Garmin measurement gives an estimate of actual physical human energy expended in performing a specific task with considering all conditions such as height, weight, age, handedness, and smoking status of the worker.

Declarations

Author contribution statement

Suha Elsoragaby: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Azmi Yahya & Modather Mairghany: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Nazmi Mat Nawi, Muhammad Razif Mahadi, A. Muazu & Mohamad Firdza Shukery: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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