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Research Article

Analysis of Fuel Consumption and Carbon Dioxide Emission in Direct Seeding Wetland Rice Cultivation Systems in Malaysia

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Abstract: A farm level evaluation of fuel consumption and the resulting Carbon Dioxide (CO_2) emission in wetland rice cultivation was conducted in 40 farms, in Malaysia. Analysis of the results showed that the mean total fuel consumption for the entire cultivation operation was 59.57 l/ha with corresponding total CO_2 emission of 153.80 kg/ha. The highest fuel consumption was in tillage and the lowest was in planting operation with corresponding values of 21.39 and 1.10 l/ha respectively. Fuel consumption in tillage was significantly affected by number of passes, field condition and type of implement used. A decreasing trend in fuel consumption rate of about 0.04 l/min was observed with increases in the number of tillage passes. Tractor-rotary tiller combination consumed about 14% more fuel to that of tractor-chisel plow combination. Fuel consumption rate of tractors was lower in wet fields (0.09 l/min) by about 31% compared to in dry fields. Estimated government subsidy on fuel in rice cultivation is about RM45.58/ha amounting to more than RM31 million/year at country level.

Keywords: Carbon dioxide emission, field capacity, fuel consumption, fuel consumption rate, Malaysia, wetland rice

INTRODUCTION

Rice ranks the top major food crop in the world in terms of the production volume catering for the food requirements of more than half of the world population. The world production of rice in 2012 was estimated to be 719,738,273 tons harvested from 163,199,090 ha of farmlands with average yield level of 4.41 tons/ha (FAOSTAT, 2012). In the same year, Southeast Asian countries with combined rice production output of 217,174,887 tons accounted for 30% of the world's total production. In Malaysia, about 692,340 ha of arable land are under rice cultivation and the country ranked 23^{rd} both in terms of volume of production and cultivation area. Typically the country produces $2/3^{rd}$ of its rice requirements. About 72% of the wetland rice produced in the country comes from eight granary areas practicing double cropping per year (Najim *et al*., 2007). Globally differences in rice yield and productivity gains exist between farmers due to the differences in the way they used and managed the crop inputs (Byerlee, 1987). The inputs include both renewable (human labor, seeds and organic fertilizers) and non-renewable (fuel, mineral fertilizer and agrochemicals) fossil based resources with the latter being used in larger quantities than the former. Apart from high resource requirements in its production, rice cultivation also has some detrimental effects on the environment bordering mainly on Green House Gas (GHG) emissions. These problems have been investigated and reported by many researchers including (Yoshida, 1981; Uchijima, 1986; Neue, 1997; Sass and Fisher, 1997; Bouman and Tuong, 2001; Ohta and Kimura, 2007).

Similarly, concern about the environment and the need for sustainable crop production has led many researchers to conduct energy and energy related studies on rice production (Baker *et al*., 1992; Law *et al*., 1993; Jin *et al*., 1995; Matsui *et al*., 1997; Nakagawa and Horie, 2000; Pathak *et al*., 2002; Blengini and Busto, 2009) with a view to determining the contribution of the inputs used in the production system. Thus farming practices that promote optimum resource utilization could be pinpointed for the farmers to adopt. With the increasingly consciousness on the negative consequences of human actions on the environment due to ever increasing GHG emissions, many governmental and non-governmental organizations are stepping up campaigns to curtail production processes that lead to excessive release of methane (CH_4), Carbon Dioxide (CO_2) and Nitrous Oxide (N_2O) into the atmosphere and those that lead to the pollution of soil and water. Whereas in crop production CH_4 and N_2O are soil based processes, CO_2 emissions are the results of combusting of fossil fuels (Robertson *et al*., 2000; Koga *et al*., 2003).

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Rapid population growth and the diminishing fertile lands for agricultural production in most countries across the globe requires more intensification of crop cultivation and high use of fossil based resources in order to meet the food demand of the people. Intensified crop cultivation is facilitated through timely completion of activities by mechanizing production. Mechanized systems of crop production rely heavily on fossil fuel to power the engines of the machinery for performing the entire crop production processes. The fossil based fuels are not only non-renewable but their combustion generates GHG such as CO and CO_2 that are inimical to the environment and also threat to crop production sustainability. Further more, the prices of fossil fuel are never stable and in most cases are strongly affected by world politics. The increase in the prices of fossil fuel means additional cost to crop production thereby making the prices of agricultural produce to be high.

Fuel consumption in crop production is influenced by the mechanization status of the farms and operating conditions. Smith (1993) reported that fuel consumption by tractor in performing field operations is affected by size of tractor, implement type; soil type and condition, depth of implement operation and engine speed and gear selected by the operator in performing the operations. Sümer *et al.* (2010) in their studies on fuel consumption distribution for machine and tractor activities in some PTO driven machine operations found that less fuel was consumed by using disc fertilizer spreader compared to working with turbo atomizer. The variations in the fuel consumptions are due to the high power and torque requirements of turbo atomizer as compared to that of the disc fertilizer spreader. Fathollahzadeh *et al.* (2010) examined variation in fuel consumption due to changes in plowing depth for moldboard plow and found fuel consumption increased by about 9.66 and 24.10% when the plowing depth increased from 0.15 to 0.25 m and from 0.15 to 0.35 m, respectively. Fuel consumption for the three plowing depths of 0.15, 0.25 and 0.35 were reported as 27.446, 30.096 and 34.060 l/ha, respectively. The authors developed a linear regression model linking fuel consumption with plowing depth and the model has R^2value of 0.987. The developed model is of the form FC = 0.33h + 22.26 where FC is fuel consumption (l/ha) and h is plowing depth (cm). Coffman *et al.* (2010) examined fuel use efficiency of John Deere tractor Model 8530 with dual (automatic and manual) transmission modes and found better fuel use efficiency when the tractor operated in the automatic mode than in manual mode particularly at lower drawbar power. Data generated in the study were used to develop predictive fuel consumption model given as Q = 9.1+0.215* P+9.9*M-0.052* P*M where Q is the predicted fuel consumption (kg/h), P is the drawbar power (kW) and M is the transmission mode. The model was decomposed into two based on transmission modes resulting into Q = 9.10 + 0.215 * P for automatic mode and Q = 19.1 + 0.163 * P for manual mode. Kheiralla *et al.* (2004) developed four fuel models one each for disc harrow, disc plow, rotary tiller and moldboard plow using fuel data generated from experimental tillage operations conducted on sandy clay loam soil of Serdang, Malaysia. The models have R^2 values in the range of 0.802 -0.829. Grisso *et al.* (2004) developed two fuel consumption models for predicting diesel consumed by tractors at full throttle and reduced engine speeds, the models respectively were given as: 1). Q = (0.22X + 0.096) * Ppto, where Q is the diesel fuel consumption at partial load (l/h), X is the ratio of equivalent PTO power to rated PTO power (decimal) and Ppto is the rated PTO power (kW) and 2). Q = (0.22X + 0.096)*(1-(-0.0045XNRed + 0.0877NRed)) * Ppto, where Q is the diesel fuel consumption at partial load and full/reduced throttle (l/h), NRed is the percentage of the reduced engine speed for a partial load from full throttle, (%), X and Ppto are as defined previously.

Koga *et al.* (2003) observed that fuel savings through efficient utilization is an important step to reducing CO_2 emissions in crop production systems. Grisso *et al.* (2010) suggested eight ways of reducing fuel consumption during field operations. They include:

- Decreasing the number of tillage passes
- Substituting one implement type with another
- Combining tillage and other operations in one pass
- Use of proper ballast and tire inflation to optimize tractor performance
- Adopting the practice of “Gear-up and throttle-down,"
- Proper matching of tractor and implement sizes
- Use of controlled traffic and navigation aids to optimize field efficiency
- Timely maintenance of machinery

Maraseni *et al.* (2009) estimated GHG emissions from rice farming in some major rice producing and consuming countries in the world. The result of their study indicated that on the aggregate emissions due to combustion of fossil fuel accounted for about 30.7% of the total emissions from all sources considered in their research. Nelson *et al.* (2009) estimated fossil fuel consumptions and associated CO_2 emissions involving nine crops in the United States and found that on-site CO_2 emissions for rice cultivation ranges from 69.12 kg/ha under no-tillage system to 153.93 kg/ha under conventional tillage system. Most studies which assessed the level of carbon dioxide emissions due to combustion of fuels in crop production were either restricted to some operations e.g., tillage (Namdari *et al.*, 2012) or the evaluation was done based on estimated fuel consumption (Koga *et al.*, 2003; Fong *et al.*, 2012). Such studies do not capture actual variations in fuel consumption due to varying operations hence the CO_2 emission levels resulting from such studies do not capture the inherent variations in operations across farms.

Diesel and petrol fuels in Malaysia are subsidized substantially by the government, which make farmers cared less about their efficient use. However the current ongoing economic transformation agenda has led to a significant reduction in the subsidies and the deregulation on the diesel and petrol fuel prices. In the near future, the entire subsidies of RM0.80/l and RM0.63/l for diesel and petrol respectively could be removed and the prices of these products in the country will be at par with the international markets. Selamat and Abidin (2012) claimed that proven fossil oil reserve in Malaysia is estimated to last for 19 years at the current exploration rate. Marium (2011) also pointed out that oil production in the country is gradually decreasing while its demand is rapidly increasing. Thus, this implicates that in a few years to come, the country will have to import oil to meet its domestic energy demand unless if more oil wells are discovered. Thus, it may likely force the government to remove all subsidies on diesel and petrol fuels even if it has no absolute desire to do so. The recent hike in the prices of fossil fuel in the country has encourage farmers to consider alternative crop production options targeted at achieving optimum fuel use efficiency.

A complete fuel consumption and CO_2 emission data from rice cultivation along with the primary factors influencing both are currently lacking in Malaysia. Information on the quantity of fuel used could easily indicate the future fuel cost the farmers will have to contend in the absence of subsidies. In the case of farmers, information about fuel consumption data to the field activities will allow them to adapt farming practices that will optimize fuel use more rigorously. From an environmental point of view, any reduction in fuel use, in rice cultivation will have a commensurate positive effect on the reduction of CO_2 emissions there by promoting sustainable production. As for the government, information about fuel consumption will allow them to know the exact additional financial burden a farmer is likely to face with each reduction in subsidy and the potential price hike on rice and rice products in the market. In this way, adequate provisions could be made to cushion the undesired effects of additional economic burden on the consumers. Further more, information about fuel consumption per unit area will enable government to evaluate it commitments in meeting ratified international conventions (such as Kyoto Convention) on GHG emission reduction from rice production sector. The country is a signatory to Kyoto protocol with commitment to reduce green house gas emissions by 40% in 2020 (Shafie *et al*., 2011). This study is, therefore, aimed at determining actual fuel consumption associated with direct seeding rice cultivation operations in Malaysia and to identify factors affecting it. Data generated from the study were used to develop fuel predictive models for use at farm level by farmers and in quantifying the level of carbon dioxide emissions due to fuel use in rice cultivation, in the country.

METHODOLOGY

The study was conducted at Block E5 Parit Lima Timur, Sungai Besar District of Selangor, Malaysia during the March to July, 2013 rice cropping season. The block is located at $3^0$41'51.60" to $3^0$41'19.01" latitude and $101^0$01'21.09" to $101^0$01'59.51" longitude and has a net land area of 27.005 ha. The whole area is divided into 40 lots with lot area ranging from 0.255-1.125 ha with average lot area of 0.675 ha. The block was selected based on a recommendation from North-West Selangor Integrated Agricultural Development Authority (IADA) for being the most productive block with in the zone and the farmers' inclination towards practicing standard wet land rice cultivation operations in Malaysia. The data collection exercise on fuel consumption covered six standard direct seeding wet land rice cultivation operations namely tillage, seeding, fertilizing, spraying, harvesting and slashing operation. Data on fuel consumption for irrigation activities were not collected because none of the farmers in the study area used any fuel consuming prime movers in pumping the needed water to irrigate the rice plants throughout the season. All the farmers enjoyed free water supply from the national irrigation scheme through its subsidy program on rice cultivation. The water was gravity fed to the farmlands from constructed water canals/channels that transverse the entire wetland rice growing areas in the country. Figure 1 to 6 illustrates some of the machineries used by the farmers in performing various wetland rice cultivation operations.

The net cultivable land area of each farm lot was determined through direct measurements to allow for precise determination of fuel expenditures in each operation and its subsequent expression on per hectare basis for comparison among operations and with other similar published studies. The machinery field time for each operation in each farm was also recorded using a digital stop watch in order to allow for the expression of fuel consumption in liters/minutes basis and its relationship with machinery field capacity. The fuel consumed by the prime movers was determined through direct measurements by filling the machinery tanks at the start and end of operations and noting the difference. The fuel measurements were made using graduated measuring cylinders. This method of evaluating fuel consumption was preferred and adopted because it is accurate, cost efficient and easy to handle.

Fig. 1: Tillage operation

Fig. 2: Seeding operation

Fig. 3: Fertilizer broadcasting

Overall, the method does not require tempering with the fuel lines of the prime movers being evaluated as is the case with other methods.

Three operations (tillage, harvesting and slashing) out of the six included in this study, were conducted using diesel powered prime movers. While the other three operations (seeding, chemical and fertilizer applications) were performed using gasoline powered engines. Therefore, the data collection included both diesel and gasoline fuels used by the farmers in performing the entire wetland rice cultivation operations during the seasons. All together fuel data on tillage operations covering a total of 112 runs in the 40 farm lots were collected and analyzed. The numbers of fuel data collected from the 40 farms covering seeding,

Fig. 4: Spraying operation

Fig. 5: Harvesting operation

Fig. 6: Slashing operation

fertilizing, spraying, harvesting and slashing operations respectively were 40, 132, 246, 40 and 37. It is pertinent to mention here that fuel data on fertilizer application were collected from 36 farms where the operation was conducted using knapsack power blowers. No any fuel data were collected in four farm lands on fertilizer use because the operation was performed manually by the farmers. Similarly fuel data on slashing operation were collected in 37 out of the 40 farmlands studied because farmers in three of the farmlands did not perform slashing operation on their farms.

In order to estimate the level of CO_2 emissions due to the burning of fossil fuel used in the cultivation, a conversion coefficient of 2.64 and 2.36 kg/l for diesel and petrol fuels respectively were adopted following an approach by Koga *et al*. (2003). The total CO_2 emission in the country from rice cultivation was computed as the product of estimated CO_2 emission per hectare and the total area of rice land cultivated. Similarly fuel subsidy by type (diesel or petrol) per hectare was determined as the product of fuel consumed in liters and the amount of government subsidy on fuel type in Malaysian Ringgit (RM) per liter. Total fuel subsidy per hectare was then computed as the summation of subsidies due to diesel and petrol fuels used in RM/ha.

RESULTS AND DISCUSSION

Analysis of fuel consumption rates according to operations: As shown in Table 1, farmers in the study area used different types of machinery for the operations involved in the rice cultivation system. The machineries comprise of both the diesel and petrol powered engines, with power rating ranging from 2.5 to 82 kW.

The operation-wise mean total fuel consumption (l/ha) and fuel consumption rate (l/min) along with their respective 95% confidence intervals are presented in Table 2. Analysis of the result on the total fuel consumption among the six operations covered by the study showed that the tillage operation accounted for about 35.91% (21.39 l/ha) of the total fuel used in wet land rice cultivation and was the highest contribution. It was closely followed by harvesting operation with share contribution of 33.32% (19.85 l/ha) of the total fuel used. Similar results were reported by Khan *et al*. (2010) in Australia for rice production and Safa *et al*. (2010) for wheat production in New Zealand where tillage and harvesting operations accounted for the highest fuel consumption. Tebrügge and Düring (1999) in Germany, reported fuel consumption for conventional tillage of up to 35 l/ha. Filipovic *et al*. (2006) and Koga *et al*. (2003) identified tillage operation as one of the most demanding direct energy in crop production system. The least fuel consuming operation is seeding that accounted for only 1.85% (1.10 l/ha) of the total fuel used for the entire cultivation operations. Sarauskis *et al*. (2012) showed that for the same tractor implement combination engaged in rotary tillage operation fuel consumption decreases with increases in field capacity. The authors reported field capacity values of 1.61, 1.76 and 1.91 ha/h with corresponding fuel consumption of 11.40, 11.00 and 10.60 l/ha, respectively. Suggesting that farmers targeting to achieve good fuel savings should adopt proper work design that facilitates reduction in the time spends on the non-productive aspect of field operations. Such as reducing turning and reversing time at headlands, minimizing travel distances for loading/offloading activities, in addition to selecting implement that matches the tractor size. A no-load fuel requirement of up to 81% was reported by Smith (1993) for implement (row cultivator) with small draft requirements and the author emphasized on the importance of proper matching of tractor size to implement as a means of saving fuel during operation.

Tillage, harvesting and slashing operations were performed using diesel powered engines while seeding, fertilizing and spraying were done using petrol powered engines. Implying that diesel accounted for about 79.22% (47.19 l/ha) of the total fuel consumed by the machineries in wetland rice cultivation, in the study area and the remaining 20.78% (12.39 l/ha) by petrol fuel. Since in Malaysia government is presently maintaining a fuel subsidy of RM0.80/l on diesel and RM 0.63/l on petrol, it means that the paddy farmers in the country are currently enjoying fuel subsidy of about RM45.58/ha. With 692,340 ha of land under rice cultivation (FAOSTAT, 2012) in Malaysia it means that rice cultivation as a sector in crop production is, therefore, getting over RM31 million (Note: RM3.49 = $1.00 USD) annually from the government in the form of fuel subsidy.

The mean total fuel consumption of 59.57 l/ha recorded in the present study is close to the value of 66.3 l/ha reportedly used in the cultivation of cereal crops in Germany (Hulsbergen *et al*., 2001). However, it represented only about 14.71% of the total diesel fuel used by rice farmers in USA of 373 l/ha (Pimentel, 2009). Perhaps a reflection in the use of smaller size farm machineries and absence of water pumping activities on the part of Malaysia's rice farmers compared to their counter parts in the USA and the lack of mechanization for some rice cultivation operations in Malaysia. Seeding, fertilizing and spraying operations are not fully mechanized in the country. Paddy farmers in the study area used power knapsack blowers in conducting seeding and fertilizer application operations and they used similar mist blowers in performing spraying operation. Both of these blowers were found to have engine power rating ranging from 2.5-3.6 kW (Table 1) and they have low total fuel consumption as shown in Table 2. At mean yield level of 7625.30 kg/ha

Table 1: Machinery specification used by the farmers

Operation	Machinery used
First tillage	2WD 70 kW diesel engine Kubota M9540 tractor + 2.4 m wide rotavator
	2WD 55 kW diesel engine Fiat 640 tractor + 2.4 m wide rotavator
Second tillage	2WD 70 kW diesel engine Kubota M9540 tractor + 2.4 m wide rotavator
	2WD 55 kW diesel engine Fiat 640 tractor + 2.4 m wide rotavator
Third tillage	2WD 70 kW diesel engine Kubota M9540 tractor + 2.4 m wide rotavator
Seeding	3.6 kW petrol engine Robin NF-500 knapsack power blower
	3.6 kW petrol engine 3WF-3A mist duster
Fertilizing	3.6 kW petrol engine Robin NF500 knapsack power blower
	3.6 kW petrol engine 3WF-3A mist duster
Spraying	3.6 kW petrol engine Cifarelli M3VPSA power mist blower
	3.6 kW petrol engine Tasco M-77 mist blower
	2.5 kW petrol engine Echo DM-6110 mist blower
Harvesting	82 kW diesel engine 7.5 tons New Holland self-propelled rice combine
Slashing	2WD 70 kW diesel engine Kubota M9540 tractor + 1.7 m wide paddy straw cutter
	2WD 55 kW diesel engine Fiat 640 tractor+1.7 m wide paddy straw cutter

Table 2: Fuel consumption, operation frequency and field capacity

Field operation	Number of Samples	Fuel consumption rate (l/min)	Total fuel consumption (l/ha)	Operation frequency	Field capacity (ha/h)
Tillage	112	0.127±0.004	21.39±1.39	2.80	1.03±0.05
Seeding	40	0.012±0.001	1.100±0.19	1.00	0.72±0.07
Fertilizing	132	0.012±0.001	2.980±0.61	4.45	1.25±0.17
Spraying	246	0.017±0.002	8.300±1.19	6.33	0.90±0.05
Harvesting	40	0.218±0.014	19.85±1.25	1.00	0.67±0.03
Slashing	37	0.138±0.006	5.950±0.68	1.00	1.33±0.08

Table 3: Comparison of fuel consumption based on tillage pass number

Details	Number of observations	Fuel consumption rate (l/min)	Total fuel consumption (l/ha)
First tillage pass	40	0.16±0.008	10.17±0.35
Second tillage pass	40	0.12±0.007	7.170±0.58
Third tillage pass	32	0.08±0.007	4.050±0.72

recorded in the study area, the fuel use productivity was 128.01 kg/l. Signifying that farmers in the study area utilized one liter of fuel (approximately 790 and 210 mL of diesel and petrol, respectively) in producing 128.01 kg of rice.

Analysis of the fuel consumption rate among the six operations showed that it ranged from 0.012 l/min in seeding and fertilizer application to 0.215 l/min in the harvesting operation. Similarly analysis of machinery field performance showed that the field capacity was lowest in the harvesting operation (0.67 ha/h) and highest in the slashing operation (1.33 ha/h) conducted using paddy straw cutter attached to tractors with engine power rating ranging from 55-70 kW.

Although both seeding and fertilizing operations were performed using the same power knapsack blowers and both have the same fuel consumption rates, the total fuel used per unit area was different in the two operations. The total fuel consumption of 2.98 l/ha used in fertilizer application (Table 2) is about 2.71 times higher than that used in the seeding operation. The reason is attributed to the differing frequencies for the two operations. Whereas seeding operation was conducted only once, fertilizer application operation was made about 4.45 times in each of the farm lots during the study period as indicated in Table 2. Similarly, the observed difference in the total fuel used in spraying compared to fuel used in fertilizer application reflected on the lower field capacity, higher fuel consumption rate and higher application frequency recorded during the spraying operation.

As indicated in Table 2, on the average farmers in the study area made about 2.8 tillage passes on their respective farms before seeding operation. Accordingly the study captured three basic scenarios in the cause of collecting data on fuel consumed by tractors used in performing tillage operations. They include differing number of tillage passes, types of implements used and field conditions at the time of tilling the farms. With respect to the number of tillage passes made, the maximum number of passes was three and the minimum was two passes before seeding operation. Thirty two of the farms received three tillage passes and eight farms received only two tillage passes. In the eight farms that received only two tillage passes, the second tillage pass was made after flooding the farms with water. While in the 32 farms that received three tillage passes, the second tillage pass was made on dry fields. Moreso, in conducting the third tillage pass, rotary tillers were used in 30 out of the 32 farmlands that received three tillage passes. The remaining two farmlands received the third tillage pass using chisel plow. In order to analyze variation in fuel consumption based on tillage pass number, the 112 fuel data on tillage operation from the 40 farmlands were splits into three groups the summary statistics results for the averages of fuel consumption rates and total fuel consumption and their 95% confidence interval in performing the three tillage passes are presented in Table 3.

The results presented in Table 3 indicated that higher fuel consumption rates were recorded in the first

Table 4: Fuel consumption in tillage operation according to field conditions

Details	Number of samples	Fuel consumption (l/ha)	Fuel consumption rate (l/min)
Dry field	8	7.67±1.77	0.13±0.02
Wet field	32	5.19±0.61	0.09±0.01

Table 5: Fuel consumption in tillage operation according to implement type

Implement	Number of samples	l/ha	l/min
Rotavator	30	5.11±1.26	0.09±0.02
Chisel	2	4.37±0.18	0.04±0.00

tillage pass than in the second and third tillage passes. Comparison of fuel consumption among the three tillage passes showed less use of fuel in the second and third tillage passes amounting to 3.00 and 6.12 l/ha, respectively compared to fuel consumed in the first tillage pass. The fuel consumption rate of 0.16 l/min recorded in the first tillage pass was also found to be 1.33 and 2.00 times the fuel consumption rates in the second and third tillage passes. Essentially a decreasing trend in fuel consumption rate of about 0.04 l/min was observed with increases in the number of tillage passes. Cumulatively, the first tillage pass accounted for about 47.55% of the fuel used in tillage operation or about 17.07% of the fuel used in performing the entire cultivation operations. The second tillage passes consumed more fuel than the third tillage passes by about 3.12 l/ha. The observed decreasing trend in fuel consumption with increases in the number of tillage passes reflected draft reduction for the soil engaging implements operating on loose soil leading to improvement in the tractor traffic efficiency, hence higher field capacity and reduced fuel consumption. Safa *et al.* (2010) cited Barber (2004) identified improvement in traction efficiency as one of the factors for achieving savings in fuel consumption during field operations. A significant reduction in fuel consumption is achieved by operating the tractors at part loads and reduced engine speeds (Kheiralla *et al*., 2004; Smith, 1993; Grogan *et al*., 1987; Schrock *et al*., 1986; Chancellor and Thai, 1984).

The data for the second tillage passes were separated into two groups based on field conditions at the time of performing the operations. It is important to mention here that both farms used the same tractors and implements while the only variation was field condition. Result for the fuel used under the two field conditions (Table 4) showed lesser fuel consumption for the tractors of about 2.48 l/ha in wet fields (5.19 l/ha) than in dry fields (7.67 l/ha). The recorded mean fuel consumption rate for the tractors that performed tillage in wet fields of 0.09 l/min was about 31% lower than for tractors used in dry fields. The result corroborated the findings of Namdari *et al.* (2012), Cullum *et al.* (1989) and Abbaspour-Gilandeh *et al.* (2009) who showed an inverse relationship between tractor fuel consumption during tillage operation with the field moisture content.

As in Table 3 and 4, the fuel consumed by the tractors used in farms that received three tillage passes is about 6.55 l/ha higher than the mean fuel of 15.36 l/ha used in farms that received two tillage passes. Farmers who made only two tillage passes on their farms saves up to 30% in fuel expenditure compared to farmers who made three tillage passes on their farms. Nelson *et al.* (2009) posited that an energy use in crop production can increase or decrease with changes in cropland management. They also showed that on-site energy expenditure for rice production under conventional tillage system (7.37 GJ/ha) was higher than under reduced tillage (7.16 GJ/ha) and no-tillage (3.88 GJ/ha) systems.

The fuel data for the third tillage operation were also separated into two groups according to the implements used in performing the tillage passes with a view to determine the variation in fuel consumption therein. Table 5 indicates that tractor-rotary tiller combination consumed about 14% more fuel as compared to the fuel consumed by tractor-chisel plow combination. The fuel consumption rates were also lower in tractor-chisel plow combination (0.04 l/min) than in tractor-rotary tiller combination (0.09 l/min) by a margin of about 56%. The reason for the less fuel consumption in chiseling than in rotary tilling was because chisel plow demands less tractive power compared to the power demand by rotary tillers. The result revealed that the fuel consumption in tillage operation is significantly influenced by the type of implement used. Similar findings exist in the literature, for example, Kheiralla *et al.* (2004) reported variations in fuel consumption due to differences in the types of implement used in conducting tillage operations. Smith (1993) reported less fuel consumption by tractors in tillage operation with spring tooth harrow compared to fuel consumed by tractors working with disc harrow and seedbed conditioners. Michel *et al.* (1985) showed that the same level of yield for sugar beets, beans and corn could be attained with 40% less tillage energy by using chisel plow compared to moldboard plow.

Predictive fuel consumption models: Since fuel consumption in tillage operation is affected by the number of tillage passes, type of implement used and field condition, a multiple linear regression model for predicting fuel consumption in tillage operation is being proposed in this study. The proposed model is assumed to be a function of the above listed factors in addition to field capacity, weight of implement used and tractor engine power. The model is of the form as expressed in Eq. (1):

$$FCt = A + C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 + C_6X_6 \quad (1)$$

Table 6: Fuel consumption model parameters for tillage operation

Variable	Coefficient (C)	Standard error	T-value
Intercept (A)	3.437	4.504	0.76*
Field Capacity (X1)	-5.279	0.805	-6.56*
Implement type (X2)	-3.507	0.962	-3.65*
Tillage pass number (X3)	-1.954	0.258	-7.57*
Soil condition (X4)	1.945	0.430	4.53*
Implement weight (X5)	0.026	0.009	2.83*
Tractor engine hp (X6)	0.017	0.025	0.69*
R^2	0.810		
Durbin-Watson	1.966		

*Significant at 5% probability level

Table 7: Fuel consumption model parameters for semi - mechanized operation

Variable	Coefficient (C)	Standard error	T-value
Volume (V)	1.19	0.2672	4.4536*
Net operation time (T)	14.94	0.6275	23.8088*
Type of operation (O)	105.03	11.8985	8.8272*
R^2	0.94		

*Significant at 1% probability level

Table 8: Correlation analysis on fuel consumption model parameters for semi - mechanized operations

	FCsm	V	T	O
FCsm	1.0000			
V	0.7724	1.0000		
T	0.9082	0.8029	1.0000	
O	0.1824	-0.0343	0.1178	1.000

where,

FCt = Predicted fuel consumed by the tractor in performing tillage (l/ha)
A = Intercept (constant)
X1 = Effective field capacity (ha/h)
X2 = Implement used (1 = Rotavator and 2 = Chisel plow)
X3 = Tillage pass number
X4 = Soil condition (1= Flooded field and 2 = Dry field)
X5 = The weight of implement used (kg)
X6 = Tractor engine power (hp) and Cs are the model's estimated coefficients as given in Table 6.

Analysis on the model's variables revealed that field capacity, implement type and tillage pass number are negatively related with fuel consumption. While soil condition, implement weight and tractor engine power had a positive relationship with fuel consumption of type of operation, tractor in performing tillage operation. Field capacity had the highest impact on fuel consumption. Doubling field capacity (e.g., from 1 to 2 ha/h) would lead to decrease in fuel consumption by 5.28 l/ha. As indicated in Table 6, the model has R^2value of 0.81 and Durbin-Watson test result of 1.966 shows no auto-correlation at 5% significance level among the six variables used in the model. In other words there is no misspecification in the choice of the model variables. The model is, therefore, found to be adequate in predicting tractor fuel consumption in performing wetland tillage operations under varying field conditions, implement types and tractor engine power.

A single fuel consumption predictive model was developed for seeding, fertilizing and spraying operations. Because all the three operations were performed using similar power knapsack blowers and the tasks involved in each of the operations were identical. The tasks include loading, lifting up the loaded knapsack, actual broadcasting/spraying activity and walking in the field to reloading point. The developed model was assumed to be a function of type of operation, mass/volume of material applied and the actual task time as expressed in Eq. (2). Actual task time was considered more appropriate for use in the model than field capacity because the farm workers always put off the blower's engine after exhausting the loaded material and the engine remains off throughout the loading time:

$$FCsm = C_1V + C_2T + C_3O \tag{2}$$

where, $FCsm$ is the fuel consumption by a knapsack power blower in performing semi-mechanized operations (ml/ha), S and T are, respectively the volume/mass rate (l/ha or kg/ha) and net spraying/broadcasting time (min/ha) and O denotes type of operation where, 1 = seeding, 2 = fertilizing and 3 = spraying operations.

The regression coefficients for the fuel consumption model in performing the semi-mechanized operations were estimated as presented in Table 7. Analysis on the coefficients of the model shows that volume/mass of material applied had the least impact on fuel consumption with an elasticity of 1.19 as compared to net operation time having an elasticity value of 14.94. The result indicated that a 1% increase or decrease in the net operation time and volume/mass of material applied will results into about 14.94 and 1.19% increase/decrease in fuel consumption. T-test result on the three variables showed them as being statistically significant at 1% probability level. The model was also found to have a coefficient of determination (R^2) of 0.94 therefore, adequate in making good prediction for fuel consumption by knapsack power blowers used in broadcasting of seeds/fertilizers and spraying of pesticides.

The correlation matrix for the model presented in Table 8 shows a higher positive correlation between fuel consumption and net operation time of 0.9082 as compared to the correlation between fuel consumption and volume/mass rate of 0.7724. A strong correlation was also recorded between volume/mass rate and net operation time with the value being 0.8029.

The fuel consumption in performing slashing operation with tractor is best estimated using Eq. (3):

$$FCs = C_1Y + C_2X \tag{3}$$

where,

FCs = The tractor fuel consumption in slashing operation (l/ha)

Table 9: Fuel consumption model parameters for slashing operation

Variable	Coefficient (C)	Standard error	T-value
Field capacity (Y)	-4.841	0.838	-5.777*
Tractor engine hp (X)	0.138	0.012	11.500*
R^2	0.972		
Durbin-Watson	1.678		

*Significant at 1% probability level

Table 10: Correlation analysis on fuel consumption model for slashing operation

	FCs	Y	X
Fcl	1.0000		
Y	-0.8270	1.0000	
X	-0.5988	0.5771	1.0000

Table 11: Fuel consumption model parameter for harvesting operation

Variable	Coefficient (C)	Standard error	T-value
Field capacity (X)	28.932	1.357	21.321*
R^2	0.9210		
Durbin-Watson	1.6510		

*Significant at 1% probability level

Table 12: Carbon dioxide emission according to operations

Operation	CO_2 emission (kg CO_2 /ha)	Total CO_2 emission (Gg CO_2)
Tillage	56.470	39.100
Seeding	2.6000	1.8000
Fertilizing	7.0300	4.8700
Spraying	19.590	13.560
Harvesting	52.400	36.280
Slashing	15.710	10.880
Total	153.80	106.48

Y, X = The field capacity (ha/h) and tractor engine power rating (hp), respectively
Cs = The model's estimated coefficients presented in Table 9

Analysis on the fuel consumption model variables for slashing operation is presented in Table 9, where it is shown that field capacity had the highest impact on fuel consumption with a negative elasticity value of -4.841 while the tractor rated engine power had a positive elasticity of 0.138. The result indicated that a 1% increase in the field capacity will result into about 4.841% decrease in the fuel consumption. The coefficient of determination (R^2) for the model was 0.972. The Durbin - Watson test statistics at 5% level of significance was found to be 1.678 and it shows absence of auto-correlation among the two models independent variables. Therefore, there is no misspecification including the two variables in the model. The T-test also confirmed the two variables as being highly significant at 1% probability level. Field capacity and rated tractor engine power are therefore, good variables for estimating fuel consumption of tractors engaged in slashing operation.

The correlation matrix for the model presented in Table 10 shows a higher negative correlation between fuel consumption and field capacity of -0.8270 as compared to the correlation between fuel consumption and the rated tractor engine power of -0.5988. The correlation between the two models independent variables was computed to be 0.5771.

All of the farmers in the study area harvested their paddy using alone self propelled combine harvester. Simple linear regression model for estimating fuel consumption for the combine was, therefore, developed with field capacity as the only independent variable as expressed in Eq. (4):

$$FCh = CY \tag{4}$$

where,

FCh = Fuel consumption by combine (l/ha)
Y = Field capacity (ha/h)
C = Estimated model coefficient given in Table 11

The coefficient for the model independent variable was estimated to be 28.932 implying that a 1% change in field capacity for the combine harvester will lead to about 28% change in the fuel consumption. The model has coefficient of determination (R^2) of 0.921 and Durbin-Watson test shows no auto correlation at 5% significance level. Implying that field capacity is a good parameter for estimating fuel consumption for the combine harvester.

Analysis of carbon dioxide emissions according to operations: The estimated carbon dioxide emission equivalent that resulted from the combustion of fuels used by the machineries is presented in Table 12. On average, about 153.80 kg/ha CO_2 was emitted to the atmosphere seasonally. This value translates into some 106.48 Gg CO_2 emissions from rice fields across the country. Nelson *et al*. (2009) reported a total carbon dioxide emission in the United States of 365.29 kg/ha resulting from the combustion of diesel used by machineries in the entire rice cultivation operations under conventional tillage. The highest emission recorded in this study was in tillage operation (56.47 kg/ha CO2) accounting for about 36.72% of the total emissions. Koga *et al*. (2003) reported that CO_2 emissions due to tillage operations ranges from 23-44% of the total CO_2 emissions among the four crops they investigated in Japan.

Analysis of the emission data by fuel type showed that CO_2 emissions from diesel powered engines used in conducting tillage, harvesting and slashing operations were about 4.26 times higher than emissions from petrol powered engines used in performing seeding, fertilizing and chemical application operations. Since on-farm CO_2 emissions resulted directly from the burning of fossil fuels any management practices that lead to a reduction in fuel consumption in performing field operations also influences the level of CO_2 emissions in a similar manner. Therefore, reducing the number of tillage passes from three to two and using chisel plow instead of rotary tiller will lead to reductions in CO_2 emissions by about 17.29 and 1.95 kg/ha respectively. Harada *et al*. (2007) reported that up to 1.78 Gg/ha CO_2 emissions from rice field could be saved through no-tillage compared to the conventional system of cultivation.

CONCLUSION

In this study, the mean total fuel consumption required to perform six standard direct seeding wetland rice cultivation operations namely tillage, seeding, fertilizing, chemical application, harvesting and slashing operation was about 59.57 l/ha. Country-wide, the estimated fuel consumption was about 41.25 million l/yr thereby generating 106.48 Gg/yr CO_2 emission. Emission of CO_2 due to combustion of diesel was found to be about 4.26 times higher than CO_2 emission resulting from burning petrol fuel used in the rice cultivation operations. Tillage operation accounted for about 35.91% (21.39 l/ha) of the fuel used in the entire cultivation operations and it represented the highest fuel consumption operation. The least fuel consuming operation was seeding, with share contribution of 1.85% (1.10 l/ha) representing CO_2 emission of 2.60 kg/ha. Fuel consumption in tillage operation was found to be influenced by the number of tillage passes, field condition and type of implement used. Comparison of fuel consumption among the three tillage passes showed that second and third tillage passes consumed fewer fuels by 3 and 6.12 l/ha, respectively compared to the first tillage pass. Performing tillage operation on wet fields (flooded farms) consumed less fuel by about 2.48 l/ha compared to performing the tillage on dry fields. Similarly, chiseling operation in wetland rice cultivation consumed only about 85.52% of the fuel used in performing rotary tillage operation. In terms of machinery field performance, the highest and lowest field capacities of 1.33 and 0.67 ha/h respectively was in slashing and harvesting operation. Farmers in the study area utilized one liter of fuel (approximately 790 and 210 mL of diesel and petrol respectively) to produce 128.01 kg of rice.

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