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OPTIMIZATION OF ENERGY USE INTENSITY USING DATA ENVELOPMENT ANALYSIS AND BENCHMARKING METHODOLOGY FOR SUSTAINABLE RICE CULTIVATION UNDER WETLAND DIRECT SEEDING CONDITIONS IN MALAYSIA

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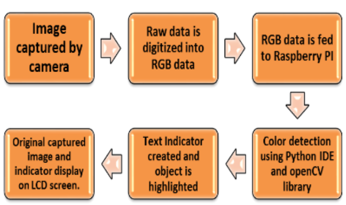
Graphical abstract



Abstract

Rice is tan important crop and main staple food In Malaysia, The country typically produces about two third of its total requirements with the balance met through import. The imported rice cost less compared to the same grade produce locally. One way to reduce production cost is by improving energy use intensity through optimum use of farm inputs. In this study we investigated the energy use intensity of 40 farms that practices direct seeding system of wetland rice cultivation in Malaysia. At mean yield level of 7,630 kg/ha, the optimum energy use intensity was 1.73 MJ/kg which is lower compared to the energy use intensities in efficient farms, all farms, and the inefficient farms by about 3%, 18% and 26% respectively. Three efficient farms identified as having the highest reference frequency in the study area had a mean yield level of 8,723 kg/ha and a mean energy productivity of 0.642 kg/MJ which were found to be about 1,368 kg/ha (19%) and 0.201 kg/MJ (46%), respectively higher than the mean yield and energy productivity in the inefficient farms. An average farmer in the study area used about 2,914 MJ/ha of energy in excess of the optimum level, representing RM626/ha in lost revenues.

Keywords: Rice cultivation, Energy intensity, optimization, economic analysis, sustainable production

1.0 INTRODUCTION

Rice is an important food crop which is widely cultivated in some 115 countries across the globe, with total annual production of more than 720 million tons. The global mean yield resulting from both the rainfed and irrigated rice in 2013 was 4.53 t/ha [1]. Malaysia typically produces about 2.6 million tons of rice, about 98% of which is wet paddy and more than 70% of which is produce in eight granary areas that are located in the main peninsular. The mean yield for rice in Malaysia in 2013 of 3.82 t/ha was about 13% lower than the world average. With per capita rice consumption of about 110 kg/year and population of 28.4 million people in 2013, the demand for rice was 3.2 million tons, while local production was about 2.6 million tons depicting a deficit of 0.6 million tons. For a projected population of 32.6 million people in 2020, demand for rice will reach 3.6 million tons. If the current local production level for rice of 2.6 million tons/year remains unchanged, then the deficit will widen to about 1 million tons by the year 2020. Therefore, for Malaysia to maintain its present level of self-sufficiency or even achieved complete self-sufficiency in rice production by the year 2020, production must be raised substantially. Increases in rice production could be achieved by either increasing area under paddy cultivation or increasing farmland productivity through efficient utilization of inputs, or both. Muazu *et al*. [2] observed that increasing rice production in Malaysia through area expansion is not feasible because of the limited arable land suitable for rice production. Therefore, the only option to exploit is increasing farmland productivity, in which energy analysis (output-input energy analysis and energy optimization studies) could play a central role for its ability to identify areas of excess use of energy.

Whereas the output-input energy study is limited to assessing the level of energy inputs used from various sources and the output energy (yield) that resulted from crop production, in energy optimization studies, the input and output energy data are subjected to an optimization technique to find the optimum values of the inputs that would result into maximum crop yield. Optimization approach to solving problems has at its core the selection of the best possible alternative, among various alternative causes of action. The selection is influenced by the desire to make the best decision capable of producing the desired result [3]. In optimization problems there is always an objective function or cost function to be maximized or minimized subject to certain constraints, which may be linear or non-linear in form. Different types of methods are available for solving optimization problems and the methods are called optimization techniques or optimization algorithms. Using the optimization techniques enable researchers to determine the level of excess energy use in crop cultivation, which would otherwise not be accounted through the ordinary output-input energy analysis.

Several optimization techniques (linear programming, multi-variable unconstrained optimization, etc.) have been tried to varying degrees by researchers in their quest to find optimum energy inputs to maximize crop yield. Singh *et al*. [4] used linear programming model based on the concept of one-to-one function to optimize the energy input for wheat production in Punjab, India. The result of the study revealed that farmers in zone 1 could save about 22% of the energy inputs they used without affecting the wheat productivity. Chauhan *et al*. [5] used data envelopment analysis (DEA) methodology in their study to improved energy productivity of paddy production. The technical efficiency estimation showed that only 15 farmers were efficient in the use of farm inputs. The study found that farmers could save about 12% of the total energy inputs used in the production without lowering yield. Nassiri and Singh [6] used DEA on the energy input and output data of 363 paddy farmers in India. The study found that about 78% of the farmers had technical efficiency of less than 80%. Other studies in energy analysis in crop production that employed DEA to quantify the level of excess energy used by farmers are reported in Eyitayo *et al*. [7] for cocoa production, Banaeian *et al*. [8] for greenhouse strawberry, Mohammadi *et al*. [9] for kiwifruit production. The purpose of this study were to determine the energy use intensity for direct seeding system of rice cultivation in Malaysia, evaluate the cost savings accruable to farmers resulting from optimum use of farm inputs and to determine best cultivation practices for the less performing farms to adapt for increased rice productivity in Malaysia.

2.0 MATERIALS AND METHODS

The study was conducted at Block E5 Parit Lima Timur, Sungai Besar District of Selangor, Malaysia during the rice cropping season of March to July 2013. The block is located at 3°41'51.60" to 3°41'19.01" latitude and 101°01'21.09" to 101°01'59.51" longitude. It has a net land area of 27.005 ha, divided into 40 farm lots with areas ranging from 0.255 to 1.125 ha and an average area of 0.675 ha. The block was selected based on a recommendation from the Integrated Agricultural Development Authority (IADA) of North–West Selangor for being among the most productive areas in the irrigation scheme and having dedicated farmers practicing standard wetland paddy cultivation operations in Malaysia.

Data were collected on six farm inputs (human labor, machinery, fuel, seeds, fertilizer, and pesticides) involving six field operations (tillage, seeding, fertilizing, spraying, harvesting, and slashing operations) from the 40 farm lots. No data collection was done in respect of pumping water for irrigation operations, because all the farmers followed the scheduled water distribution under the scheme throughout the cultivation period. The water was gravity fed to the farms via canals constructed and maintained by the national government in Malaysia. The recorded farm inputs and rice yield from each farm lot were converted into equivalent energy values using the appropriate conversion coefficients. The source-wise energy budget in megajoules per hectare, total input energy, total output energy, energy use efficiency, and energy intensity for each farm were then computed using classical equations given in [2]. To segregate the farms (efficient and inefficient) according to their technical efficiency scores, the energy inputs data from five operations (tillage, seeding, fertilizing, spraying and harvesting) and yield data in the 40 farms were subjected to input-oriented constant return to scale, data envelopment analysis methodology (DEA) discussed in [10]. In order to satisfy key requirement in DEA, which stipulates homogeneity of the entities (decision making units) in the analysis, the energy input data for the slashing operations was not included in the analysis. Not all of the farmers in the study area performed slashing operations on their farms. Besides, regardless of whether slashing is performed or not the rice straw is burnt by the farmers. Therefore, the effect of slashing operation on rice yield could not be ascertained, due to lack of rice straw reintegration back to the soil after the slashing operation. Excess use of energy inputs in the farms was quantified using results from the DEA identified benchmarks. The method of reference frequency was then used to identify best rice cultivation practices for the less efficient farms to adapt for increased rice productivity. The cost of all inputs were evaluated based on the prevailing market rates in Sungai Besar at the time of the research as discussed in Muazu *et al*. [11].

3.0 RESULTS AND DISCUSSION

3.1 Distribution of Energy Inputs

From the results presented in Table 1, at optimum use of farm inputs the total energy input for rice cultivation was 13,215 MJ/ha, which is lower by about 2914, 1184 and 3947 MJ/ha, compared respectively with the total energy input in all farms, efficient farms and inefficient farms. The highest and lowest energy expenditure among the different categories of farms was in fertilizer and human labor, accounting for 60 – 63% and 0.24 – 0.26% respectively of the total energy inputs used in the cultivation. Similar results were reported by Kumar and Hugar [12] in India, and Khan *et al*. [13] in Pakistan, where fertilizer energy accounted for the highest share of the total energy used in rice cultivation. Compared with the inefficient farms, the efficient farms used the least energy input from all the six sources employed in the cultivation except for chemical energy, which they used more by about 9%. The efficient farms used less energy for human labor, fuel, machinery, fertilizer and seeds by about 10%, 15%, 10%, 20% and 8%, respectively compared to the inefficient farms.

Table 1 Source-wise mean energy distribution among farm groups, MJ/ha

Details	All farms	Efficient farms	Inefficient farms	Optimum level
Human energy	40	38	42	34
Fuel energy	2545	2289	2699	2162
Machinery energy	453	425	470	398
Fertilizer energy	9931	8580	10742	7915
Chemical energy	667	702	646	565
Seeds energy	2493	2365	2563	2141
Total	16129	14399	17162	13215

Excessive use of farm inputs particularly fertilizer, not only makes a farmer to spend more money to procure the fertilizer which lower profit, but as well has some polluting effect downstream [14, 15], which is detrimental to the environment. The use of nitrogen fertilizer in high dose is reported to cause reduction in the growth of rice plant, decrease yield and promotes the rice plant to lodged [16] at maturity causing yield loss.

In terms of field operations, the three farm groups (all farms, efficient farms and inefficient farms) used more energy than the required optimum levels to varying degree as shown in Table 2. For instance, in tillage operation the excess use of energy input above the optimum level by all farms, efficient farms and inefficient farms was 157 MJ/ha (14%), 44 MJ/ha (4%) and 224 MJ/ha (19%) respectively. Similar trends were observed in other operations with recorded use of excess energy, especially in the inefficient farms vis-à-vis other farm groups. In order for the farmers to achieve significant reductions in the use of energy inputs in rice cultivation, they should adopt proper work design that reduces time spent on non-productive 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 service tractor. Having farm areas larger than 1 ha has been shown to improved machinery field performance substantially [11] hence, reduces energy inputs in rice cultivation.

Table 2 Operation-wise energy distribution among farm groups, MJ/ha

Details	All farms	Efficient farms	Inefficient farms	Optimum
Tillage	1137	1024	1204	980
Seeding	2548	2408	2625	2180
Fertilizing	10083	8699	10915	8028
Spraying	1072	1046	1089	867
Harvesting	1289	1222	1329	1160
Total	16129	14399	17162	13215

3.2 Comparison of Energy Ratios Among Farm Groups

In Table 3, the output energy in the efficient farms of 135,259 MJ/ha is about 10% and 6%, higher than the mean output energy recorded respectively, in the inefficient and all farms. The output-input energy ratio at optimum use of energy inputs of 9.67 is higher than that of the all farms (7.92), efficient farms (9.39) and inefficient farms (7.17). Analysis of the result reveals a deficit in the output-input energy ratio for the inefficient farms of about 24% compared to that of the efficient farms. As indicated in Table 3, at optimum use of energy inputs the energy intensity was 1.73 MJ/ha, which means that about 1.73 MJ of energy is required to produce 1 kg of rice. However, none of the three farm groups attained the optimum energy intensity for the rice cultivation. The efficient farms with energy intensity value of 1.78 MJ/ha, fell below the optimum energy intensity level by a small margin of about 3%. Accordingly, the inefficient farms with energy intensity of 2.34 MJ/ha uses about 26%, more energy in producing 1 kg of rice compared to the optimum level. The inefficient farms produced about 428 g of rice using 1 MJ of energy, which is about 24% higher than the energy intensity recorded in the efficient farms. In a nutshell, the inefficient farms losses about 133 g of rice from every 1 MJ of energy they used in the cultivation compared to the efficient farms. Compared to the energy intensity at optimum used of energy inputs, the inefficient farms losses about 149 g of rice per 1 MJ of energy expended in the cultivation. The energy use intensity of 2.11 MJ/kg recorded by an average farmer in the block, was about 18% higher than the optimum level. From this analysis, it is evident that higher rice productivity was obtained through optimum use of the available energy inputs. With higher yield and reduced energy inputs, farmers' net income increases many folds.

Table 3 Comparison of mean energy ratios among farm groups

Details	All farms	Efficient farms	Inefficient farms	Optimum
Energy input, MJ/ha	16129	14399	17169	13215
Energy output, MJ/ha	127726	135259	123039	127726
Energy gain, MJ/ha	111597	120860	105870	114511
Output/Input energy ratio	7.92	9.39	7.17	9.67
Energy intensity, MJ/kg	2.11	1.78	2.34	1.73

3.3 Best Paddy Cultivation Practices

Resulting from the comparison of energy ratio analysis presented in the preceding section, it is clear that the inefficient farms lags behind the efficient farms both in terms of input resource utilization and yield obtained. The efficient farms in the study area used the least energy inputs and they had the highest energy output (rice yield) compared to the inefficient farms. Therefore, the inefficient farms stand a good chance for improving their farm input resource management by following in the footsteps of the efficient farms. In doing so, the overall paddy productivity level will increase, thereby raising the average farmer's income. Summary of the paddy cultivation practices for the three most efficient farms in the study area is presented in Table 4. The three farms were selected as models depicting good cultivation practices for other farms to emulate, based on their high reference frequency in serving as benchmarks to the inefficient farms.

From Table 4, the three most efficient farms (reference farms) operated on farmlands with an average area of 0.704 ha, which is about 8% greater than the average farmland area of 0.65 ha used by the inefficient farms. By this, the machinery that operated on the three reference farms recorded higher field capacities with attendant reductions both in fuel consumption, and machinery and human energy expenditures compared to what obtains in the inefficient farms.

Table 4 Rice cultivation practices of the reference farms

Details	Mean values
Reference frequency	12
Farm size (ha)	0.704
Planting date	7/4/2013
Harvesting date	14/7/2013
Plant age (days) at harvest	98.333
Number of tillage runs	3
Tillage intervals (days)	15
Rice variety	MR220CL2
Seed rate (kg/ha)	123
Fertilizing frequency	4
Fertilization rate (kg/ha)	552
Nitrogen use rate	108
Phosphorus use rate	45
Potassium use rate	90
Magnesium use rate	6
Pesticides use rate (kg/ha)	4.89
Insecticide use rate	2.14
Herbicide use rate	2.05
Fungicide use rate	0.70
Spraying frequency	6
Total energy input (MJ/ha)	13590
Rice yield (kg/ha)	8723
Energy productivity (kg/MJ)	0.642

Three tillage passes were performed in the reference farms prior to seeding operation. The mean interval between the tillage runs was 15 days, which is adequate enough to allow for considerable decomposition of the buried trash, thereby improving the humus content of the soil. It is worth mentioning that whereas long intervals between tillage passes leads to the re-growth of weeds, short intervals however, may cause the semi-decomposed trash material to be exposed to the soil surface, which may cause it to sprout back to life. All the three reference farms planted the same rice variety (MR220-CL2) on their farms using a mean seeding rate of 123 kg/ha, which is about 30 kg/ha (20%) lower than the mean seeding rate of 153 kg/ha employed by the inefficient farms. Low seed rate means higher spacing between rice plants, leading to lower competition for sunlight and essential soil nutrients among the plants. Therefore, better filled grains which translate into higher paddy yield.

The used of MR220-CL2 by all the reference farms in the study area, is a clear indication that it is the preferred variety of choice in the area because of its apparent better performance compared to the other varieties.

The three reference farms used a mean fertilization rate of 552 kg/ha, which is about 92 kg/ha (14.31%) lower than the mean fertilizer use rate of 644 kg/ha adopted by the inefficient farms. The use of two key fertilizer elements of nitrogen and phosphorus were found to be lower in the reference farms compared to their use in the inefficient farms by about 29 and 4 kg/ha respectively. However, in the case of potassium and the oxide of magnesium their use was higher in the reference farms compared to in the inefficient farms by about 15 and 2 kg/ha respectively. It is important to note that one advocated method of improving nitrogen use efficiency (NUE) is by combining it with other elements. Choudhury and Kennedy [17], listed ammonia volatilization as one of the main reasons for the low NUE and further stated that application of calcium, potassium and magnesium can reduce ammonia volatilization in soil-water system. Further, it was observed that up to 60% of the applied N may be lost to the atmosphere in the form of ammonia [18, 19]. The application of urea with potassium chloride was shown to significantly reduce ammonia volatilization, thereby increased NUE [20]. Similarly, it is reported that use of potassium helps to fight diseases in crops [21]. The higher use of magnesium and potassium perhaps facilitated better nitrogen use efficiency in the reference farms, hence it low use by them. Snyder and Slaton [22] concluded that in most rice fields, balanced fertilization with P, K, S, and Zn helps to attained maximum NUE and higher rice yield. The mean fertilization frequency in the reference farms amounted to about four applications per cropping season.

Regarding use of agrochemicals targeted at offering maximum protection to the paddy plant against attacks by pest and diseases, the reference farms utilized about 4.89 kg/ha of assorted chemicals. The mean distribution for the pesticide use rate according to type: insecticides, herbicides and fungicides respectively, is 2.14, 2.05 and 0.70 kg/ha. Compared to the mean pesticides use rate of 5.38 kg/ha adopted by the inefficient farms, the reference farms use less insecticides and fungicides, and more herbicides to the tune of 866, 40 and 415 g/ha respectively. By using more herbicide, the reference farms had a better weed control compared to the inefficient farms. This helps them to eliminate the vital environment which supports the breeding and growth of pests and diseases, hence less need for the application of insecticides and fungicides.

Reductions in seeds, fertilizer and pesticides use rates means less demand for human, fuel and machinery energy required to apply them on the farm. Essentially, the reference farms utilized a mean total energy input of about 13,590 MJ/ha in performing the entire five paddy cultivation operations (tillage, seeding, fertilizing, spraying and harvesting) included in the analysis. The mean total energy input covers human energy (33 MJ/ha), fuel energy (2628 MJ/ha), machinery energy (449 MJ/ha), fertilizer energy (7831 MJ/ha), pesticide energy (587 MJ/ha) and seed energy (2062 MJ/ha) as presented in Table 5. The total energy input used by the reference farms represented only about 79% of the mean total energy input used by the inefficient farms. In other words, the inefficient farms could save up to 21% of their current energy use if they operate at the level of the reference farms. The reference farms had a mean rice yield level of 8723 kg/ha and a mean energy productivity level of 0.642 kg/MJ (Table 4). The mean yield and mean energy productivity in the reference farms were about 1368 kg/ha (19%) and 0.201 kg/MJ (46%), respectively higher than in the inefficient farms.

In a nutshell, the inefficient farms will have better economic return resulting from reduction in energy input and higher yield if they adapt the cultivation package of the reference farms. With increased output and reduced inputs the farmer's net income increases many fold. From this analysis it is therefore, evident that with improved efficiency in the used of farm inputs in rice cultivation, yield was increased and production cost decreased. There is therefore, the need for the inefficient farms to adopt these practices not only because of the high economic potentials therein, but as a way of bridging the huge productivity gap between farms, thus enabling the country to achieve the desired self-sufficiency in rice production.

Table 5 Distribution of mean energy input in the three reference farms, MJ/ha

Operations/Energy source	Human energy	Fuel energy	Machinery energy	Fertilizer energy	Pesticide energy	Seed energy	Total
Tillage	5	1048	99	-	-	-	1152
Seeding	2	38	1	-	-	2062	2103
Fertilizing	8	148	2	7831	-	-	7989
Spraying	15	312	4	-	587	-	918
Harvesting	3	1082	343	-	-	-	1428
Total	33	2628	449	7831	587	2062	13590

3.4 Comparison of Cost Ratios Among Farm Groups

In Table 6 comparison of cost ratios among the different farm groups is presented, where it is shown that the benefit-cost ratio and the total cost productivity in the efficient farms of 1.52 and RM791/ha, respectively are at par with the optimum levels. This indicated that the efficient farms achieved maximum financial benefit in the rice cultivation. The gross margin at optimum use of energy input of RM3118/ha was about RM627/ha higher than the gross margin earned by an average farmer in the block of RM2491/ha. The efficient farms made lower cost spending on farm inputs of about RM404/ha compared to the inefficient farms. The gross margin in the two groups of farms was found to be different by about RM1254/ha, being higher in the efficient farms. In other words, the efficient farms gained about 1.61 times the profit margin made by the inefficient farms. The benefit-cost ratio was 1.52 for the efficient farms compared to 1.30 for the inefficient farms. The break-even yield for efficient farms was found to be 5.33 tons/ha compared to a value of 5.65 tons/ha for the inefficient farms. Similarly, the cost of producing one ton of rice was lowest in efficient farms (RM791/ton) compared to that of the inefficient farms (RM923/ton). Whereas the efficient farms spend about RM0.79 to produce 1 kg of rice, the inefficient farms spend higher amount of RM0.92 to produce the same 1 kg of paddy. This means that the efficient farms have a cost savings of about RM0.13/kg compared to inefficient farms. In terms of cost productivity due to operational energy sources of human labor, machinery used and fuel consumed by the machinery used in the cultivation, the highest productivities (i.e. lowest cost per ton of paddy produced) were recorded in the efficient farms. The efficient farms were found to expend about RM71/ton of paddy produced on human labor, which is about RM15/ton lower than the amount of money paid to farm workers by the inefficient farms. The cost expenditure on machinery used was RM100/ton in efficient farms, which is about 10% lower than machinery use cost of RM111/ton recorded in the inefficient farms. The cost of fuel used by inefficient farms of RM16/ton is about 1.28 times higher than fuel cost recorded in the efficient farms.

Table 6 Comparison of cost ratios among farm groups

Details	All Farms	Efficient Farms	Inefficient Farms	Optimum level
Yield (tons/ha)	7.63	8.08	7.35	7.63
Paddy price (RM/ton)	1200	1200	1200	1200
Value of yield (RM/ha)	9150	9691	8826	9150
Break even yield (ton/ha)	5.55	5.33	5.65	5.03
Total cost of inputs (RM/ha)	3906	3632	4036	3279
Rent (RM/ha)	2600	2600	2600	2600
Transport cost (RM/ha)	153	162	147	153
Total cost of production (RM/ha)	6659	6394	6783	6032
Gross margin (RM/ha)	2491	3297	2043	3118
Benefit-cost ratio	1.37	1.52	1.30	1.52
Labor cost productivity (RM/ton)	81	71	86	69
Fuel cost productivity (RM/ton)	15	12	16	13
Machinery cost productivity (RM/ton)	108	100	111	94
Total cost productivity (RM/ton)	873	791	923	791

4.0 CONCLUSION

This study examined the energy use intensity and cost expenditures in direct seeding systems of rice cultivation in North-west IADA Selangor. Resulting from the application of DEA and benchmarking methodology to the energy inputs and output data of the 40 farms studied, the following conclusions are made:

i. At mean total energy inputs of 16,129 MJ/ha in all farms, 14,399 MJ/ha in the efficient farms and 17,169 MJ/ha in the inefficient farms, the energy intensities were 2.11, 1.78 and 2.34 MJ/kg, respectively. The optimum total energy inputs for the cultivation was 13,215 MJ/ha with corresponding energy intensity of 1.73 MJ/kg, which is about 3%, 18% and 26% lower compared respectively, to the energy use intensity in the efficient farms, all farms, and inefficient farms.
ii. The efficient farms had an output/input energy ratio of 9.486 which is about 22% higher than the output/input energy ratio of the inefficient farms. The benefit-cost ratio was 1.52 in efficient farms compared to 1.30 in the inefficient farms.
iii. An average farmer in the study area looses about RM672/ha resulting from excess use of farm inputs above the optimum level.
iv. The three reference farms selected for their high benchmarking reference frequencies, employed seed, fertilizer and pesticide use rates of 123, 552 and 4.89 kg/ha respectively, which were significantly lower compared to the mean values used by the inefficient farms. The mean yield and mean energy intensity in the reference farms were about 19% and 46% higher than in the inefficient farms. It is evident that with improvement in energy use intensity in rice cultivation, the yield was significantly increased. There is therefore, the need for the inefficient farms to adapt the cultivation practices of the reference farms not only because of the high economic potentials therein, but as a way of bridging the huge rice productivity gap between farms, thus enabling Malaysia to achieve the desired 100% self-sufficiency in rice production in the near future.

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References

[1] Food and Agriculture Organization Statistics (FAOSTAT). 2013. Accessed on 12/2/2015 @http://www.faostat.fao.org/.
[2] Muazu, A., Yahya, A., Wan Ishak, W.I. and Khairunniza-Bejo, S. 2015a. Energy Audit for Sustainable Wetland Paddy Cultivation in Malaysia. *Energy*. 87: 182-191.
[3] Chong, E. P. K. and Zak, S. H. 2001. *An Introduction to Optimization.* 2nd Edition. John Wiley & Sons Inc, New York.
[4] Singh, G., Singh, S. and Singh, J. 2004. Optimization of Energy Inputs for Wheat Crop in Punjab. *Energy Conservation and Management*. 45: 453-465.
[5] Chauhan, N. S., Mohapatra, P. K. J. and Pandey, K. P. 2006. Improving Energy Productivity in Paddy Production

through Benchmarking–An Application of Data Envelopment Analysis. *Energy Conservation and Management*. 47: 1063-85.

[6] Nassiri, S. M. and Singh, S. 2009. Study on Energy Use Efficiency For Paddy Crop Using Data Envelopment Analysis (DEA) Technique. *Applied Energy*. 86: 1320-1325.

[7] Eyitayo, O. A., Chris, O., Ejiola, M. T. and Enitan, F. T. 2011. Technical Efficiency of Cocoa Farms in Cross River State, Nigeria. *African Journal of Agricultural Research*. 6: 5080-5086.

[8] Banaeian, N., Omid. M. and Ahmadi, H. 2011. Application of Data Envelopment Analysis to Evaluate Efficiency of Commercial Greenhouse Strawberry. *Research Journal of Applied Sciences, Engineering and Technology*. 3: 185-193.

[9] Mohammadi, A., Rafiee, S., Mohtasebi, S. S., Mousavi Avval, S. H. and Rafiee, H. 2011. Energy Efficiency Improvement and Input Cost Saving in Kiwifruit Production Using Data Envelopment Analysis Approach. *Renewable Energy*. 36: 2573-2579.

[10] Muazu, A., Yahya, A., Wan Ishak, W.I. and Khairunniza-Bejo, S. 2014. Yield Prediction Modeling Using Data Envelopment Analysis Methodology for Direct Seeding, Wetland Paddy Cultivation. *Agriculture and Agricultural Science Procedia*. 2: 181-190.

[11] Muazu, A., Yahya, A., Wan Ishak, W. I. and Khairunniza-Bejo, S. 2015b. Machinery Utilization and Production Cost of Paddy Cultivation under wetland Direct Seeding Condition in Malaysia. *Engineering in Agriculture, Environment and Food*. Article in Press, doi: 10.1016/j.eaef.2015.03.007.

[12] Kumar, P. S. P. and Hugar, L. B. 2011. Economic Analysis of Energy Use in Paddy Cultivation under Irrigated Situations. *Karnataka Journal of Agricultural Science*. 24(4): 467-470.

[13] Khan, M. A. Awan, I. U. and Zafar, J. 2009. Energy Requirement and Cost Analysis of Rice Production in Western Part of Pakistan. *Soil & Environment.* 28: 60-67.

[14] Kasmaprapruet, S., Paengjuntuek, W., Saikhwan, P. and Phungrassami, H. 2009. Life Cycle Assessment of Milled Rice Production: Case Study in Thailand. *European Journal of Scientific Research*. 3(2): 195-203.

[15] Ferry, J. G. 1992. Biochemistry of Methanogenesis. *Critical Reviews in Biochemistry and Molecular Biology*. 27(6): 473-503.

[16] Prasertsak, A. and Fukai, S. 1992. Nitrogen Availability and Water Stress Interaction on Rice Growth and Yield. *Field Crops Research*. 52: 249-260.

[17] Choudhury, A. T. M. A. and Kennedy, I. R. 2005. Nitrogen Fertilizer Losses from Rice Soils and Control of Environmental Pollution Problems. *Communications in Soil Science and Plant Analysis*. 36: 1625-1639.

[18] De Datta, S. K. 1985. Availability and Management of Nitrogen in Lowland Rice in Relation To Soil Characteristics. In Wetland Soils: Characterization, Classification, and Utilization. Banta, S. J. ed.; International Rice Institute: Los banos, Philippines. 227-267.

[19] Xiang, G. X. and Zhu, Z. L. 2000. An Assessment of N Loss from Agricultural Fields to the Environment in China. *Nutrient Cycling in Agroecosystems*. 57: 67-73.

[20] Khanif, Y. M and Wong, L. P. 1987. Control of Volatilization Loss by Soluble Cations and Urease Inhibitors. Proceedings of International Symposium on Urea Technology and Utilization; Pushparajah, E., Huusin, A. and Bachik, A.T., eds.; Malaysian Society of Soil Science: Kuala Lumpur, Malaysia. 311-320.

[21] Ferrero, A. and Tinarelli, A. 2008. Rice Cultivation in the EU Ecological Conditions and Agronomical Practices. Pesticides Risk Assessment in Rice Paddies: Theory and Practice. Capri, E. and Karpouzas, D. G., eds. Elsevier B.V; 2008. 1-24.

[22] Snyder, S. K. and Slaton, N. A. 2001. Rice Production in the United States–An Overview. *Better Crops*. 8(30): 1-7.