UNIVERSITI PUTRA MALAYSIA

MODELING FOR ENERGY OPTIMIZATION IN WETLAND PADDY PRODUCTION IN NORTH-WEST SELANGOR, MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2015

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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June 2015

Chair: Associate Prof. IR. Azmi bin Dato Yahya, PhD

Faculty: Faculty of Engineering

In Malaysia, rice is the staple food for the populace and a source of income to the majority of the rural dwellers. The country relies on imported rice to argument the shortfall in local production vis-à-vis demand. The locally produced rice cost more than similar grade of imported rice. Reducing production cost and enhancing paddy productivity are achieved through optimum use of resources, to which on-farm energy analysis plays a central role by addressing issues of excess energy use.

In this study, a thorough on-farm evaluation of farm inputs and output was conducted in 40 farms with net cultivation land area of 27.005 ha at Block E5 Parit Lima Timur, Sungai Besar, North-West Integrated Agricultural Development Authority Selangor, to determine energy and cost efficiency of paddy production in the area and to develop a computer-based platform for appraising performance. The measured farm inputs were converted into energy values using appropriate conversion coefficients and the cost of inputs evaluated based on the prevailing market rate. The technical efficiency of the farms was determined using input oriented constant return to scale Data Envelopment Analysis (DEA) methodology. Quantification of excess energy used in the farms was done using DEA identified benchmarks. The benchmarking results were used to develop maximum yield predictive models for performance appraisal. A method of reference frequency was used to determine best paddy cultivation practices for enhanced paddy productivity. A motion study was conducted to evaluate the mechanization indexes of operations and in the development of fuel predictive models.

From the results of the study, at mean yield of 7625 kg/ha, the energy expenditure was 16,440 MJ/ha with energy intensity value of 2.16 MJ/kg. Cost-wise farmers in the study area expended about RM6658/ha and had a benefit-cost ratio of 1.37 and 1.68 with and without government subsidy respectively. Results from DEA analysis showed that about 18% (2915 MJ/ha) of the total energy input was used in excess of the required optimum. The excess use of energy ranges from 12% for machinery to 20% for fertilizer. Three best farms selected for their high reference frequency use less farm inputs and they have higher yield by about 19%, compared to the inefficient farms. The mean mechanization index (MI) for the cultivation was 0.92 and spraying operation with MI of 0.19, is identified as the most critical operation requiring mechanization priority. The developed multiple linear regression maximum yield predictive models revealed an inverse relationship between paddy yields with seed energy. A quadratic relationship exists between total optimum energy inputs with paddy yield. Resulting from this study, a novel decision support graphical user interface for computing optimum energy input and cost has been developed using Java programming language in NetBeans IDE release 7.2.1. The program is distributable in the form of an executable file with a computer hard disk space requirement of about 3.65 MB.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN UNTUK OPTIMIZATION TENEGA DALAM PAYA PADI PENGELUARAN ALAM BARAT LAUT SELANGOR, MALAYSIA

Oleh

ALIYU MUAZU

June 2015

Pengerusi: Prof Madya IR. Azmi bin Dato Yahya, PhD

Fakulti: Fakulti Kejuruteraan

Di Malaysia, beras adalah makanan ruji bagi penduduk dan merupakan sumber pendapatan kepada majoriti penduduk luar bandar. Negara ini bergantung kepada beras import kerana kekurangan dalam permintaan pengeluaran tempatan vis-à-vis beras keluaran tempatan lebih mahal daripada beras import gred yang sama. Mengurangkan kos pengeluaran dan meningkatkan produktiviti padi dicapai melalui penggunaan sumber optimum, yang mana analisis tenaga di ladang memainkan peranan utama dengan menangani isu lebihan penggunaan tenaga. Dalam kajian ini, satu penilaian menyeluruh di ladang input ladang dan output telah dijalankan di 40 ladang dengan kawasan Tanah penanaman bersih 27.005 ha di Blok E5 Parit Lima Timur, Sungai Besar, Lembaga Utara-Barat Pembangunan Pertanian Bersepadu Selangor, untuk menentukan Tenaga dan kos kecekapan Pengeluaran Padi di kawasan itu dan untuk membangunkan satu platform berasaskan komputer untuk menilai prestasi. Input ladang diukur telah ditukar, ke dalam nilai-nilai Tenaga menggunakan pekali penukaran yang sesuai dan kos input dinilai berdasarkan kadar pasaran semasa. Kecekapan teknikal ladang-ladang telah ditentukan dengan menggunakan berorientasikan Input berterusan kembali ke skala Data Penyampulan Analisis (DEA) metodologi. Kuantifikasi tenaga berlebihan yang digunakan di ladang-ladang telah dilakukan dengan menggunakan tanda aras Dea dikenal pasti. Penandaarasan hasilnya digunakan untuk membangunkan hasil maksimum model ramalan bagi penilaian prestasi. Kaedah kekerapan rujukan telah digunakan untuk menentukan amalan penanaman padi terbaik untuk peningkatan produktiviti padi. Kajian motion telah dijalankan untuk menilai indeks jentera operasi dan dalam pembangunan bahan api model ramalan.

Dari hasil kajian, pada kadar hasil purata 7625 kg / ha, perbelanjaan tenaga adalah sebanyak 16,440 MJ/ha, dengan tenaga intensiti nilai 2.16 MJ/kg. Kos bijaksana petani di kawasan kajian dibelanjakan kira-kira RM6658/ha dan adalah nisbah faedah-kos GNT john 1.37 dan 1.68 dengan dan tanpa subsidi kerajaan masing-masing. Keputusan daripada analisis DEA menunjukkan kira-kira 18% (2915 MJ/ha) tenaga jumlah input telah digunakan melebihi optimum yang diperlukan. Penggunaan berlebihan tenaga ranges daripada 12% untuk jentera hingga 20% untuk baja. Tiga ladang terbaik dipilih untuk rujukan tinggi kekerapan kurangkan input ladang dan mereka mempunyai hasil yang lebih tinggi oleh kira-kira 19%, berbanding dengan ladang-ladang yang tidak cekap. Purata penggunaan jentera indeks (MI) untuk penanaman adalah 0.92 dan semburan operasi dengan MI daripada 0.19, dikenal pasti sebagai operasi kritikal terbesar yang memerlukan keutamaan kepada jentera. Maju regresi linear pelbagai maju hasil maksimum model ramalan mendedahkan hubungan songsang antara padi terhasil dengan tenaga biji berih. A hubungan kuadratik wujud di antara jumlah input tenaga optimum dengan hasil padi. Hasil daripada kajian ini, antara muka pengguna grafik sokongan keputusan novel untuk mengira input tenaga optimum dan kos telah dibangunkan dengan menggunakan bahasa pengaturcaraan Java dalam NetBeans IDE pelepasan 7.2.1. Program ini boleh diagihkan dalam bentuk fail boleh laku dengan komputer keras keperluan ruang cakera kira-kira 3.65 MB.

ACKNOWLEDGEMENTS

All special praises are due to Allah for granting me the ability to undertake the program without much adieu.

I wish to acknowledge with high level of appreciation the unquantifiable, timely and valuable contributions of the chairman of my supervisory committee, Assoc. Prof. Dr. Azmi bin Dato Yahya, for his constructive criticisms, valuable advice, thorough guidance and consistent words of encouragement, which evidently led to the successful completion of this research within the time limit. Similarly, the valuable contributions of the members of my supervisory committee in persons of Prof. Wan Ismail Wan Ishak and Assoc. Prof Siti Khairruniza binti Bejo are highly acknowledged.

My appreciation also goes to the Universiti Putra Malaysia for providing funds for the research project under the Research University Grant Scheme (RUGS) 2 – 20/2 Grant No 9347400. I thank my employer, Kebbi State College of Agriculture, Zuru for the opportunity and all the supports accorded to me throughout the period of my study. The enormous support from the paddy farmers at Block E5 Parit Lima Timur Sungai Besar is also highly appreciated. I also want to appreciate the kind assistance from Mr. Roshdi of our Machine Design Laboratory, Mr. Erwin my field assistant and my lab mates: Dr. Tajudeen, Dr. Renny, Suha, Mumtaz, Husna and Haslina. The timely assistance from my brothers especially Muhammad Muazu and Ibrahim Saidu and my sisters who are too numerous to mention here is also highly acknowledged. I also wish to appreciate the supports from my friends, Umar, Yakubu, Yusuf, Ibrahim and Sulaiman. To my wife and children I salute their courageous and thoughtful understanding.

I certify that a Thesis Examination Committee has met on 9th June, 2015 to conduct the final examination of Aliyu Muazu on his thesis entitled "Modeling for energy optimization in wetland paddy production in North-West Selangor" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Degree of Doctor of Philosophy.

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Rice is a cereal crop grown and consumed on every continent of the world because of its adaptive capabilities which enables it to grow in areas of differing soil types and climatic conditions (Ferrero and Tinarelli, 2008). It ranks as 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, 2014). In the same year, Southeast Asian countries with combined rice production output of 217,174,887 tons accounted for about 30% of the world's total production

About 692,340 ha of arable land in Malaysia were subjected to rice cultivation in 2012. The country has eight rice granary areas which practice double cropping per year. The granary areas account for about 72% of lowland rice cultivated in the country (Najim et al., 2007). Considerable upland rice cultivation is also done in Malaysia (Hanafi et al., 2009). The year round rainfall distribution, tropical temperatures and high humidity serving as great assets supporting multiple paddy cropping systems in the country. In the past four decades successive governments in Malaysia have put emphasis on rice production being the national staple food, with a view to achieving self-sufficiency in the production. The emphasis on achieving self-sufficiency in rice production has led to considerable infrastructural developments. Such as construction of good access roads to paddy fields, irrigation/drainage facilities, provision of extension services, machinery packages, in addition to the subsidy and special incentive support packages, including guaranteed minimum price and bumper harvest prize to farmers. Despite the huge yearly budgetary expenditure dedicated to supporting paddy production, the average national yield of 3.782 tons/ha (FAOSTAT, 2014) is still about 10% lower than the world average.

Rice in Malaysia is not only the national staple food but as well its cultivation in the country is a source of employment/income to majority of rural dwellers. As much as 150,000 farmers depend exclusively on rice cultivation for their overall sustenance (Najim, 2007). Despite massive government support extended to rice farmers over the years through subsidy which virtually covers all farm inputs as mentioned in the preceding paragraph, the country is still not self-sufficient in rice production. Nearly one third of the country's rice requirement is met through import. Although according to FAOSTAT (2014), from 1970 to 2010 rice productivity in Malaysia rose from 2.386 t/ha to 3.782 t/ha (up 58.51%), however the area under rice cultivation declined 4.4% when it drops from 704,767 ha to

673,745 ha, population rose by 1.6 times and rice import jumped from 355,450 tons to 931,444 tons (i.e. increased 162.05%). Corresponding to these jumps, the rice import bill skyrocketed 10.91 times from $42,011,000 in 1970 to $500,369,000 in 2010, thereby straining the economy through foreign exchange depletion. Given the country's current population figures of 28,401,000 and per capita rice consumption of 110 kg/year, for the country to achieve 100% self-sufficiency from the present 73% sufficiency level, rice production must reach 3,216,100 tons from the present production level of 2,548,000 tons. Furthermore, given the present trend in annual population growth of 1.43% the country's population is projected to hit 32.56 million people by 2020. As such rice production must reach 3,581,600 tons by the said year in order to attain 100% self-sufficiency level. In other words for the country to be 100% self-sufficient in rice, production will have to be raised by 1,033,600 tons, up 40.57% from the current production level. Assuming the current land area under rice cultivation remains unchanged, average national yield must reach 5.32 tons/ha by 2020 if the country must be 100% self-sufficient.

Production increase is generally achieved by either increasing area under rice cultivation or increasing farm land productivity through optimization in the use of farm inputs or both. Increasing rice production in Malaysia through area expansion is not feasible because of limited arable land suitable for rice cultivation in the country. Malaysia is unable to have a breakthrough in terms of achieving 100% rice self-sufficiency level, because the recorded increases in rice productivity over the years was not commensurate with the decline of land under rice cultivation, population explosion and the change in the eating habit of the people. In order for the country to be fully sufficient in rice production, productivity must be increased tacitly in such a manner pursued by some countries with similar problems of dwindling land area under rice cultivation e.g. China which was able to raised production 74.37% by nearly doubling its rice productivity level.

Furthermore, it is worth mentioning here that rice production in Malaysia is expensive compared to what obtains in some neighboring countries. As a matter of fact the country lacks competitive advantage (Murad et al., 2008) in terms of local rice production and this suggests that paddy production is neither viable nor sustainable in the country (Man and Sami, 2009). Najim et al., (2007) claimed that imported white milled rice cost less by about RM590/ton compared to the cost of similar grade of rice produced locally. Assuming a total annual production of 2.4 million tons and a conservative production cost difference of only RM300/ton between local and imported rice in favor of imported rice, this translates into a staggering sum of RM720 million/annum in lost revenue to local paddy farmers. It represents a clear case of financial loss the side effects of which is multi-faceted and must not be allowed to go unchecked. Particularly that incidence of poverty is higher among paddy farmers in the country compared to other segments of the population engaged in other occupations. Study conducted by Man and Sami (2009) revealed that more than 35% of the farmers surveyed had income in the range of RM3000 – RM6000/annum with about 2 – 6 dependents. Increasing rice productivity will go a long way in enhancing the quality of life for the farmers by increasing profitability, sustainability and above all self-reliance.

Considering the abundant water resources, productive land (though greatly limited) and the performance of high yielding rice varieties introduced in Malaysia which are key factors in boosting rice production, the country has the potential to increase rice productivity not only to achieve self-sufficiency level but as well become a net rice exporting country. The average annual rainfall in the country is well above 2,500 mm higher than in China, Thailand, Australia, Vietnam and Myanmar and is a huge competitive edge over these countries. The rice varieties introduced in the country by the Malaysian Agricultural Research and Development Institute (MARDI), particularly the MR219 and MR220, are high yielding and so far are doing well and have potential output of up to 10 tons/ha. At individual farm level, reported cases of bumper harvest greater than 8 tons/ha exist. With a total annual land area of 673,745 ha dedicated to rice cultivation, if the national average rice yield is raised to 6 tons/ha, the country's rice output will hit 4 million tons, and this could easily place Malaysia in the league of rice exporting nations even at the face of population growth. The major drawback to realizing this being the huge differences in rice yield recorded at the granary areas. For example whereas the farmers IADA North-west Selangor obtained mean yield above 5 tons/ha, in other irrigation schemes example at Kemasin Semerak, the farmers obtained yield as low as 2.877 tons/ha (DOA, 2010). The high disparity in rice yield across the country continues to be a strong barrier for its quest to achieve the desired 100% self-sufficiency in rice production with the given limited paddy cultivation area.

The huge difference in yield particularly at farm levels is worrisome, hence its nature need to be investigated, causes determined and remedial actions effectively proffered. The best viable approach is to conduct a thorough on-farm input and output audit (energy analysis) study, which will cover all the operations involved in wet paddy cultivation, in the most productive irrigation scheme in the country. In this way the technical efficiency of the farmers involved in the study along with their cultivation practices would be uncovered. So that the practices of the most efficient farmers among them, could serve as models for the less performing farmers to adopt, especially by farmers operating in the less productive irrigation schemes in the country. This becomes necessary because any meaningful improvement, in rice productivity will only be achieved through effective and efficient application of available farm inputs. In a nutshell, a possible way of raising farm productivity at reduced cost is through optimum use of resources, to which on-farm energy analysis plays a central role by addressing the issues of excess energy utilization. Energy analysis is a sure methodology for providing synthesized information, useful to both farmers and agricultural policy makers, regarding best practices capable of promoting optimum energy resource utilization, rice productivity and profitability. It has especially been identified as a valuable tool for computing financial savings and fossil fuel conservation (Lu et al., 2010).

In crop production, energy analysis is usually performed to determine where and how energy is being used, the information obtained is then used to improve efficiency and reduce costs. For the information to be of great importance to the farmers however, a critical performance assessment methodology is required to expose level of inefficiencies in the farms in their use of energy inputs, and in suggesting appropriate practices to remedy wastage and make the occupation profitable. Such capabilities are found in Data Envelopment Analysis (DEA), which is a mathematical programming model applied to observation data and it provides a way of obtaining empirical estimates of relationships (Cook and Zhu, 2005). It is an excellent and easily to used methodology for modeling operational processes for performance evaluations. Unlike traditional statistical approaches used to evaluate farmers' performance relative to an average farmer (central tendency), it compares each farmer with the best farmers (frontier approach). DEA is most useful when a comparison is intended against best farmers and it opened up possibilities for use in scenarios that have been resistant to other approaches. Particularly in complex cases with an unknown relationship between inputs and outputs (e.g. ability to quantify effects of varying energy inputs on rice yield) involved.

DEA has found wide application in the area of energy optimization studies in agriculture for its ability to benchmark farmers and in identifying their technical efficiencies. It was used in energy optimization studies for canola production (Unakitan et al., 2010 and Mousavi-Avval et al., 2011), kiwi production (Mohammadi et al., 2011), apple production (Mousavi-Avval et al., 2011b) and broiler production (Heidari et al., 2011b). In DEA there are a number of producers also called decision making units (DMUs) using varying levels of inputs to generate varying levels of outputs. The basic idea behind DEA is that the efficiency of a DMU can be determined by the ratio of its weighted output and weighted input. DEA attempts to determine which of the DMUs are most efficient and point out specific inefficiencies of other DMUs. In crop production the DMUs are the participating farms in the study.

1.2 Statement of the problem

Rice production involves several energy expending operations which include seed selection, seedbed and land preparation, planting, weeding, fertilizing, pest management, harvesting, threshing, drying and irrigation activities. These operations are conducted using energy from different sources including human, fuel, machinery, fertilizer, pesticides and seeds. Generally, in crop production energy is used directly in operating machinery and equipment, and indirectly through the application of fertilizer and agro-based chemicals. Availability of the right energy in sufficient quantity, at the right time, is a prerequisite for the timely completion of rice production operations, which is a key to securing maximum yield. In order to achieve maximum benefits, farmers must have the correct energy mix at the right time. Too much energy input signifies uneconomic production and therefore waste, which may lead to decrease or loss in benefit, increase in global warming and pose some stress on the environment. Too little energy than required, makes it difficult to attain maximum productivity level to guarantee the required level of food sufficiency.

Modern paddy cultivation in Malaysia involves the use of different types of machinery that are powered through the combustion of fossil fuel, which is subsidized by government. Information on the quantity of fuel use could easily indicate the future fuel cost the farmers will have to contend with, in the absence of the government subsidies and encourage them to adopt farming practices that will optimize fuel use more rigorously. Furthermore, data generated on the fuel consumption by the machinery in performing field operations, could be used to develop fuel predictive models, for use at farm level by the farmers and in quantifying the level of carbon dioxide (CO_2) emissions due to fuel use in rice cultivation. 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 thereby 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. Furthermore, 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 greenhouse gas emissions by 40% in 2020 (Shafie et al., 2011).

The lack of enough labor force in the paddy cultivation sector is another area of great concern both to farmers and agricultural policy makers because of its strong influencing effects on production cost and the need for achieving timeliness in completion of critical farm operations in order to avoid undue losses. In the last two decades labor availability in agriculture in Malaysia has declined by about 21.83% from 1,901,000 people in 1993 to 1,486,000 people in 2013 (FAOSTAT, 2014). Presently, studies have shown imported white milled rice cost less compared to similar grade of rice produced locally. One way to reduce production cost is by mechanizing operations with the highest human labor engagement in paddy production. The need for human labor in agriculture reduces with an increase in the level of mechanization (Baruah and Bora, 2008). Complete information about the level of machinery inclusion in each operation is required for effective assessment of farm mechanization status for paddy production system. Such information has the potentials to reveal critical operations requiring mechanization, so as to enhance paddy yield through efficient and timely completion of operations. With correct farm machinery of appropriate power ratings, availability of water for irrigation and proper planning, paddy cropping intensity per year could be increased, thereby boosting the annual production.

Currently, there are no documented studies regarding the extent of the machinery involvement in typical direct seeding wetland paddy cultivation systems, in Malaysia. Information about the level of machinery involvement at each level of paddy cultivation could be used by the agricultural policy makers in their tasks of making comprehensive farm mechanization plan for the country, in line with the rapid modernization and industrialization going on in the country. The developments are increasingly making paddy production less attractive to the educated youths partly because of the perceived field work drudgeries and the widely acknowledged low income earned by paddy farmers compared to earnings made by segment of the society engaged in other occupations.

Another area of concern is in the used of mineral fertilizer and chemical pesticides. Although rice yield is said to increase with an increase in fertilizer input (Fan et al., 2005), excessive application of nitrogen fertilizer pollutes the environment, ground water and may lead to surface erosion and the leakage of nitrogen (Ya-Guang et al., 2010). Considering the fact that about $2/3^{rd}$ of the country's annual fertilizer requirements are met through imports, high price change for fertilizer in the global market may likely affect the level of subsidy offered by government on fertilizer to farmers. With or without subsidy, paddy farmers must make profit and continue to make profit for them to remain in the occupation. Profit making and its consolidation are only possible when inefficiencies in the system are eliminated – i.e. the need for optimum resource utilization. The optimum use of fertilizer is necessary in order to promote sustainable rice production at reduced cost. With an on-farm energy study, the amount of fertilizer required to achieve maximum yield could be ascertained through a modeling approach. Such a modeling work in direct seeding paddy cultivation is lacking in the database.

Similarly although the significant contribution of chemical pesticides in improving paddy productivity is well documented however, on the one hand, it is obvious that an excessive use of pesticides, apart from polluting the environment, has some negative effects on the growing paddy plants in terms of their growth and survivability. On the other hand, using the pesticides below recommended dose may cause the pests to mutate and becomes resistant to the chemicals, leading to the need for increased application frequencies. The key to good pesticides management includes adherence to manufacturers' recommendations in terms of mixing ratio and dosage used per hectare, in addition to the employment of appropriate technology in performing the applications. One way of raising the farmers' awareness about their compliance level in the use of the chemicals, is by having a computing algorithm that could indicate the required volume of solution to use, while considering the recommended mixing ratio and application dose for the chemicals. This needed computing algorithm is to date not known to exist in the literature.

Since efficient management of resources in any production system relates the production of outputs with maximum economic returns. A mathematical model that relates inputs with outputs is used by researchers to gain insight into the responses of output due to changes in inputs, so that the most influential input variables are adequately managed for maximum yield. In crop production, yield is globally acknowledged to have a positive correlation with energy input (Singh, 1999). Knowledge of this relationship stirs the interests of researchers towards performing energy analysis with a view to improving the performance of the production system through modeling. Several energy studies in crop production that link energy flows with crop yield are available in the literature. However, the currently available models do not predict the maximum yield a farmer should expect from a given level of energy inputs. Thus, it is desirable for a farmer to have a user-friendly model that can predict expected maximum yield from a given level of primary energy inputs (seeds, labor, machinery, fuel, fertilizer and pesticides). The model could readily serve as a tool for performance appraisal of previous paddy cultivations and quantification of the level of underperformance, so that appropriate remedial actions can be taken to improve future paddy productivity. To our knowledge, to date there is no energy study that have investigated optimum energy input in the direct seeding wetland paddy cultivation system and related it with the crop yield.

Considering all these challenges, a comprehensive on-farm energy audit study for direct seeding paddy cultivation targeted at optimizing the use of farm inputs, will be a welcomed development to farmers, as well as the agricultural policy makers in the country. The study results when integrated into a computer program, will not only help foster our understandings about the likely effect of changes in the energy mix on paddy productivity, but as well accord farmers the opportunity to make informed decisions in selecting energy mix to maximize crop productivity. To ensure food security and get rid of poverty among the paddy farmers, rice productivity must increase appreciably and at reduced cost. Therefore, an easy to use computing system is required to serve as a decision support system to the farmers in their quest to achieve higher yield with less use of farm inputs.

1.3 Research objectives

The main aim of this research is to develop an energy optimization model for direct seeding rice cultivation system in Malaysia with due regards to farm size and cultural practices employed by the farmers.

The specific aims of the current study include:

1. Determine the energy inputs and production cost for direct seeding wetland paddy cultivation in Malaysia.
2. Develop a regression model for predicting maximum rice yield for given levels of energy inputs.
3. Develop a robust computer decision support program for computing optimum energy and cost requirements based on farmers' supplied paddy cultivation data.
4. Identify best agricultural practices with respect to optimum energy use and cost obligation to ensure sustainable paddy production.

1.4 Scope of the study

Paddy farmers in Malaysia practice both direct seeding and transplanting system of cultivation, this study is limited to the direct seeding system of cultivation. Farmers practicing direct seeding system of paddy cultivation perform about eleven different types of operations namely: tillage, seeding, fertilizing, spraying, harvesting, slashing, liming, leveling, irrigation, dredging of drainages and foot path making activities in some seasons. The research is however, limited to evaluating six standard operations (tillage, seeding, fertilizing, spraying, harvesting and slashing) practiced by farmers in the study area. For the purpose of developing yield predictive models, the study utilized energy data from five operations (tillage, seeding, fertilizing, spraying and harvesting) because of their relationship with paddy yield.

Generally, the scope of the study is limited to developing computer based decision support program, for evaluating energy and cost expenditures in wetland paddy cultivation, so that wasteful uses of energy hence, cost expenditures therein, may be pinpointed and described more precisely vis-à-vis cultural practices of the farmers. The study while using measured farm input data, shall offer a complete platform for computing the various measures of energy and cost indicators; generate reports on machinery utilization, and to effectively appraise the performance of farmers in their use of energy resources.

REFERENCES

Aguilar, M. and Borjas. F., 2005. Water use in three rice flooding management systems under Mediterranean climatic conditions. *Spanish Journal of Agricultural Research,* 3(3): 344-351.

Ahmed, T., Takigawa, T., Noguchi, R. and Tian, L., 2010. System design for renewable energy resources in agriculture.

Alam, M.M., bin Toriman, M.E., Siwar, C., Molla, R.I. and Talib, B., 2011. The impacts of agricultural supports for climate change adaptation: Farm level assessment study on paddy farms. *American Journal of environmental Sciences,* 7(2): 178-182.

Alluvione, F., Moretti, B., Sacco, D. and Grignani, C., 2011. EUE (energy use efficiency) of cropping systems for a sustainable agriculture. *Energy,* 36: 4468-4481.

American Society of Agricultural and Biological Engineers (ASABE) Standard D497.5., 2006. *Agricultural machinery management data.* St Joseph, Mich.

Appl, M., 1997. *Ammonia, Methanol, Hydrogen, Carbonmonoxide. Modern Production Technologies.* CRU Publishing Ltd., London, UK.

Asgharipour, M.R., Mondani, F. and Riahinia, S., 2012. Energy use efficiency and economic analysis of sugar beet production system in Iran: A case study in Khorasan Razavi province. *Energy*, 44: 1078-1084.

Aung, N.M., 2012. Production and economic efficiency of farmers and millers in Myanmar rice industry. Institute of developing economies, Japan external trade organization. V.R.F. Series No.471

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.

Barber, A., 2004. Seven case study farms: total energy and carbon indicators for New Zealand arable and outdoor vegetable production. AgriLINK New Zealand Ltd.

Barker, R., R.W. Herdt, and B. Rose. 1985. The rice economy of Asia. Washington, D.C.

Barr, R.S., 2013. DEA software tools and technology – state of the art survey. Retrieved online @ http://faculty.smu.edu/barr/pubs/tr04-05.pdf on 12/12/2013.

Baruah, D.C. and Bora, G.C., 2008. Energy demand forecast for mechanized agriculture in rural India. Energy Policy, 36: 2628–2636.

Baruah, D.C. and Dutta, P.K., 2007. An investigation into the energy use in relation to yield of rice (Oryza sativa) in Assam, India. *Agriculture, Ecosystems and Environment,* 120: 185-191.

Bautista, E.G. and Minowa, T., 2010. Analysis of the Energy for Different Rice Production Systems in the Philippines. *Philipp Agric Scientist,* 93: 346-357.

Bayer D, and Hill J. Weeds. In: Flint M, editor. Integrated pest management for rice. University of California and Division of Agricultural and Natural Resources, Oakland, California; 1993. Vol. 3280, p. 32-55.

Bertin, J., J. Hermardinquer, M. Keul, et al. 1971. Atlas of food crops. Paris.

Bockari-Gevao, S.M., 2005. Systems approach to efficient field machinery utilization for lowland rice production. Unpublished PhD thesis, Universiti Putra Malaysia.

Borin, M., Menini, C., Sartori, L., 1997. Effect of tillage system on energy and carbon balance in north-eastern Italy. *Soil and Tillage Research,* 40: 209-226.

Bureau of Energy Efficiency (BEE), 2015. Fuels and combustion. Retrieved @ www.em-ea.org/guide%2520books/book-2/2.1%2520fuels%2520and%2520comustion.pdf. On 19/6/2015.

Burgess, M.H., Miller, P.R. and Jones, C.A., 2012. Pulse crops improve energy intensity and productivity of cereal production in Montana, USA. *Journal of Sustainable Agriculture,* 36: 699-718.

Canakci, M, Topakci, M, Akinci, I. and Ozmerzi, A., 2005. Energy use pattern of some field crops and vegetable production: case study for Antalya Region, Turkey. *Energy Conversion and Management,* 46: 655-666.

Cetin, B. and Vardar, A., 2008. An economic analysis of energy requirements and input costs for tomato production in Turkey. *Renewable Energy,* 33: 428-433.

Chaichana, T., Cahitep, S., Jompakdee, W. and Dussadee, N., 2008. Energy analysis of wet season rice production in northern Thailand. *International Agricultural Engineering Journal,* 17(1-4): 1-7.

Chamsing, A. and Salohke, V., 2006. Energy consumption analysis for selected crops in different regions of Thailand. Agricultural Engineering International. *The CIGR Ejournal.* Manuscript EE06013. Vol. VIII.

Chan, C.W. and Cho, M.C. Country report: Malaysia. Asia Pacific Economic Cooperation (APEC) Workshop on food security Tokyo, Japan. 17-19, January 2012.

Chang T.T. Domestication and spread of the cultivated rices. In Foraging and farming — the evolution of plant exploitation, Harris D.R., Hillman G.C., editors, London; 1989. p. 408-17.

Chang, T.T. 1976. The rice cultures. In The early history of agriculture, Hutchinson J. et al. editors, London; 1976. p. 143-55.

Charnes, A., Cooper, W.W. and Rhodes, E., 1978. Measuring the efficiency of decision making units. *European Journal of Operational Research,* 2: 429-444.

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: 1063-1085.

Chong, E. K. P and Zak, S. H. 2001. An introduction to optimization, 2nd ed. John Wiley & Sons, Inc, New York.

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.

Coffman, B.A., Kocher, M.F., Adamchuk, V.I., Hoy, R.M. and Blankenship, E.E., 2010. Testing fuel efficiency of a tractor with a continuously variable transmission. *Applied Engineering in Agriculture,* 26: 31-36.

Cook W.D. and Zhu J. Modeling performance measurement: Applications and implementation issues in DEA. Springer Science + Business Media Inc., 233 Spring Street, New York, NY 10013, USA; 2005. 407p.

Cornell. 2004. Conditions for growing rice. Retrieved online at ricelab.plbr.cornell.edu/docs/CONDITIONS_FOR_GROWING_RICE.doc on 20/6/2014.

Dalgaard, T., Halberg, N. and Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture, Ecosystems and Environment,* 87: 51- 65.

Dazhong, W. and Pimentel, D., 1984. Energy inputs of agricultural systems of China. *Agriculture, Ecosystems and Environment,* 11: 29-35.

De Datta, S.K. 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 Research Institute: Los Ban˜os, Philippines; 1985. p. 247-267.

Department of Agriculture Peninsular Malaysia (DOA) 2010. Paddy statistics of Malaysia 2007. 113pp.

Department of Agriculture Peninsular Malaysia (DOA) 2012. Perangkaan padi Malaysia 2011. Retrieved online @ www.doa.gov.my/data-perangkaan-tanaman1. On 8/2/2015.

Department of Agriculture Peninsular Malaysia (DOA) 2013. Statistik tanaman (Sub sektor tanaman makanan). Retrieved online @ www.doa.gov.my/data-perangkaan-tanaman1. On 8/2/2015.

Dixon, J., Gulliver, A. and Gibbon, D., 2001. Global Farming Systems Study: Challenges and Priorities to 2030-Synthesis and Global Overview. World Bank/FAO, Rome, Italy. Retrieved online at http://www.fao.org/ag/magazine/GFSS.pdf on 21/2/2012.

Dobermann, A., Witt, C., Dawe, D., Abdulrachman, S., Gines, H.C., Nagarajan, R., et al., 2002. Site specific nutrient management for intensive rice cropping systems in Asia. *Field Crops and Research,* 74: 37-66.

Doering III, O.C. Accounting for energy in farm machinery and buildings. In: Pimentel D, editor. Handbook of Energy Utilization in Agriculture. CRC Press, Boca Raton, FL; 1980. p. 9-14.

Dyer, J. A. and Desjardins, R.L., 2003. Simulated Farm Fieldwork, Energy Consumption and Related Greenhouse Gas Emissions in Canada. *Biosystems Engineering,* 85 (4): 503-513.

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.

Fan, M., Jiang, R., Liua, X., Zhanga, F., Lua, S., Zenga, X. and Christie, P., 2005. Interactions between non-flooded mulching cultivation and varying nitrogen inputs in rice–wheat rotations. *Field Crops Research,* 91: 307-318.

Filipovic, D., Kosutic, S., Gospodaric, Z., Zimmer, R. and Banaj, D., 2006. The possibilities of fuel savings and the reduction of CO2 emissions in the soil tillage in Croatia. *Agriculture Ecosystem and Environment,* 115: 290-294.

Food and Agriculture Organization Statistics (FAOSTAT) 2012. Retrived online @ http://www.faostat.fao.org/ on 2/2/2014.

Fathollahzadeh, H., Mobli, H., Rajabipour, A., Minaee, S., Jafari, A. and Tabatabaie S.M.H., 2010. Average and instantaneous fuel consumption of Iranian conventional tractor with moldboard plow in tillage. *ARPN Journal of Engineering and Applied Sciences,* 5: 30-35.

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, Karpouzas D.G., editors. Elsevier B.V; 2008. p. 1-24.

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

Flavin, C. and Dunn, S., 1998. Responding to the threat of climate change. In Brown, L.R., Flavin, C.F., French, H. (eds.). State of the world, W.W. Norton, New York, 7: 113-130.

Fong, W., Matsumoto, H., Ho, C. and Lun, Y., 2012. Energy consumption and carbon dioxide emission considerations in the urban planning process in Malaysia. Retrieved online at www.eprints.utm.my._On 25/4/2012.

Franzluebbers, A.J. and Francis, C.A., 1995. Energy output:input ratio of maize and sorghum management systems in eastern Nebraska. *Agriculture, Ecosystems and Environment,* 53: 271-278.

Freedman, S.M., 1980. Modifications of traditional rice production practices in developing world. An energy efficiency analysis. *Agro-Ecosystems,* 6: 129-146.

Gajaseni, J., 1995. Energy analysis of wetland rice systems in Thailand. *Agriculture, Ecosystems and Environment,* 52: 173-178.

Ghorbani, R., Mondani, F., Amirmoradi, S., Feizi, H., Khorramdel, S., Teimouri, M., Sanjani, S., Anvarkhah, S. and Aghel, H., 2011. A case study of energy use and economical analysis of irrigated and dryland wheat production systems. *Applied Energy,* 88: 283-288.

Grisso, R.D., Kocher, M.F. and Vaughan, D.H., 2012. Predicting tractor fuel consumption. Biological Systems Engineering: Papers and Publications Paper 2004;164. Retrieved @ http://digitalcommons.unl.edu/biosysengfacpub/164. On 18/4/2012.

Grisso, R.D., Perumpral, J.V., Vaughan, D.H., Roberson, G.T. and Pitman, R., 2010. Predicting Tractor Diesel Fuel Consumption. Virginia Cooperative Extension Publication **2010**; 442-473.

Haas, G., Geier, U., Schulz, D.G., Köpke, U., 1995. Vergleich konventioneller und organischer Landbau — Teil I: Klimarelevante

Kohlendioxid-Emission durch den Verbrauch fossiler Energie. Ber. Landw. 73, 401–415.

Hanafi, M.M., Hartinie, A., Shukor, J. and Mahmud, T.M.M., 2009. Agronomic and soil physico-chemical characteristics of upland rice varieties in Malaysia. *Pertanika J. Trop. Agric. Sci.,* 32 (2): 225-246.

Harada, H., Kobayashi, H. and Shindo, H., 2007. Reduction in greenhouse gas emissions by no-tilling rice cultivation in Hachirogata polder, northern Japan: Life-cycle inventory analysis. *Soil Science and Plant Nutrition,* 53: 668-677.

Heidari, M.D. and Omid, M. 2011. Energy use patterns and econometric models of major greenhouse vegetable productions in Iran. *Energy,* 36: 220-225.

Heidari, M.D., Omid, M. and Akram, A., 2011. Optimization of energy consumption of broiler production farms using Data Envelopment Analysis Approach. *Modern Applied Science,* 5(3): 69-78.

Hormozi, M.A., Asoodar, M.A. and Abdeshahi, A., 2012. Impact of mechanization on technical efficiency: A case study of rice farmers in Iran. *Procedia Economics and Finance,* 1: 176-185.

Hulsbergen, K.J., Fiel, B., Biermann, S., Rathke, G.W., Kalk, W.D. and Diepenbrock, W., 2001. A method of energy balancing in crop production and its application in a long – term fertilizer trial. *Agriculture, Ecosystems and Environment,* 86: 303-321.

IFIAS, 1974. Workshop on methodology and conventions. Workshop report, No. 6, International Federation of Institutes for Advanced Study (IFIAS), Stockholm, Sweden.

Iqbal, M.T., 2008. Energy input and output for production of Boro rice in Bangladesh. *Electronic Journal of Environment Agriculture and Food Chemistry,* 7: 2717-2722.

IRRI (1997). Rice Almanac 2nd edn. International Rice Research Institute, Los Banos, Philippines, 181 p.

IRRI (2006). Bringing Hope, Improving Lives-Strategies. Plan 2007–2015 International Rice Research Institute, Los Banos, Philippines, 61 p.

Islam, A.K.M.S., Hossain, M.M., Sarker, R.I., Saleque, M.A., Rahman, M.A., Haque, M.E. and Bell, R.W. Energy utilization in unpuddled transplanting of wet season rice. In: World Congress on Conservation Agriculture, 26-29 September, 2011 Brisbane, Australia.

Islam, A.K.M.S., Rahman, M.A., Saker, R.I., Ahiduzzaman, M. and Baqui, M.A., 2001. Energy audit for rice production under power tiller and bullock farming systems in Bangladesh. *Journal of Biological Sciences,* 1(9): 873-876.

Janssen, B. H., Guiking, F.C.T., Van Der Eijk, D., Smaling, E.M.A., Wolf, J., and Reuler, H., 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). *Geoderma,* 46: 299-318.

Jones, M.R., 1989. Analysis of the use of energy in agriculture—Approaches and problems. *Agricultural Systems* 29: 339–355.

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,* 30(2): 195-203.

Kecojevic, V. and Komljenovic, D., 2011. Impact of Bulldozer's Engine Load Factor on Fuel Consumption, CO2 Emission and Cost. *American Journal of Environmental Sciences,* 7 (2): 125-131.

Kentaro, K., 2010. The costs and benefits of land fragmentation of rice farms in Japan. *The Australian Journal of Agricultural and Resource Economics,* 54: 509-526.

Khan, S., Khan, M.A. and Latif, N., 2010. Energy requirements and economic analysis of wheat, rice and barley production in Australia. *Soil & Environment,* 29(1): 61-68.

Khan, MA., Awan, IU., Zafar, J., 2009. Energy requirement and cost analysis of rice production in western part of Pakistan. *Soil & Environment,* 28: 60-67.

Khanif, Y.M. and Wong, L.P., 1987. Control of volatilization loss by soluble cations and and urease inhibitors. In Proceedings of International Symposium on Urea Technology and Utilization; Pushparajah, E., Husin, A. and Bachik, A.T., eds.; Malaysian Society of Soil Science: Kuala Lumpur, Malaysia, 311-320.

Kheiralla, F.A., Yahya, A., Zohadie, M. and Ishak, W., 2004. Modelling of power and energy requirements for tillage implements operating in Serdang sandy clay loam, Malaysia. *Soil & Tillage Research,* 78: 21-34.

Khosruzzaman, S., Asgar, M.A., Karim, N. and Akbar, S., 2010. Energy intensity and productivity in relation to agriculture – Bangladesh perspective. *Journal of Agricultural Technology,* 6(4): 615-630.

Kitchen, N.R., Goulding, K.W.T. and Shanahan, J.F., 2008. Proven practices and innovative technologies for on-farm crop nitrogen management. In Nitrogen in the Environment: Sources, Problems, and Management. J.L. Hatfield and R.F. Follett (Eds), Elsevier Inc. 483-517.

Koga, N., Tsuruta, H., Tsuji, H. and Nakanoa, H., 2003. Fuel consumption derived CO2 emissions under conventional and reduced tillage cropping systems in northern Japan. *Agriculture Ecosystems and Environment,* 99: 213-219.

Kögel-Knabner, I., Amelung, W., Cao, Z., Fiedler, S., Frenzel, P., Jahn, R., Kalbitz, K., Kölbl, A. and Schloter, M., 2010. Biogeochemistry of paddy soils. *Geoderma,* 157: 1-14.

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.

Ladha, J. K., Pathak, H., Krupnik, T.J., Six, J. and van Kessel, C., 2005. Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Advances in Agronomy,* 87: 85-156.

Lu, H., Bai Y., Ren, H. and Campbell, D.E., 2010. Integrated emergy, energy and economic evaluation of rice and vegetable production systems in alluvial paddy fields. Implication for agricultural policy in China. *Journal of Environmental Management,* 91: 2727-2735.

Lychnaras, V. and Schneider, U.A., 2011. Multi-farm economic analysis of perennial energy crops in Central Greece, taking into account the CAP reform. *Biomass and Bioenergy,* 35: 700-715.

Man, N. and Sami, I.S., 2009. Off-farm employment participation among paddy farmers in the MUDA agricultural development authority and Kemasin Semerak granary areas of Malaysia. *Asia-Pacific Development Journal,* 16: 141-153.

Maraseni, T.N., Mushtaq, S. and Maroulis, J., 2009. Greenhouse gas emissions from rice farming inputs: a cross-country assessment. *Journal of Agricultural Science,* 147: 117-126.

Martinez, J. and Guiraud, G., 1990. A lysimeter study of the effects of a ryegrass catch crop during a winter wheat – maize rotation on nitrogen leaching and on following crop. *Journal of Soil Science,* 41: 5-16.

Mendoza, T.C., 2002. Comparative productivity, profitability and energy use in Organic, LEISA and Conventional rice production in the Philippines. *Livestock Research for Rural Development,* 14(6).

Michel, Jr. J.A., Fornstrom, K.J. and Borelli, J., 1985. Energy requirements of two tillage systems for irrigated sugarbeets, dry beans and corn. Trans. ASAE, 28(6): 1731-1735.

Mikkola, J.H. and Ahokas, J., 2010. Indirect energy input of agricultural machinery in bioenergy production. *Renewable Energy,* 35: 23-8.

Mitin, A. 2009. Documentation of selected adaptation strategies to climate change in rice cultivation. East Asia Rice Working Group. Retrieved online at www.eastasiarice.org; on 12/6/2012.

Mohammadi, A. and Omid, M., 2010. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. *Applied Energy,* 87: 191-196.

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.

Molin, J.P., and Milan, M., 2002. Trator-implemento: dimensionamento, capacidade operacional e custo. In Conservação e cultivo de solos para plantações florestais, Ed. J.L.M. Gonçalves; J.L., Stape, ch.13, 409-436. Piracicaba:IPEF.

Monsi, M. 2011. Methods of optimization. Unpublished lecture notes, Universiti Putra Malaysia.

Moraru, P., Rusu, T., Paulette, L., Buta, M., Oroiani, I., Odagiu, A., Clapa, D. and Cosma, S., 2013. Reducing energy consumption and soil conservation by tillage system. *ProEnvironment,* 6: 164-170.

Morgunov, E.P., 2013. Theory and practice of computer technologies used for creating DEA software. Retrieved at http://morgunov.org/docs/paper36.pdfmorgonov. On 12/3/2013.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A., 2011. Improving energy use efficiency of canola production using data envelopment analysis (DEA) approach. *Energy,* 36: 2765-2772.

Mousavi-Avval, S,H, Rafiee, S. and Mohammadi, A., 2011. Optimization of energy consumption and input costs for apple production in Iran using data envelopment analysis. *Energy,* 36: 909-916.

Muchow, R.C., Higgins, A.J. and Andrew, W.T., 2002. Towards improved harvest management using a system approach. Proceedings of Australian Society of Sugar Cane Technologist, 22: 30-37.

Murad, M.W., Mustapha, N.H.N. and Siwar, C., 2008. Review of Malaysian Agricultural Policies with Regards to Sustainability. *American Journal of Environmental Sciences,* 4: 608-614.

Najim, M.M.M., Aminul Haque, M. and Bockari-Gevao, S.M., 2010. Irrigation energy consumption in a tropical lowland rice field. *Journal of Agricultural Sciences,* 5(18): 1-8.

Najim, M.M.M., Lee, T.S., Haque, M.A. and Esham, M., 2007. Sustainability of rice production: A Malaysian perspective. *Journal of Agricultural Sciences,* 3(1): 1-12.

Namdari, M., Rafiee, S. and Jafari, A., 2011. CO_2 emission as a result of the fuel consumption and tillage quality in different tillage conditions. International *Journal of Environmental Sciences,* 1: 1659-1669.

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.

Naylor, R. 1994. Herbicide use in Asian rice production. *World Development*, 22:(1): 55-70.

Nelson, R.G., Hellwinckel, C.M., Brandt, C.C., West, T.O., DE La Torre Ugarte, D.G. and Marland, G., 2009. Energy use and carbon dioxide emissions from cropland production in the United States, 1990 – 2004. *Journal of Environmental Quality,* 38: 418-425.

Ngoc Chi, T.T. and Yamada, R., 2005. Assessing the technical efficiency of input in rice production in Thoi Lai commune, Co Do district, Can Thai city. *Omonrice,* 113: 116-120.

Noguchi, R. and Saito, T., 2008. Consideration of energy consumption and energy efficiency in mechanized rice production system by using inventory analysis. *Agricultural Information Research,* 17(1): 20-30.

Nowacki, T., 1978. Methodology used by ECE countries in forecasting mechanisation developments. United Nations Economic Commission for Europe, AGRI/MECH Report No. 74.

Oerke, E.C., Dehene, H.V., Schoenbeck, F. and Weber, A., 1994. Rice losses. Crop production and crop protection. Estimated Losses in Major Food and Cash Crops. Elsevier Science B.V., Amsterdam.

Olaoye, J.O. and Rotimi, A.O., 2010. Measurement of agricultural mechanization index and analysis of agricultural productivity of farm settlements in Southwest Nigeria. Agric Eng Int: *CIGR Journal,* 12: 125-134.

Ozkan, B., Akcaoz, H. and Fert, C., 2004a. Energy input–output analysis in Turkish agriculture. *Renewable Energy,* 29: 39-51.

Ozkan, B., Ceylan, R.F. and Kizilay, H., 2011a. Comparison of energy inputs in glasshouse double crop (fall and summer crops) tomato production. *Renewable Energy,* 36: 1639-1644.

Ozkan, B., Ceylan, R.F. and Kizilay, H., 2011b. Energy inputs and crop yield relationships in greenhouse winter crop tomato production. *Renewable Energy,* 36: 3217-3221.

Ozkan, B., Kurklu, A. and Akcaoz, H., 2004. An input-output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. *Biomass and Bioenergy,* 26:189-195.

Pathak, H., Aggarwal, P.K., Roetter, R., Kalra, N., Bandyopadhaya, S.K., Prasad, S. and Van Keulen, H., 2003. Modeling the quantitative evaluation of soil nutrient supply, nutrient use efficiency, and fertilizer requirements of wheat in India. *Nutrient Cycling in Agroecosystems,* 65: 105-113.

Patyk, A., Reinhardt, G.A., 1997. Düngemittel — Energie- und Stoffstrombilanzen, Vieweg Verlag Braunschweig/Wiesbaden.

Pellizzi, G. 1992. Use of energy and labour in Italian agriculture. Journal of Agricultural Engineering Research, 52: 111-119.

Pimentel, D. 2009. Energy inputs in crop production in developing and developed nations. *Energies,* 2: 1-24.

Pimentel, D and Pimentel, M. 1979. Food, energy and society. Resource and Environmental Science Series, Edward Arnold, London.

Pishgar-Komleh, S.H., Sefeedpari, P. and Rafiee, S., 2011. Energy and economic analysis of rice production under different farm levels in Guilan province of Iran. *Energy,* 36: 5824-5831.

Prasad, R. 2011. Aerobic rice system. *Advances in Agronomy,* 111: 207-247.

Prasertsak, A. and Fukai, S., 1992. Nitrogen availability and water stress interaction on rice growth and yield. *Field Crops Research,* 52: 249-260.

Ramachandra, T.V. and Nagarathna, A.V., 2001. Energetics in paddy cultivation in Uttara Kannada district. *Energy Conversion & Management,* 42: 131-155.

Rathke, G.W., Wienhold, B.J., Wilhelm, W.W. and Diepenbrock, W., 2007. Tillage and rotation effect on corn-soybean energy balances in eastern Nebraska. *Soil and Tillage Research,* 2007:97: 60-70.

Refsgaard, K., Halberg, N., Kristensen, E., 1998. Energy utilization in crop and dairy production in organic and conventional livestock production systems. *Agriculture Systems,* 57(4): 599-630.

Robertson, G.P., Paul, E.A. and Harwood, R.R., 2000. Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. *Science,* 289: 1922-1925.

Romanelli, T.L. and Milan, M., 2012. Machinery management as an environmental tool – material embodiment in agriculture. Agric Eng

Int: CIGR Journal, 14(1): 63. Retrieved @ http://www.cigrjournal.org on 12/3/2013.

Rowett Research Institute, 2013. Improving Fact Sheet 1 Energy Expenditure. p 1-6.

Sadar A.R.,1993. Farm infrastructure for mechanized agriculture. In Mechanization towards Increased productivity, Proceedings of the National Conference on Mechanized agriculture. pp. 87 – 95. Editors: Ayob, S., O.H. Seng and T.I. Ailin, Malaysian Agricultural Research and Development Institute and Agricultural Institute of Malaysia, Malaysia.

Safa, M., Samarasinghe, S. and Mohssen, M., 2010. Determination of fuel consumption and indirect factors affecting it in wheat production in Canterbury, New Zealand. *Energy,* 35: 5400-5405.

Samavatean, N., Rafiee, S. and Mobli, H., 2011. An analysis of energy use and estimation of a mechanization index of Garlic production in Iran. Journal *of Agricultural Science,* 3(2): 198-205.

SenseWear, 2015. Wearable metabolic monitoring: Free living data acquisition with the Sensewear Armband. Retrieved @ www.bodymedia.com. On 15/6/2015.

Shafie, S.M., Mahlia, T.M.I., Masjuki, H.H. and Andriyana, A., 2011. Current energy usage and sustainable energy in Malaysia: A review. *Renewable and Sustainable Energy Reviews,* 15: 4370-4377.

Sharifudin, J. and Abullahi, H. Machinery contract hiring services in padi industry. National Conference on Agricultural and Food Mechanization, 30-31 October, 2001, Kuala Lumpur: 126-136.

Shrestha, D.S., 1998. Energy use efficiency indicator for agriculture; See also <http://www.usaskca/agriculture/caedac/PDF/mcrae.PDF>, 10/10/2002.

Singh, G. Relationship between mechanization and productivity in various parts of India. In: XXXIV Annual Convention Indian Society of Agricultural Engineers, CCSHAU, Hisar, India, 16-18December, 1999.

Singh, G., Singh, S. and Singh, J., 2004. Optimization of energy inputs for wheat crop in Punjab. *Energy Conversion and Management,* 45: 453-465.

Singh, H., Singh, A.K., Kushwaha, H.L. and Singh, A., 2007. Energy consumption pattern of wheat production in India. *Energy,* 32: 1848-1854.

Singh, S., Mittal, J.P., Pannu, C.J.S. and Bhangoo, B.S., 1994. Energy inputs and crop yield relationships for rice in Punjab. *Energy,* 19(10): 1061-1065.

Singh, S., Singh, S., Pannu, C.J.S. and Singh, J., 2000. Optimization of energy input for raising cotton crop in Punjab. *Energy Conversion and Management,* 41(17): 1851-1861.

Sirirat, K., Schmitz, P.M. and Thongrak, S. Technical efficiency improvement of rice farming in southern Thailand. International Association of Agricultural Economists Conference, Beijing, China, 16 – 22 August, 2009.

Siwar, C., Mohd Idris, N. D., Yasar, M. and Morshed, G., 2014. Issues and challenges facing rice production and food security in the granary areas in the east coast economic region (ECER), Malaysia. *Research Journal of Applied Sciences, Engineering and Technology,* 7(4): 711-722.

Smith, LA., 1993. Energy requirements for selected crop production implements. *Soil & Tillage Research,* 25: 281-299.

Snyder, C.S. and Slaton, N.A., 2001. Rice production in the United States – an overview. *Better Crops,* 8(3): 1-7.

Sümer, S.K., Kocabıyık, H., Say, S.M. and Çiçek, G., 2010. Fuel consumption distribution for machine and tractor activities in some PTO driven machine operations. *African Journal of Agricultural Research,* 5: 824-828.

Swaminatham, M.S. Rice in 2000 A.D. Report of National Relevance No. 1 Indian National Science Academy, New Delhi (1984) 23 pp.

Tabatabaeefar, A., Emamzadeh, H., Varnamkhasti, M.G., Rahimizadeh, R. and Karimi, M., 2009. Comparison of energy of tillage systems in wheat production. *Energy,* 34: 41-45.

Talluri S., 2000. Data envelopment analysis: Models and Extensions. *Decision Line,* 8-11.

Taylor, E.B., O'Callaghan P.W. and Probert, S.D., 1993. Energy audit of an English farm. *Applied Energy,* 44: 315-335.

Terano, R., Zainalabidin, M. and Golnaz, R., 2013. Farm management analysis in paddy granary areas in enhancing on-farm income. Agris on-line Papers in Economics and Informatics, 5:73-81. Retrieved on 2/8/2014.@ http://ageconsearch.umn. edu/bitstream /148105/2/agris_on-line_2013_1_terano_zainalabidin_golnaz.p...

Uhlin, H., 1999. Energy productivity of technological agriculture – lessons from the transition of Swedish agriculture. *Agriculture, Ecosystems and Environment,* 73: 63-81.

Uhlin, H., 1998. Why energy productivity is increasing: an I–O analysis of Swedish *Agriculture. Agriculture, Ecosystems and Environment,* 56(4): 443-465.

Unakitan, G., Hurma, H. and Yilmaz, F., 2010. An analysis of energy use efficiency of canola production in Turkey. *Energy,* 35: 3623-3627.

Upasani, R.R., Kumari, P., Thakur, R. and Singh, M.K., 2012. Effect of seed rate and weed control methods on productivity of wetland rice under medium land conditions. *Indian Journal of Weed Science,* 44(2): 98-100.

Vengedasalam, D., Harris, M. and MacAulay, G. Malaysian rice trade and government interventions. Contributed paper presented to the 55th annual conference of the Australian Agricultural and Resource Economics Society, Melbourne, 8 – 11 February, 2011.

Vigne, M., Vayssières, J., Lecomte, P. and Peyraud, J., 2012. Evaluating the ability of current energy use assessment methods to study contrasting livestock production systems. *Journal of Environmental Management,* 112: 199-212.

Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R. K., Howell, G., Pathak, H. and Sumfleth, K., 2009. Climate Change Affecting Rice Production: The Physiological and Agronomic Basis for Possible Adaptation Strategies. *Advances in Agronomy,* 101: 59-122.

Williford, J.R., 1981. Fuel measurement for cotton production in the Mississippi Delta. ASAE Paper No. 81- 1027, ASAE, St. Joseph, MI, 12 p.

Witt, C., Dobermann, A., Abdulrachman, S., Gines, H.C., Guanghuo, W., Nagarajan, R., Satawathananont, S., Son, T.T., Tan, P.S., Van Tiem, L., Simbahan, G., and Olk, D.C., 1999. Internal nutrient efficiencies in irrigated lowland rice of tropical and subtropical Asia. *Field Crops Research,* 63: 113-138.

Witte, R., van Elzakker, B and van Mansvelt, J.D., 1993. Rice and the environment: Environmental impact of rice production, policy review and options for sustainable rice development in Thailand and the Philippines. UNCTAD/COMI22.

Xing, 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.

Yadav, S.N., Chandra, R., Khura, T.K. and Chauhan, N.S., 2013. Energy input–output analysis and mechanization status for cultivation of rice and maize crops in Sikkim. Agricultural Engineering International: *CIGR Journal,* 15(3): 108-116.

Ya-Guang, X., Ting-Ting, C., Cheng, Y., Zhi-Qin, W., Li-Jun, L. and Jian-Chang, Y., 2010. Effect of different cultivation patterns on yield and physiological characteristics in mid-season Japonica rice. *Acta Agron Sin,* 36(3): 466-476.

Yan, Z., Jin, J., He, P. and Liang, M., 2008. Recent advances on the technologies to increase fertilizer use efficiency. *Agricultural Sciences in China,* 7(4): 469-479.

Zangeneh, M., Omid, M. and Akram, A., 2010. A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. *Energy,* 35: 2927-2933.

Zentner, R.P., Campbell, D.W., Campbell, C.A., Read, D.W.L., 1984. Energy considerations of crop rotations in southwestern Saskatchewan. *Canadian Journal of Agricultural Engineering,* 26: 25-29.

Zhang, X., Yina, S., Li, Y., Zhuang, H., Li, C. and Liu, C., 2014. Comparison of greenhouse gas emissions from rice paddy fields under different nitrogen fertilization loads in Chongming Island, Eastern China. *Science of the Total Environment,* 472: 381-388.