Analysis of Energy Requirement for Vegetable Oil Production in Northern Thailand 's Farms

Nakorn Tippayawong*, Archai Pittayapak and Wasan Jompakdee

Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai 50200, Thailand

**Corresponding author. E-mail: nakorn@dome.eng.cmu.ac.th*

ABSTRACT

Because most energy intensive farm operations use diesel powered equipment, this has created substantial interest in vegetable oil as an alternative source of fuel for agriculture. It is, therefore, important to establish that the energy required for vegetable oil production is less than the energy content of the vegetable oil as fuel. This paper describes the evaluation of the energy output/input ratio for vegetable oil production in Northern Thailand 's small local farms. The energy ratio is defined as the ratio between energy content of fuel and total energy inputs to produce it. Vegetable oils studied in this project are from groundnut and soybean seeds. Data collection is carried out by field survey and personal interview with farmers and industrialists. The results indicated that existing oil production system produced more energy than that used as production inputs. From an energy budget view, it is therefore feasible to produce vegetable oils to use as a substitute for diesel fuel in local farms.

Key words: Energy efficiency analysis, Vegetable oils, Biofuels, Diesel substitute

INTRODUCTION

Demand for diesel fuel in Thailand is higher than the total production capacity of local refineries. Imported diesel oil accounts for about 14% of the total demand (Wilbulswas, 2002). This amounts to a large proportion in the country's energy imports. Furthermore, economic and political factors make supplies of petroleum uncertain and have given rise to tremendous price escalation. The search for alternatives to partial or total substitution of diesel fuels has, therefore, been intensified in the last few decades. Among the many different types of alternative fuels, vegetable oils and their products appear to be promising choices. Vegetable oils are gaining importance as a source of energy in Thailand, especially usage as a diesel fuel substitute. Vegetable oils are biodegradable and nontoxic, have low emission profiles, are made from renewable resources and so are environmentally beneficial (Ma and Hanna, 1999). They have been used as an alternative to the partial or total substitution of diesel fuels without requiring extensive engine adjustments or modifications and found to perform satisfactorily (Barsic and Humke, 1981; Pryde, 1983; Graboski and McCormick, 1998; Nwafor, 1999; Wilbulswas et al., 1999; Karaosmanoglu et al., 2000; Tippayawong et al., 2002). Recent concerns over the price and availability of liquid fuels have created substantial interest in vegetable oils as diesel fuel and in on-farm production method because most energy intensive operations in field crop production use diesel engines. It is therefore essential to establish that the production and extraction of the vegetable oil is economically feasible and it is important to establish that the energy required for production is less than the energy content of the fuel. In other words, the net energy output must be positive. Yields of vegetable oils depend on many factors and should be evaluated in terms of energy inputs needed to achieve various levels of energy outputs. Site preparation, seed or seedling production, planting, cultivation, fertilization, harvest, transport and conversion of the crop require energy expenditures. These should also include energy needed to run machinery in the various production and utilization processes, and to feed the labour force. Indeed, energy analysis should be done by means of the process analysis method in which the use of energy in every production step is traced back from the product to the primary sources.

The objective of the ongoing research is to examine the energy efficiency of vegetable oil as a diesel fuel substitute from on-farm production and to identify important input parameters that significantly affect the energy output to energy input ratio of the whole process. In this paper, energy inputs and outputs are evaluated for the production of two vegetable oils, soybean and groundnut. These are grown locally and have shown potential for mass production in Northern Thailand. The energy ratio for vegetable oil production is calculated, using a model based on energy flows in the production chain. The operations involved in oil crop production are listed and the energy input for each stage estimated. The energy cost associated with the production and maintenance of relevant agricultural machinery is also included. The energy costs of fuel processing are also taken into account. The total energy input for a given crop, together with the fuel oil yield enables the total energy ratio to be determined.

MATERIALS AND METHODS

The energy analysis was based on a process analysis in which the direct and indirect use of energy in every successive production step was traced back from the end product to the primary sources and materials. The principal operations in oil crop production (shown in Figure 1) are as follow: land preparation; planting; irrigation; fertilization; pest control; harvesting; threshing or stripping; drying; storage; transportation (Department of Agricultural Extension, 2001). Production data for the two oilseeds were gathered by field survey and personal interviews with growers as well as giving out questionnaires to over 350 farmers in 50 villages in the irrigated areas across Lampang province, Northern Thailand. These data included personal data, detailed operations and estimated cost, labour and energy uses which were subsequently analyzed statistically for average energy usage with an SPSS software.

For a certain process, direct and indirect energy used were calculated. Coefficients are established to enable the contribution of the above processes to the total energy input required to produce unit quantity of vegetable oil. Details can be found in Pittayapak (2002).

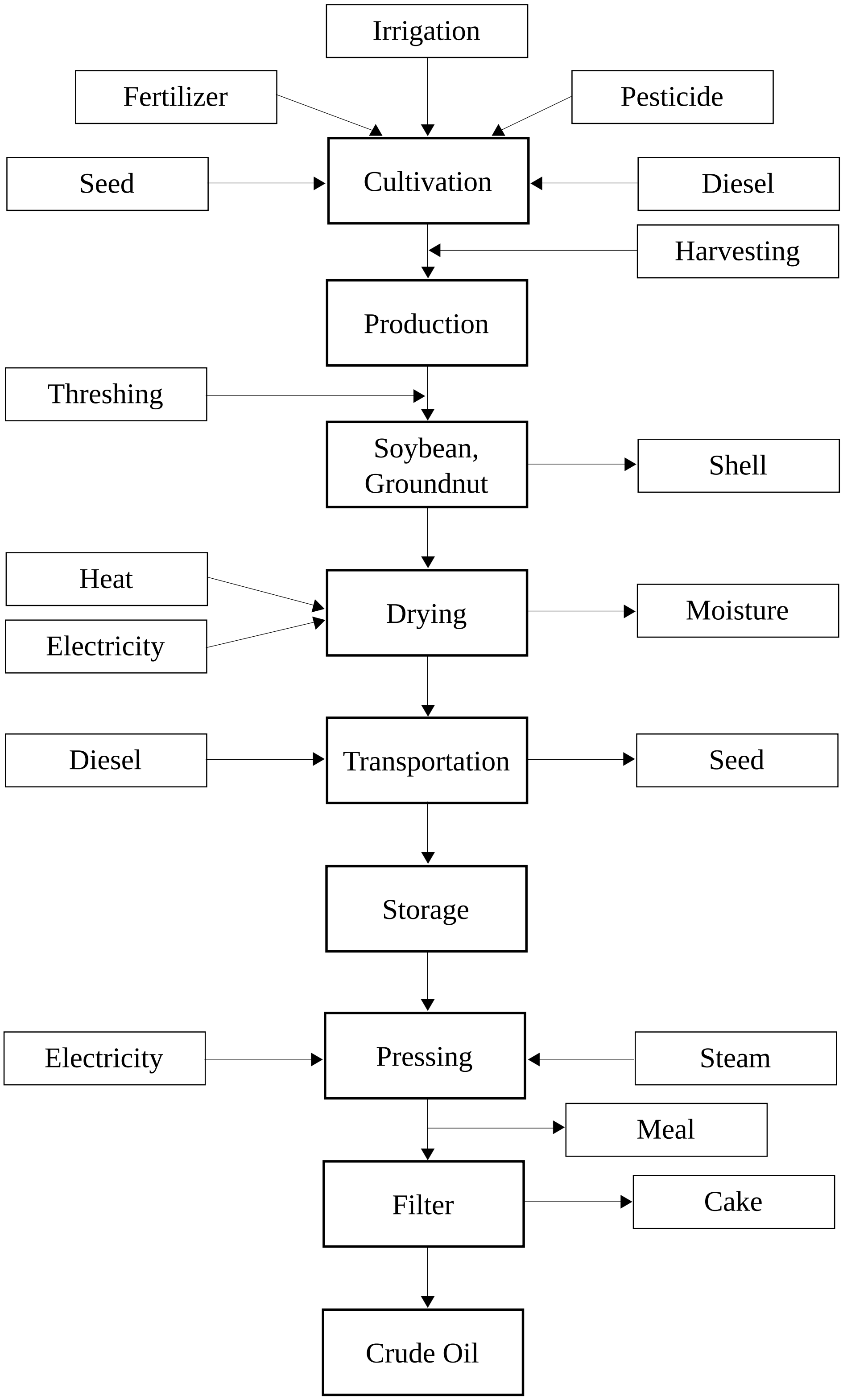

Figure 1. Flow chart of the vegetable oil production chain.

Energy Inputs

Human labour

An approach recommended by the World Health Organization to estimate energy requirement of adult based on calculation of basal metabolic rate (WHO, 1985) was employed in this study. From the data of average body weight, age and daily activities, a human labour energy coefficient of 0.62 MJ/person/hr was obtained. This is similar to the work carried out by Samootsakorn (1982) where a coefficient of 0.65 MJ/person/hr was derived and used to convert hours of labour to energy.

Fuel

From the survey, it has shown that most of the farmers in the North use diesel engines for agricultural activities. On average, diesel has a heating value of 46800 kJ/kg, and specific gravity of 0.84. From, E fuel = P fuel · HV, a coefficient of 39.3 MJ/liter was used to convert diesel fuel consumption to energy.

Machinery

The total energy cost over lifetime of the machinery was estimated by adding the cost of raw materials, the cost of production and the cost of spare parts and maintenance. From the knowledge of average lifetime, the annual energy cost could then be evaluated. Samootsakorn (1982) carried out a study, similar to Pimmentel et al., (1973) and Doering (1980)'s works, for simple-structured, two-wheeled tractors, locally assembled and obtained a figure of 40,000 MJ/tonne. Principal machinery used in this study was found to be a two-wheeled tractor and a 4 - 6 horse power water pump. The average mass of a typical two-wheeled tractor and accessories is 240 kg, lifetime of 20 years and that of a typical water pump is 23 kg with lifetime of about 10 years. The average farm size is 4 rai (1 rai = 1,600 m^2 = 0.16 ha.). Hence taking Samootsakorn's figures for a double-cropping practice, the energy for farm machinery is 62 and 12 MJ/rai for a tractor and a water pump respectively.

Fertilizers

Energy requirements for production and transport of commercial chemical fertilizers as estimated by Samootsakorn (1982) are as follow;

N as anhydrous ammonia - 80 MJ/kg

P as normal super phosphate (P_2O_5) - 14 MJ/kg

K as muriate of potash (K_2O) - 9 MJ/kg

Majority of farmers in Northern Thailand use fertilizer formula 15:15:15 (N:P:K), the numbers indicate the percentage by volume for each fertilizer.

Pesticides

Generally, farmers manually remove weeds or unwanted plants and use chemical pesticide for pest control. Pesticides are energy-intensive products. Using a result derived by Pimmentel et al., (1980), a coefficient of 101.6 MJ/kg was used in this study.

Lime

During land preparation, lime (CaO) is used to improve pH level of the soil. For lime used, an energy coefficient of 1.44 MJ/kg was obtained from Shapouri et al., (1996).

Seeds

The energy input for seeds has been estimated by using the ratio of financial energy consumption to gross domestic product, as of year 2000 which was 16.7 kg oil equivalent/ 1,000 baht (Department of Energy Development and Promotion, 2000) or 0.67 MJ/baht. The results are given in Table 1.

Seed type	Unit cost (Baht/kg)*	Energy cost (MJ/kg)
Soybean	9.56	6.44
Groundnut	12.33	8.31

Table 1. Coefficients for converting seed cost rate to energy cost (* average 3 years of production costs, 1998 - 2000).

Drying

The average moisture content of fresh groundnut and soybean is about 20 - 30%. Normally, drying of harvested groundnut and soybean is done naturally by winnowing and sun-drying in the field for several days before stripping and/or threshing. This is practised by most farmers in the North. The subsequent moisture content is reduced to about 12 - 15%. The seeds are then kept in kenaf sacks which help reduce moisture content further during storage. Because drying is done naturally, no converting coefficient is assumed in this study.

Irrigation

Water system is essential for farming. Most studied growers reside near an area where irrigation system is constructed. The energy required to pump irrigation water is given by

$$E = \frac{mgh}{\eta_p \eta_e}$$

where E = energy required for pumping per rai
g = gravitational acceleration
h = h_1+h_2
h_1 = head to lift water to the level of the field
h_2 = head required to distribute the water
m = mass of water pumped per rai
η_p = pump efficiency
η_e = prime mover efficiency

A value of 0.65 was used for pump efficiency. Values for prime mover efficiency were 0.22 for diesel and 0.20 for gasoline engines respectively.

In Northern Thailand during dry season, groundnut and soybean are grown in December after harvesting rice. Since the soil still possesses high water content, no irrigation is needed during this initial growing period. Growers normally irrigate the field twice, in February and in March. The water pump is driven by a small 3-5 horse power (2-4 kW) gasoline engine or a 3-12 horse power (2-9 kW) diesel engine. Survey results showed that the average pumping head is about 2 m. The fuel requirement is similar each time for both gasoline and diesel engines, and found to be about 3 liters/rai or a total of 6 liters/rai. This results in a coefficient of 235.9 MJ/rai.

Transportation

Samootsakorn (1982) found that with each kilogram of rice transported, on average, 445 km by a typical 10-wheeled truck (125 horse power, 8 tonnes) and consumed 0.0006 liter of diesel, resulted in a coefficient of 0.22 MJ/kg. Similar analysis was done in this study. The average distances for off-farm transportation were 505 km and 491 km for soybean and groundnut seeds respectively. Using current configuration, a typical 10-wheeled truck, weighing 9 tonnes and has 215 horse-power engine consumes on average 6-10 km/liter. Energy coefficients of 0.21 MJ/kg for soybean and 0.20 MJ/kg for groundnut were obtained.

Oil recovery process

There are two basic methods of extracting oils from oil seeds. These are mechanical or full-press extraction and solvent extraction. Combination of the two methods may also be employed. The solvent extraction method employs, as its name implies, solvent as a means to separate the oil from the seed. The solvent must then be distilled to recover the oil, which would require extensive capital investment in distillation equipment and handling of highly-volatile chemicals. The solvent extraction system may be considered inappropriate for small-scale operations. Mechanical or full-press extraction requires cheaper fixed capital investment and is relatively simple to operate. It is a continuous process, using a screw press consisting of a worm shaft rotating within a pressing cylinder which literally squeezes the oil from the seed. The oilseeds are usually pre-heated by steam to increase the oil removal efficiency from the seed fibers. Goering and Daugherty (1982) reported a typical procedure for oil recovery from seeds which involved a combination of mechanical press and the use of solvent extraction to recover remaining oil in the seed cake. They calculated that 1.34 MJ of energy would be required per kilogram of seed for the process including mechanical and solvent recovery.

In this research project, data concerning small-scale vegetable oil extraction facilities were gathered from several equipment manufacturers (IBG Monforts GmbH, Germany), industrial users (Lanna Products Co. Ltd., Lamphun, Thailand) and laboratory-scale operators (Department of Industrial Chemistry, Chiang Mai University, Thailand). Facilities studied use KOMET DD85G pressing machines, similar to that illustrated in Figure 2, and have processing capacities in the range of 40 - 60 kg per hour per machine depending on seed type, and normally operate 24 hours a day. This is typical of the size which could be acquired and maintained on an individual farm or a small group or cooperatives. Experimental findings were also carried out in a departmental laboratory to obtain information on heating value using a bomb calorimeter, and oil content of typical samples of soybeans and groundnuts using a Soxhlet extraction method. For energy input coefficient, the assumption of 1.34 MJ/kg of seed of both crops is used in this study though only crude vegetable oil is produced.

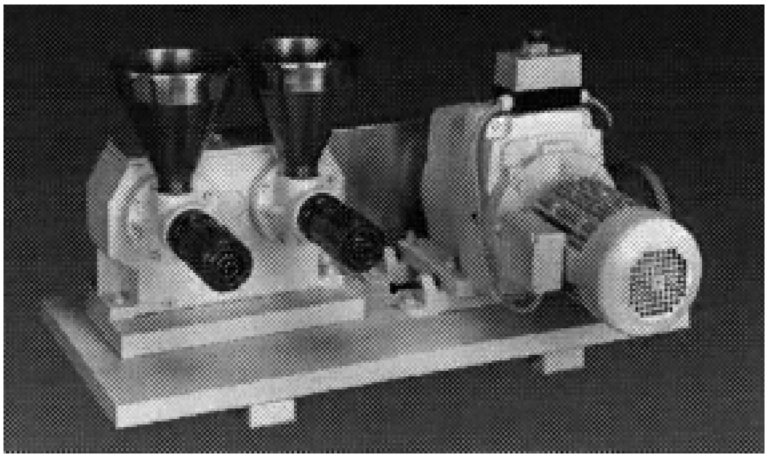

Figure 2. KOMET DD 85 G oil press machine (IBG Monforts Oekotec, 2003).

RESULTS

Table 2 summarizes the energy requirements in each of the production process on a MJ per rai basis. The total energy use for vegetable oil production were approximately 1,320 and 1,430 MJ/rai for soybean and groundnut respectively. For soybean oil production, the biggest energy consumer in production was the oil recovery system which accounted for about a quarter of the total energy use, closely followed by irrigation and fertilization which accounted for about 18% and 16% respectively. If only soybean seed production process was considered (from land preparation for plantation to harvesting), the biggest energy consumer in production would be the irrigation which accounted for about 25% of the total energy use. Fertilizer and diesel fuel accounted for about 21% and 16% respectively (Figure 3). Similar observation was also reported in the case of groundnut oil production in which fertilizer and irrigation being of similar magnitude.

	Soybean		Groundnut	
Inputs	min. - max.	average	min. - max.	average
Labour	47.8 - 382.3	97.5	47.8 - 382.4	97.5
Machinery	74	74	74	74
Diesel fuel	39.3 - 589.7	159.2	39.3 - 1179.3	189.1
Fertilizer	0 - 463.5	207.2	154.4 - 463.5	256.5
Seed	64.4 - 225.4	128.3	83.1 - 415.5	179.9
Limestone	0 - 30.2	22.7	0 - 30.2	13.1
Pesticide	0 - 50.8	11.0	0 - 51.0	12.7
Irrigation	235.9	235.9	235.9	235.9
Drying	0	0	0	0
Transportation	20.8 - 83.0	51.7	22 - 64	48.1
Oil recovery	134 - 536	333.1	134 - 428.8	322.3
Total Energy (MJ/rai)		1320.4		1429.0
Outputs				
Seed yield (kg/rai)	100 - 400	248.6	100 - 320	240.5
Oil content (%)	18	18	35	35
Total Energy (MJ/rai)	706.1 - 2824	1755.2	1329 - 4252	3195.5
Output/input ratio		1.35		2.27

Table 2. Energy inputs and outputs for irrigated vegetable oil crops in Northern Thailand.

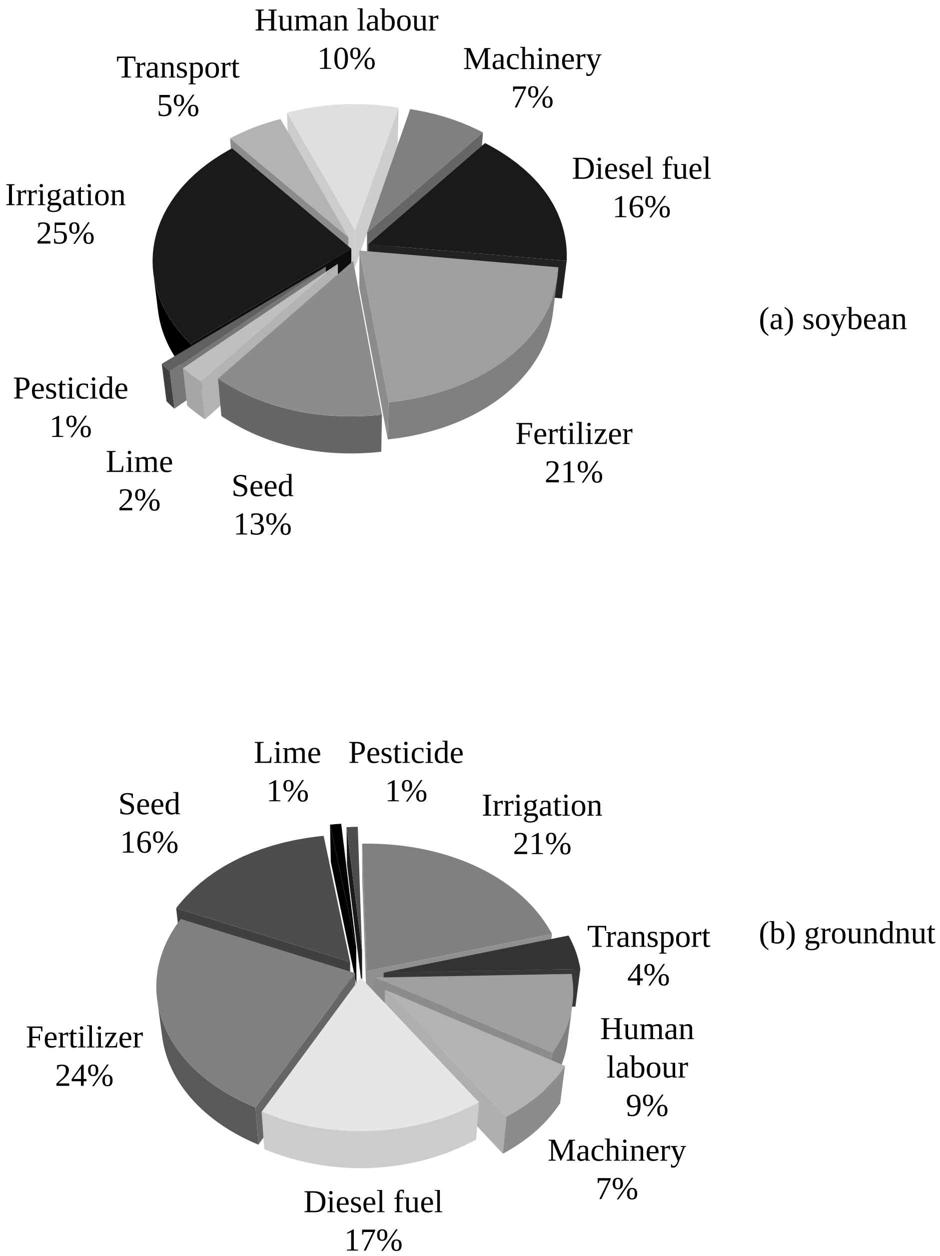

Figure 3. Energy use in a Northern Thailand vegetable oilseeds production for (a) soybean and (b) groundnut.

Energy Outputs

The energy content of the oil was estimated as follow. The average seed yields and percent of oil contents of soybean and groundnut grown in Lampang farms are used in computing the energy yields of the oils. Results are also shown in Table 2. The average seed yields of groundnut and soybean in dry season are approximately 240 kg/rai (35% oil content) and 250 kg/rai (18% oil content) respectively.

Energy Output/Input Ratios

Table 2 also shows the total energy ratio evaluated for soybean and groundnut grown in Northern Thailand. The results indicated that existing oil production system produced more energy that they used as production inputs. The energy output/input ratio is 1.35 for soybean oil and groundnut oil gives the energy ratio of 2.27. The results are rather inconclusive because the seed cake or meal energy content was not taken into account in this analysis. The reason for this is that the seed cake or meal is not readily usable as a fuel source but it is rich in protein and normally sold for animal feed.

DISCUSSION AND CONCLUSIONS

The resulting vegetable oils have energy equivalent to about 1.5 - 2.5 times that required for their production. This is not a significant difference, especially for small-scale oil crop growers. Oil recovery system, fertilization, irrigation and diesel fuel inputs are the inputs which contribute most to the total energy use. A sensitivity analysis was carried out for these inputs in the production chain to quantify their influence on the energy performance measures. The analysis showed that if the quantity of the fertilizer was halved, the energy ratio would increase by about 10%. However, it was shown that the reduction in fertilization would have an adverse effect on seed yield. If the quantity of the diesel fuel use was reduced by about 50%, the energy ratio would increase by almost 10%. The effects of reducing energy in irrigation input were found to improve the energy ratio. For a case of a small cooperative in Lampang which has a total cultivated area of about 700 rai, the need for diesel fuel in growing groundnut each time is approximately 3,350 liters. This is equivalent to crude groundnut oil of about 3,700 liters or groundnut seeds of around 12,000 kg. This would account for groundnut yield from less than 10% of total cultivated area. Similar figures were also obtained from calculation for soybean.

This study represents a first approximation of the energy balance for local vegetable oil production in Northern Thailand. A long term prospect of increasing yields and reducing energy cost for vegetable oil production may also be considered by the substitution of an alternative renewable energy source for oil and chemical fertilizers; wind energy for irrigation, biological N-fixation for fertilization. Oilseed crop production needs to be enhanced by selection, breeding, and improved agronomic practices for crops that appear to be attractive on technical and economic grounds. Modern agriculture and better equipment specifically designed to operate with less fuel should also improve the energy output/input ratio substantially. The energy cost is expected to rise with an increase in fuel price. It is, however, possible to replace a large, if not all, fraction of the fuel input by renewable energy sources.

The next key issue in utilizing vegetable oil is to evaluate whether it is technically and economically feasible and appropriate to manufacture and process oilseeds into crude liquid oil on a sufficiently small and locally sustainable scale by a small cooperative of farmers. This would promote self-sufficiency among farmers within community and add value to traditional agricultural products.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support provided by the Fund for Energy Conservation Promotion, Thailand's National Energy Policy Office (NEPO) for this research project.

REFERENCES

Barsic, N. J., and A. L. Humke. 1981. Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels. SAE paper no. 810955.

Department of Energy Development and Promotion. 2000. Ministry of Science, Technology and Environment, Thailand. <www.dedp.go.th>

Department of Agricultural Extension. 2002. Ministry of Agriculture and Cooperatives, Thailand. <www.doae.go.th>

Doering, O. C. 1980. Accounting for machinery in farm machinery and buildings. Handbook of Energy Utilization in Agriculture, CRC, Boca Peten, Florida, USA.

Goering, C. E., and M. J. Daugherty. 1980. Energy accounting for eleven vegetable oil fuels. ASAE paper no. 81-3586, Trans ASAE: 1209-1215.

Graboski, M. S. and R. L. McCormick. 1998. Combustion of fat and vegetable oil derived fuels in diesel engines. Progress in Energy and Combustion Science 24: 125-164.

IBG Monforts Oekotec GmbH & Co. KG. 2003. <www.oekotec.ibg-monforts.de>

Jompakdee, W. 1991. The Use of local vegetable oils as alternative fuels for small farm diesel engines in Northern Thailand. Ph.D. Thesis. University of Reading, Reading, Berkshire, UK.

Karaosmanoglu, F., G. Kurt, and T. Ozaktas. 2000. Long term CI engine test of sunflower oil. Renewable Energy 19: 219-221.

Ma, F., and M. A. Hanna. 1999. Biodiesel production: a Review Bioresource Technology 70: 1-15.

Nwafor, O. M. I. 1999. Effect of varying fuel inlet temperature on the performance of vegetable oil in a diesel engine running under part-load conditions. Intl. J. Ambient Energy 20(4): 205-210.

Pimmentel, D., L. E. Hurd, A. C. Belotti, M. J. Foster, I. N. Oka, O. D. Sholes, and R. J. Whitman. 1973. Food production and the energy crisis. Science 182: 443-449.

Pittayapak, A. 2002. Evaluation of alternative fuel production potentials from local oil plants. M.Eng. Thesis. Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand. (in Thai).

Pryde, E. H. 1983. Vegetable oils as diesel fuel: Overview. J. American Oil Chemists Soc. 60: 1557-1558.

Samootsakorn, P. 1982. Energy budgeting for Thai rice agriculture. Ph.D. Thesis. University of Reading, Reading, Berkshire, UK.

Shapouri, H., J. A. Duffield, and M. S. Graboski. 1996. Energy balance of corn ethanol revisited. p.253-259. In J. S. Cundiff et al., (eds) Proceeding of the 3rd Liquid Fuel Conference, Liquid Fuel and Industrial Products from Renewable Resources. 15-17 September 1996. Nashville, Tennessee.

Tippayawong, N., T. Wongsiriamnuay, and W. Jompakdee. 2002. Performance and emissions of a small agricultural diesel engine fueled with 100% vegetable oil: effects of fuel type and elevated inlet temperature. Manuscript submitted for publication in Asian J. Energy and Environment.

Wibulswas, P. 2002. Development of biomass liquid fuels for transportation in Thailand. J. Royal Inst. Thailand 27: 429-433.

Wilbulswas, P., S. Chirachakrit, U. Keowchuang, and J. Tiansuwan. 1999. Combustion of blends between plant oils and diesel oil. Renewable Energy 16: 1098-1101.

World Health Organization. 1985. Energy and protein requirements. A Report of a joint FAO/WHO/UNU expert consultation, WHO Technical Report Series 724, WHO, Geneva.