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Energy Use and Consumption Patterns of Maize Cultivation - A Case Study in Thailand

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ABSTRACT

This study explored energy inputs and consumption patterns to determine energy and economical indices for maize cultivation in Thailand. To assess the energy performance of four used cropping systems, namely, highland cultivation in wet season (HLWS), highland cultivation in dry season (HLDS), plains cultivation in wet season (PLWS), and plains cultivation in dry season (PLDS), data from energy consumed and produced show Net Energy Value (NEV) gains of +77.0, +106.5, +191.6, and +228.5 GJ/ha, respectively. Positive signs indicate that the required energy was less than energy produced which reveals sustainability. Use of fertilizer accounted for the major input energy in all systems, followed by fossil fuels, human labor and seeds. A cost performance analysis demonstrated PLDS production exhibited the highest profit earnings (1,365.2 USD/ha). To establish an alternative way to reduce the amount of energy consumed together with increased profit returns to farmers, the renewable energy from waste manure was used to replace dependence on chemical fertilizers. Scenarios using manure from cows, chickens, and farmyards were considered. Results showed that the use of farmyard manure created greater amounts of energy efficiency and economical return rates. Moreover, the benefits increased with increased amounts of organic material applied.

1. INTRODUCTION

In the 21st century, critical issues concerning energy have drawn the attention of the United Nations Environment Programme (UNEP, 2012). High energy need, depletion of non-renewable energy resources and unlimited negative level of local environmental topics were cited frequently in many previous studies (Demirbas, 2009; Singh et al., 2019). With currently increasing rapid development and world population, staple and non-staple foods are required to serve both human and animal needs and have created competition for land and water, and increased greenhouse gas (GHGs) emissions as well as energy consumption (Qi et al., 2018; Silalertruksa and Gheewala, 2018; Jiang et al., 2020). To meet the global requirement of food in 2050, food production needs to increase 60% to meet all population demands (FAO, 2011; van Dijk and Meijerink, 2014).

The agriculture sector is one of the main producers and consumers of energy where the operations need both direct and indirect energy including human labor, fossil fuel, electricity, fertilizers and herbicides, etc. (Elsoragaby et al., 2019a; Kosemani and Bamgboye, 2020). With the progression of agriculture, energy has become a key input for activities during the age of subsistence agriculture (Król-Badziak et al., 2021). The demand of energy in the cultivation sector has increased considerably with the need for high-yielding varieties and introduction of mechanized production practices (Canakci and Akinci, 2006). Their expansion has further resulted in significant increase in food production and energy security together with the risk of environmental contamination and economic development (Nutongkaew et al., 2019; Zhong et al., 2020). To address these issues, the link between resource consumption and agricultural activity was

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analyzed. Several studies have concerned environmental problems in agricultural areas during the last decade such as loss of biodiversity and pollution in the soil and aquatic media by nitrogen and phosphorus fertilizers (Nemecek et al., 2011; Yousefi et al., 2014). However, developing energy efficient agricultural production systems with lower energy input compared with the output has been recommended from the Thai government by adopting the 4th Thai National Economic and Social Development Plan together with creating equilibrium among production, environmental, and economic dimensions to achieve the sustainable development goals (Dalgaard et al., 2001; Esengun et al., 2007; Manzone and Calvo, 2016; Singh et al., 2019).

Two evaluation methods for energy use in agricultural production system are economic analysis of energy and input-output analysis of energy use (Kusek et al., 2016; Lal et al., 2019; Elsoragaby et al., 2019b). Lately, energy input-output analysis has been widely used to investigate efficiency and environmental performance which can be applied to energy management in production systems. It can be used as the first step to identify how benefits can be obtained and further show methods to minimize energy input and increase productivity (Mohammadi et al., 2008; Mohammadi et al., 2010). Energy analysis has become an important issue and a reliable approach that can provide reasonable opportunities for planners and policy makers to determine the interactions between energy use and efficiency (Ozkan et al., 2004; Hatirli et al., 2006; Yousefi et al., 2014).

Thailand has 51.3 million hectares of land of which 41% is under cultivation of various crops (OAE, 2020). Maize (*Zea mays* L.) is one of the most important crops in tropical climatic zone plantations including Thailand (Gong et al., 2015). In 2019/2020, their total production of 4.54 million tons in a cultivation area of 1.13 million hectares proved important for both food and feed (OAE, 2021). Maize is valued as the fifth most important economic crops after rice, cassava, sugarcane, and rubber in Thailand. Its demand increased by 3.6% from previous years due to the expanding livestock industry corresponding to the increased demand for maize in animal feed. It occupies 33% of Thai upland rainfed farmlands after the rainy season with a portion of in total and debuts in paddy rice fields in the dry season in recent years from the promotion of many governmental projects (Supasri et al., 2020). To date, differences in production areas may pose varying management performances for both resource use and energy efficiency. The diversity renders difficulty in decision making and appears attractive to researchers. Therefore, several studies conducted in Thailand have concentrated on energy efficiency in field crop production such as sugarcane, tapioca, para rubber, paddy rice, etc., to improve sustainability and find strategies to minimize environmental problems (Gajaseni, 1995; Demircan et al., 2006; Neamhom et al., 2016; Silalertruksa and Gheewala, 2018; Jaroenkietkajorn and Gheewala, 2020; Prasara-A and Gheewala, 2021).

Because of the few energy analysis studies concerning maize farming in Thailand, this study aimed to determine energy input and consumption patterns of different cultivation systems of maize in Thailand. The assessment of energy consumption for maize cultivation is required to understand its existing operations and identify alternative approaches to reduce energy requirements. It will help to increase production, productivity, and profitable returns contributing to the Thai economy, and make maize production systems sustainable.

2. METHODOLOGY

2.1 Scope of study and system boundary

The energy requirements and performance of energy indicators were evaluated using energy and resource materials consumed and produced in the cultivation of maize for the animal feed industry. Figure 1 presents a schematic flow diagram of overall maize cultivation practices in Thailand divided into eight basic steps. The activity occurs by using resources and materials applied in the field including chemical fertilizers, herbicides and pesticides and fossil fuel energy. In general, maize is grown mostly in rainfed upland areas divided in two seasonal crops which are crop planted from May to September and planted from August to December (MCC, 1999; Ekasingh et al., 2004). Currently, the practices of farmers contributing to increased production of maize and reducing paddy rice cultivated during the dry season (March to July) have become common due to the lack of water and their local market price. Four maize cultivation systems were classified based on the location and growing season of the crop. These four systemsare designated as: (1) highlands in wet season (HLWS); (2) highlands in dry season (HLDS); (3) plains in wet season (PLWS) and, (4) plains in dry season (PLDS). This study used the functional unit of energy or mass per unit area to express the quantity of energy and materials consumed or produced throughout these systems. The quantity per unit area (hectare; ha) is used to indicate the importance of land where photosynthesis takes place to produce maize seed as a main product and three other co-products. These include maize straw, maize husk, and maize cob. Notably, machinery energy was not accounted for in this study as their quantity was much less than those of solar energy radiation throughout the working lifetime of the machines.

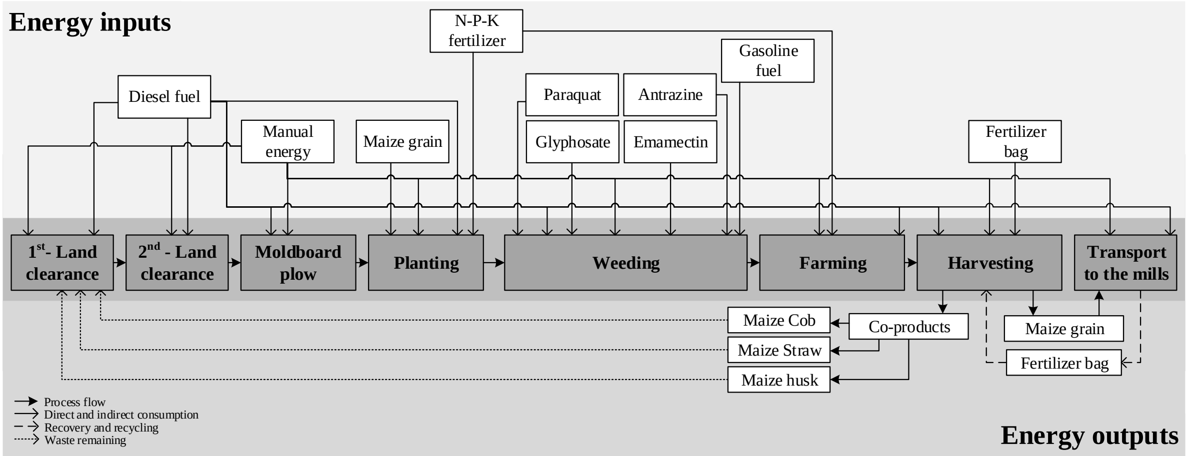

Figure 1. System boundary and pattern of energy flow in maize cultivation in Thailand

2.2 Field survey and data collection

In this study, the value of energy occurring in maize cultivation was determined using both primary and secondary data from a field survey and literature reviews, respectively. For the field survey, a face-to-face questionnaire was used to gather relevant information from 110 Thai maize farmers in HLWS, HLPS, PLWS, and PLDS systems. Sample size was calculated using a simplified formula to determine 80% confidence level and 0.2 precision (Yamane, 1967). Data were collected for one hectare maize cultivation regarding productivity, resources used, type and quantities of fossil fuel energy and fossil fuel-based materials, i.e., diesel and gasoline for machinery operation, chemical fertilizer, herbicides and pesticides for crop maintenance. Also, related human labor requirements and payroll information were obtained using the questionnaires. The energy equivalents of various energy inputs and local market prices of energy and products used in this study were sought from the literature and reliable webpages. Only energy equivalents in the maize yield collected from field trips (both product and co-products) were analyzed following the standard method for food and nutrition (FAO, 2003). Cultivation, prior to harvest, takes approximately three months beginning in October until February for the wet season and March until July for the dry season yearly. However, data variation was analyzed and presented with average values and standard deviation.

2.3 Computation of energy indicators

Data values of energy and material input and output were measured to determine the demand of energy in the production of maize and interpreted in terms of energy equivalences. In this study, the environmental input of solar radiation was considered as 168 W/m^2 over 12 h daily. Table 1 provides the energy coefficients for various materials and energy input sources.

2.3.1 Energy input-output analysis

Energy input (EI) and energy output (EO) were calculated using Equation 1 and Equation 2, respectively.

$$EI = \frac{\Sigma(E_s \times \epsilon_s)}{A} \tag{1}$$

$$EO = \frac{\Sigma(P_{mc} \times \varepsilon_{om}) + \Sigma(P_{bc} \times \varepsilon_{ob})}{A} \tag{2}$$

Where; EI is the total energy input for maize production (MJ/ha); E_s is the total amount of energy input and output components used for maize production (their functional units are presented in Table 1); ε_s is the energy equivalent coefficient for input energy forms; P_{mc} is the total production quantity of maize seed yield (kg); P_{bc} is the total production of by-products or co-products (kg); ε_{om} and ε_{ob} are the net calorific value (NCV) of maize seed yield and co-products (MJ/kg), respectively; and A is the total harvested area under cropping systems (ha).

Table 1. Energy equivalent coefficient of inputs and outputs for agricultural components

Energy inputs/productivities	Energy equivalent (MJ)	References
Organic carbon		
Diesel fuel (L)	39.6	Kosemani and Bamgboye (2020)
Gasoline fuel (L)	32.4	Kosemani and Bamgboye (2020)
Energy inputs/ Fossil-based materials		
Manual energy (h)	1.96	Šarauskis et al. (2014)
Pesticides		
i. Glyphosate (L)	454.2	Ferreira et al. (2018)
ii. Paraquat (L)	459.6	Romanelli and Milan (2005)
iii. Atrazine (L)	188.4	Ferreira et al. (2018)
iv. Emamectin (kg)	69.6	Šarauskis et al. (2014)
Chemical fertilizers (kg)		
i. Nitrogen (N)	78.1	Kosemani and Bamgboye (2020)
ii. Phosphorus (P_2O_5)	17.4	Kosemani and Bamgboye (2020)
iii. Potassium (K_2O)	13.7	Kosemani and Bamgboye (2020)
Productivities		
Maize grain (kg)	17.3	This study
Maize straw (kg)	16.3	This study
Maize cob (kg)	16.2	This study
Maize husk (kg)	16.5	This study
Organic materials		
Cow manure (kg)[a]	4.4	European Commission (2021)
Chicken manure (kg)[a]	1.7	European Commission (2021)
Farm Yard manure (kg)	0.3	Soni et al. (2018)

[a]Calculated from the net calorific value reported in (European Commission, 2021)

2.3.2 Net energy value (NEV)

NEV (MJ/ha) is the difference between the energy output and fossil fuel input required in the production processes which is calculated using Equation 3 (Dai et al., 2006; Khatiwada and Silveira, 2009; Kusek et al., 2016; Neamhom et al., 2016; Nguyen et al., 2008). When the NEV value is positive (output more than input), the products produced are said to be acceptable in terms of production efficiency.

$$\mathrm{NEV} = \mathrm{EO} - \mathrm{EI} \tag{3}$$

2.3.3 Energy transfer efficiency (ETE)

ETE indicates how efficiently a crop production system is in terms of its energy output and input forms. Modified from energy use efficiency (EUE), ETE is calculated beginning with solar radiation absorbed by the earth and continues until the energy content is stored in the end-user product (Neamhom et al., 2016). This ratio has been used to express the ineffectiveness of crop production systems (Kaur et al., 2021; Soni et al., 2018). It is calculated, using Equation 4.

$$\mathrm{ETE}\ (\%) = \frac{\mathrm{EO}}{\mathrm{EI}} \times 100 \tag{4}$$

2.4 Net return (NR)

NR is the total profit gain to farmer in a particular cropping system. Residual income remains after all production factors mentioned are paid off to calculate this value (Soni et al., 2018). It considers the farm labor cost, management cost, other resources used for operation and production of the crops which is calculated using Equation 5. Where gross income is calculated by multiplying the total crop produced by its local market price, and total input cost represents all the cost fixed to produce the crop.

$$\mathrm{NR} = \text{Gross income} - \text{Total input cost} \tag{5}$$

3. RESULTS AND DISCUSSION

3.1 Overall maize cultivation systems

Data information concerning energy and materials consumed in the field were collected from four different maize cultivation systems in Thailand. Farmers always plant maize in two seasons annually. The first crop in is planted in March and planting the second crop starts in October. To produce maize seed products, the tillage for land clearance, aimed to plow crop residues under the soil, is first operated using tractors with 3, 4, or 7-disk plows. Following the plowing using a moldboard, the soil is tilled using a 7-disk plow tractor. The planting process then employs various methods, e.g., manual and tractor-mounted seeder, which use a seed ratio of 17.6 to 23.3 kg/ha. During the cultivation process, farmers use four types of synthetic herbicides and pesticide, Emamectin, Glyphosate, Paraquat, and Atrazine, to control insects and maize diseases. Fertilizers are also applied on land using different formulae, e.g., 15-15-15, 16-20-0, and 46-0-0. Three months after planting, maize is fully mature for harvesting. Maize is harvested manually or using a seed milling machine, depending on land terrain. Not only is the maize seed produced, other co-products are also generated, i.e., maize straw, maize husk, and maize cob. Figure 2 shows the production rate of product and co-products in maize cultivation systems in Thailand. After harvesting, the maize seed yield is transported by tractor or truck to a mill located within a 10-km radius. Meanwhile, the co-products remain on the farm for the next crop planting.

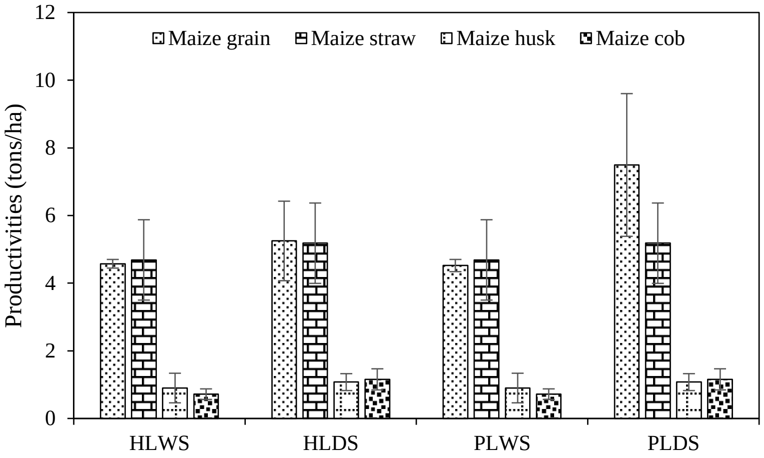

Figure 2. Yield of product and co-products in maize productions

The average main productivity of maize cultivation ranges from 4.5 to 7.5 tons per hectare and is highest in the PLDS system (7.5±2.1 tons/ha). To achieve these yields, four types and quantities of resources are consumed and applied to the maize field. First, maize farmers apply chemical fertilizers around three times per crop, first at the time of maize seed planting and then approximately 30 and 60 days later. As presented in Figure 3, the quantities of chemicals are classified ranging from 128.1 to 245.7 kg/ha for nitrogen, 31.3 to 121.9 kg/ha for phosphorus, and 31.3 to 107.5 kg/ha for potassium. Importantly, the cultivations in dry season during March consumed more overall nutrients (461.0 kg/ha for PLDS and 425.1 kg/ha for HLDS) compared with 342.7 kg/ha for HLWS and 201.9 kg/ha for PLWS. Second, diesel fuel is consumed at 66.5, 108.6, 133.8, and 204.3 L/ha for HLWS, HLDS, PLWS, and PLDS, respectively. Details of diesel fuel consumed for production processes are shown in Figure 4. Notably, around 30% of total diesel fuel consumption was applied to operate water pumping machines for plains cultivation (both in wet and dry seasons). Third, gasoline fuel for lawn mower machine operation was consumed at a rate of 40 L/ha in HLWS and PLWS while 6.3 and was for 14.1 L/ha for HLDS and PLDS, respectively. Lastly, concerning herbicide and pesticide consumption, farmers spray pre-emergence herbicide after planting and perform mechanical weeding at 7 and 45 days later.

3.2 Energy inputs

As tabulated in Table 2, summarized data were calculated from existing operations. The high land cultivation systems, in wet and dry season, required an average energy input of 32.6 GJ/ha and 32.9 GJ/ha, respectively. However, plains cultivations showed a variation of 37.2 GJ/ha in dry season and 22.1 GJ/ha during the wet season, a difference of 32%. The results showed that fertilizer had the greatest input in all systems, comprising approximately 48.5, 66.3, 52.9, and 68.9% of totals for HLWS, HLDS, PLWS, and PLDS, respectively. Nitrogen was the largest component in all fertilizer input followed by phosphorus and potash. When compared with other studies (Banaeian and Zangeneh, 2011; Kosemani and Bamgboye, 2020; Šarauskis et al., 2014), these values show similar movements due to the mindset of farmers who believe that the productivity yield depended on the direct consumption of fertilizers (Soni et al., 2018). Diesel fuel was the second ranked contributor due to its requirement in all steps of cultivation. For highlands, higher fuel consumption could be attributed to the operation of machinery for land preparation and harvesting. However, in plains, fuel was consumed significantly to pump water, around 32% and 35% of the total for WS and DS, respectively. The findings of this study were in line with those of other studies in maize cultivation reporting fertilizers and diesel fuel were the two main contributors in terms of energy input (Kaur et al., 2021; Manzone and Calvo, 2016; Yousefi et al., 2014). Energy from human work, expressed for each operation, is summarized in Table 2. The operations with the highest manpower consumption were in planting and fertilizer spreading during planting, weeding, and harvesting, respectively.

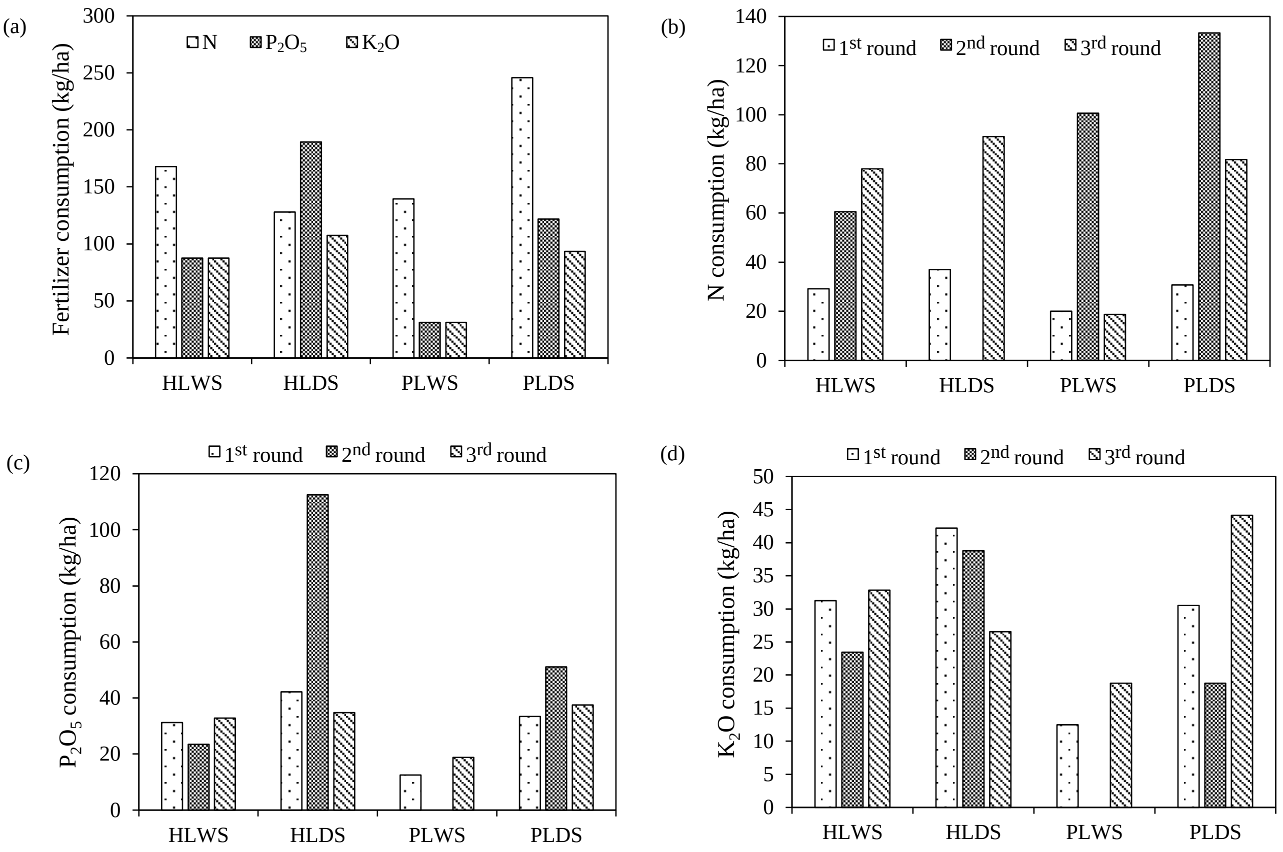

Figure 3. Quantity of fertilizer consumption in maize cultivation systems; (a) Total; (b) N fertilizer; (c) P_2O_5 fertilizer; (d) K_2O fertilizer

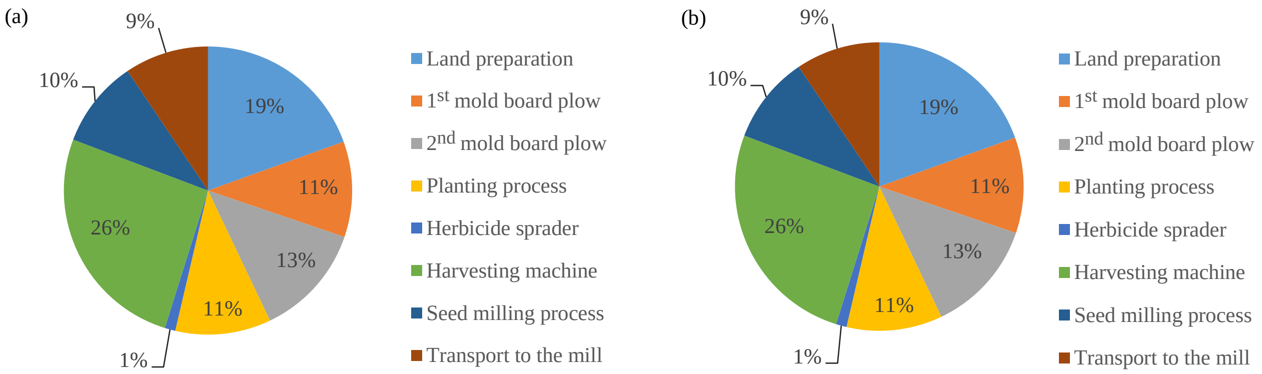

Figure 4. Diesel fuel consumption (L/ha) in maize cultivation systems; (a) HLWS; (b) HLDS; (c) PLWS; (d) PLDS

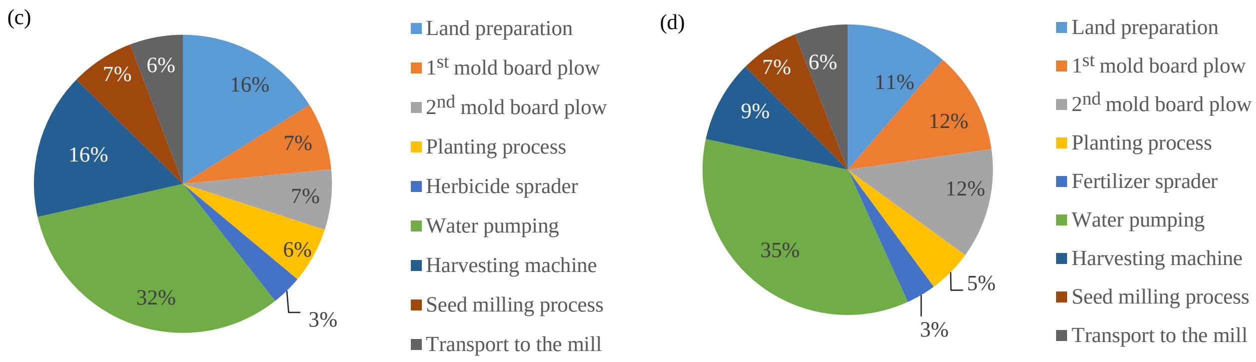

Figure 4. Diesel fuel consumption (L/ha) in maize cultivation systems; (a) HLWS; (b) HLDS; (c) PLWS; (d) PLDS (cont.)

Table 2. Energy and energy indicators analyses for four maize production systems

Resources/Productivities	Unit	Energy (MJ/ha)			
		HLWS	HLDS	PLWS	PLDS
1st Land clearance (1)					
Diesel (for plowing machine)	L	922.8±53.1	838.0±58.4	853.9±306.1	918.3±522.8
Manual energy	h	24.5±6.3	19.4±13.4	45.9±48.6	58.0±29.5
2nd Land clearance (2)					
Diesel (for tractor)	L	466.7±178.7	431.3±111.9	387.8±62.3	921.0±269.8
Manual energy	h	24.5±6.3	16.1±11.5	45.9±8.6	55.4±21.7
Moldboard plow (3)					
Diesel (for tractor)	L	618.8±525.0	546.2±153.4	346.5±0.0	993.7±347.0
Manual energy	h	17.2±3.5	18.6±12.5	45.9±8.6	54.9±27.9
Planting (4)					
Maize seed	kg	269.1±53.1	326.1±58.4	318.0±45.1	356.4±73.9
Diesel (for tractor)	L	-	-	321.8±35.0	396.6±126.4
Diesel (for fertilizer spreader)	L	-	-	-	89.1±0.0
Manual energy (for planting)	h	499.8±0.0	18.6±12.2	45.9±8.6	427.7±405.3
Nitrogen fertilizer	kg	2,277.9±1,491.2	2,889.3±1,081.3	1,562.0±390.5	2,395.9±1,054.0
Phosphorus fertilizer	kg	543.8±108.8	734.1±276.4	217.5±0.0	580.3±287.1
Potassium fertilizer	kg	428.1±121.1	578.0±135.4	171.3±0.0	417.9±206.7
Manual energy (for fertilizer spreader)	h	18.0±2.8	18.6±12.2	57.9±51.7	427.7±405.3
Weeding (5)					
Diesel (for herbicide spreader)	L	-	51.2±10.0	175.7±0.0	-
Gasoline (for lawn mower)	L	1,296.0±0.0	202.5±0.0	1,296.0±0.0	456.4±140.1
Emamectin	kg	391.5±130.5	173.8±57.2	229.6±64.6	443.2±123.5
Paraquat	L	4,883.3±3,745.3	2,528.8±691.2	1,532.0±663.4	2,238.1±503.9
Glyphosate	L	5,109.8±2,007.3	2,838.8±0.0	-	1,520.2±442.4
Antrazine	L	-	-	459.2±23.2	52.6±27.9
Manual energy	h	179.3±27.4	114.1±62.2	209.4±157.7	364.7±174.8
Farming (6)					
Diesel (for fertilizer spreader)	L	-	-	-	178.2±0.0
Diesel (for water pumping)	L	-	-	1,697.9±0.0	2,846.3±808.5
Nitrogen fertilizer	kg	10,820.1±7,119.3	15,903.4±6,879.3	9,323.2±4,763.2	16,815.1±7,457.3
Phosphorus fertilizer	kg	978.8±0.0	1,280.1±1,039.6	217.5±0.0	1,540.8±513.7
Potassium fertilizer	kg	770.6±0.0	385.3±172.8	171.3±0.0	861.6±476.4
Manual energy	h	187.8±62.7	40.5±25.5	237.9±2.3	183.7±82.7

Table 2. Energy and energy indicators analyses for four maize production systems (cont.)

Resources/Productivities	Unit	Energy (MJ/ha)			
		HLWS	HLDS	PLWS	PLDS
Harvesting (7)					
Diesel (for seed milling tractor)	L	366.3±0.0	422.1±96.3	366.3±0.0	527.5±131.8
Diesel (for small tractor)	L	-	1,113.8±0.0	841.5±373.7	742.5±0.0
Manual energy	h	1,176.0±0.0	21.0±12.8	294.0±0.0	294.0±0.0
Transport to the mills (8)					
Diesel (for truck truck)	L	307.2±8.6	481.6±212.9	305.3±14.3	479.0±137.7
Manual energy	h	24.5±6.3	21.4±14.0	57.9±51.7	56.0±27.2
Productivities (9)					
Maize grain	ton	79,065.7±2,205.8	90,738.1±20,329.6	78,165.2±3,119.5	129,572.5±36,470.3
Maize straw	ton	76,593.8±19,403.8	84,661.6±19,403.8	76,593.8±19,403.8	84,661.6±19,403.8
Maize husk	ton	14,886.0±7,236.3	17,780.5±4,135.0	14,886.0±7,236.3	17,780.5±4,135.0
Maize cob	ton	11,658.1±2,534.4	18,754.4±5,068.8	11,658.1±2,534.4	18,754.4±5,068.8
Total energy input (-) [(1)+(2)+(3)+(4)+(5)+(6)+(7)+(8)]		32,584.2	32,849.5	22,047.4	37,177.1
Total energy output (+) [(9)]		182,203.6	211,934.6	181,303.1	250,769.0
Net Energy Value (NEV)[a]	MJ/ha	77,043.4	106,509.1	86,679.7	141,015.9
	GJ/ha	77.0	106.5	86.7	141.0
Energy Transfer Efficiency (ETE)[b]		1.73	2.01	1.92	2.29

[a] Positive sign (+) means gain the energy from production process, Negative sign (-) means loss of energy.

[b] Calculated from the input starting from solar radiation (168 W/m^2, 12 h/day) through output as product and co-products.

3.3 Energy outputs of system

Total energy output from maize cultivation systems in Thailand are reported in Table 2. According to the product and co-products presented in Figure 2, energy output was computed from maize grain as a main product and co-products including maize straw, maize husk, and maize cob. In wet season, the reported values were 182.2 and 181.3 GJ/ha for HLWS and PLWS, respectively, whereas the values for HLDS and PLDS were higher. A greater amount of grain and straw products during dry season led to output energy results in more than 212.0 GJ/ha and peaked at 250.8 GJ/ha in PLDS. It could be said that production of maize and co-products cultivated during dry season (both in highlands and plains) had higher energy output. This outcome was significantly ($p<0.05$) greater to others. One reason related to this result was a significantly higher energy use resulting in greater grain yield in dry season. Moreover, different levels of climatic factors, geographical locations, and required water were also contributed. The results reported in studies of paddy rice, wheat, and other economic crops were similar to the results obtained in this study (Neamhom et al., 2016; Patthanaissaranukool and Polprasert, 2016; Soni et al., 2018).

3.4 Energy indicators

From existing maize cultivation, as shown in Figure 5, the four defined systems indicated positive values of 77.0, 106.5, 86.7, and 141.0 GJ/ha for HLWS, HLDS, PLWS, and PLDS, respectively. The positive sign showed an energy output greater than that of fossil fuel energy required in the production process. Lower values in wet season may have resulted from the loss of energy especially nutrients and crop residues (Khonpikul et al., 2017). Rainfall, pests, and the type of terrain make it difficult to grow, harvest, and collect crop residue. The results of the net energy value assessment were consistent with the findings of other studies as presented in Table 3. Grassini and Cassman (2012) reported higher NEV performance (159.0 GJ/ha) in US maize systems because of greater fertilizer input, higher yield, and more appropriate irrigated systems. Similar to the study in Germany by Felten et al. (2013) rounded net energy production amounted to 91.0 GJ/ha due to their high energy yields. Therefore, in most cases, beneficial co-products of straw, husk, and cob were absent from the computation resulting in a lower NEV.

By applying Equation 4 using the different net inputs of fossil fuel and fossil-based resources energy and sun energy radiated to the earth's mantle (168W/m^2, 12 h/d) (Masters, 1998) and the energy output of maize grain and co-products produced, ETE was found to be 1.73, 2.01, 1.92, and 2.29 for HLWS, HLDS, PLWS, and PLDS, respectively. As shown in Table 3, these values were relatively low compared with other related studied. This index for maize cultivation systems in different regions of Thailand was higher due to the high output energy obtained. The low energy efficiency of maize productions in Thailand was due to high energy consumption from activity and low product output.

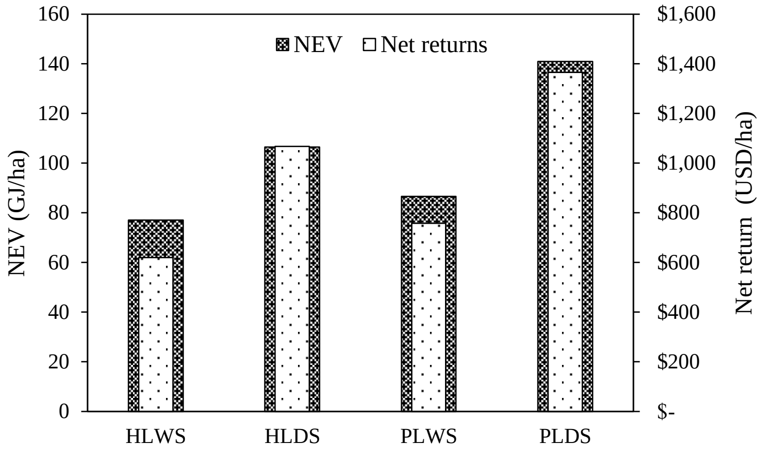

Figure 5. Net energy and cost performance in four different maize cultivation systems

Table 3. Comparison of Net Energy Value and ETE in maize cultivations

References	Country	NEV[a] (GJ/ha)	ETE (%)	Remarks
Lorzadeh et al. (2011)	Iran	+18.8	1.48	Not include co-products
Felten et al. (2013)	Germany	+91.0	5.5	High product and co-products
Akdemir et al. (2012)	Turkey	-	0.76	Not include co-products
Grassini and Cassman (2012)	USA	+159.0	6.6	-
Memon et al. (2015)	Pakistan	+52.0	5.2	Moldboard plow practice
		+47.0	5.1	Cultivator practice
		+31.8	4.1	Zero tillage practice
Chilur and Yadachi (2017)	India	+68.1	5.1	-
This study	Thailand	+77.0	1.73	HLWS
		+106.5	2.01	HLDS
		+86.7	1.92	PLWS
		+141.0	2.29	PLDS

[a]Positive sign (+) indicates energy gain; negative sign (-) indicates energy loss from production processes.

3.5 Economic return

From an economic point of view, the net return to the farmers was obtained from the difference between gross income and total input cost. At the time of this study, the current local market prices for maize grain and maize cob were found to be 0.3 USD/kg grain and 0.01 USD/kg cob. As summarized in Table 4, all cultivation systems were profitable operations in the studied region. PLDS had the highest cost of production (924.3±393.1 USD/ha), followed in rank by HLWS (778.0±208.6 USD/ha), PLWS (623.0±206.2 USD/ha), and HLDS (541.2±168.9 USD·/ha). Added chemical fertilizers, maize seed, and labor used during farming and weeding activities contributed to higher production costs. The highest gross incomes from selling the products of maize grain and maize cob were observed from the PLDS of 2,289.4±644.2 USD/ha. In wet season planting, the total selling price was lowest compared with 1,397.2±41.0 USD/ha and 1,381.4±57.0 USD/ha for HLWS and PLWS, respectively. In terms of NR, planting in dry season offered higher returns than wet season and reached the highest returns to farmers in PLDS (1,365.2 USD/ha). According to the beneficial by-products utilization occurring in the production processes, this value was relatively low as compared to 2,107.5 USD/ha/year of the sugarcane industry (Neamhom et al., 2016), 3,574.4 USD/ha/year of the palm oil production industry (Patthanaissaranukool et al., 2013), and 3,101.4 USD/ha/season of paddy rice cultivation (Polprasert and Chaiyachet, 2007).

Table 4. Cost analysis for maize cultivation systems in Thailand

Cultivation systems	Total input cost (USD/ha)	Total selling price (USD/ha)	NR[a] (USD/ha)
HLWS	778.0±208.6	1,397.2±41.0	619.2
HLDS	541.2±168.9	1,608.5±361.2	1,067.3
PLWS	623.0±206.2	1,381.4±57.0	758.4
PLDS	924.3±393.1	2,289.4±644.2	1,365.2

[a] Positive sign indicates the cost saving, Negative value indicates that the resources cost is higher than the return values.

3.6 Simulations to reduce energy consumption

According to the criteria for energy saving in crop production and heavy consumption of agro-chemical fertilizer on maize field, sharing more than 48% of total energy inputs, 15 scenarios were established as described in the following to find the sustainable ways to produce maize grain used in the animal feed industry. In this work, they are replaced with bio-nutrients and organic residues from livestock farming. Selected materials and their nutrient components used are presented in Table 5. The scenarios were ranked from 20 to 100% replacement with organic residue materials. NEV and NR were calculated to measure how much the organic materials could help reduce energy input consumption and the returns to farmers, respectively. In terms of NEV, a positive sign indicated that the substitute could not help reduce energy input while a negative sign meant it helps reduce energy consumption. In the opposite way, a negative value of NR revealed that the gross input was higher than the incomes resulting in less return to the farmer. Figure 6 shows the net energy outcome from reduced chemical fertilizer consumption. Compared to existing operation, cow manure substitute created the higher energy requirement when the replacement ratios were more than 20%, whereas chicken and farmyard manures had a lower energy consumption movement. The resulting values of NEV and NR in the results of organic residue replacement activity for each scenario as compared with those of existing operations are summarized in Table 6. Although the use of chicken and farmyard manures exhibited lower energy requirement, only replacing of chemical fertilizer by farmyard manure could achieve the maximum returns for both energy gain and profit. Therefore, the economic benefits for implementing those approaches seem attractive for maize plantation owners and local governments to follow and encourage.

Table 5. Selected materials and nutrient components of substituted residues

Organic residues	Nitrogen (N, %)	Phosphorus (P_2O_5, %)	Potassium (K_2O, %)	References
Cow manure	1.10	1.84	0.52	Ministry of Agricultural and Cooperative (2016)
Chicken manure	2.42	6.29	2.11	Ministry of Agricultural and Cooperative (2016)
Farmyard manure	0.50	0.20	0.50	Tamil Nadu Agricultural University (2016)

Table 6. Energy reduction and cost-saving potential from chemical fertilizer replacements

Maize cultivation/scenarios	NEV[a] (GJ/ha)				NR[b] (USD/ha)			
	HLWS	HLDS	PLWS	PLDS	HLWS	HLDS	PLWS	PLDS
Existing condition	+15.8	+14.8	+11.9	+22.6	-106.1	-193.4	-61.5	-141.7
S-1: 20% Cow manure	+8.2	+16.5	+7.1	+12.1	-38.8	-81.1	-37.6	-59.6
S-2: 40% Cow manure	+16.4	+32.9	+14.1	+24.2	-77.6	-162.2	-75.2	-119.3
S-3: 60% Cow manure	+24.6	+49.4	+21.2	+36.4	-116.5	-243.3	-112.8	-178.9
S-4: 80% Cow manure	+32.8	+65.9	+28.3	+48.5	-155.3	-324.4	-150.4	-238.5
S-5: 100% Cow manure	+40.9	+82.3	+35.3	+60.6	-194.1	-405.5	-188.0	-298.2

Table 6. Energy reduction and cost-saving potential from chemical fertilizer replacements (cont.)

Maize cultivation/scenarios	NEV[a] (GJ/ha)				NR[b] (USD/ha)			
	HLWS	HLDS	PLWS	PLDS	HLWS	HLDS	PLWS	PLDS
S-6: 20% Chicken manure	-0.8	-1.5	-0.4	-1.1	-5.0	-13.6	-9.5	-10.1
S-7: 40% Chicken manure	-1.6	-3.0	-0.8	-2.1	-10.0	-27.2	-19.0	-20.1
S-8: 60% Chicken manure	-2.4	-4.4	-1.2	-3.2	-15.0	-40.8	-28.5	-30.2
S-9: 80% Chicken manure	-3.2	-5.9	-1.7	-4.3	-20.0	-54.4	-38.0	-40.3
S-10: 100% Chicken manure	-4.0	-7.4	-2.1	-5.3	-24.9	-68.0	-47.5	-50.3
S-11: 20% Farmyard manure	-1.2	-2.2	-0.7	-1.6	+14.7	+25.7	+6.9	+18.8
S-12: 40% Farmyard manure	-2.3	-4.3	-1.4	-3.1	+29.4	+51.4	+13.8	+37.6
S-13: 60% Farmyard manure	-3.5	-6.5	-2.1	-4.7	+44.2	+77.1	+20.7	+56.4
S-14: 80% Farmyard manure	-4.6	-8.7	-2.8	-6.3	+58.9	+102.8	+27.5	+75.2
S-15: 100% Farmyard manure	-5.8	-10.8	-3.5	-7.9	+73.6	+128.5	+34.4	+94.0

[a] Positive sign (+) means still consumed energy, Negative sign (-) means help reduce energy consumption.

[b] Positive sign indicates the cost saving, Negative value indicates that the resources cost is higher than the return values.

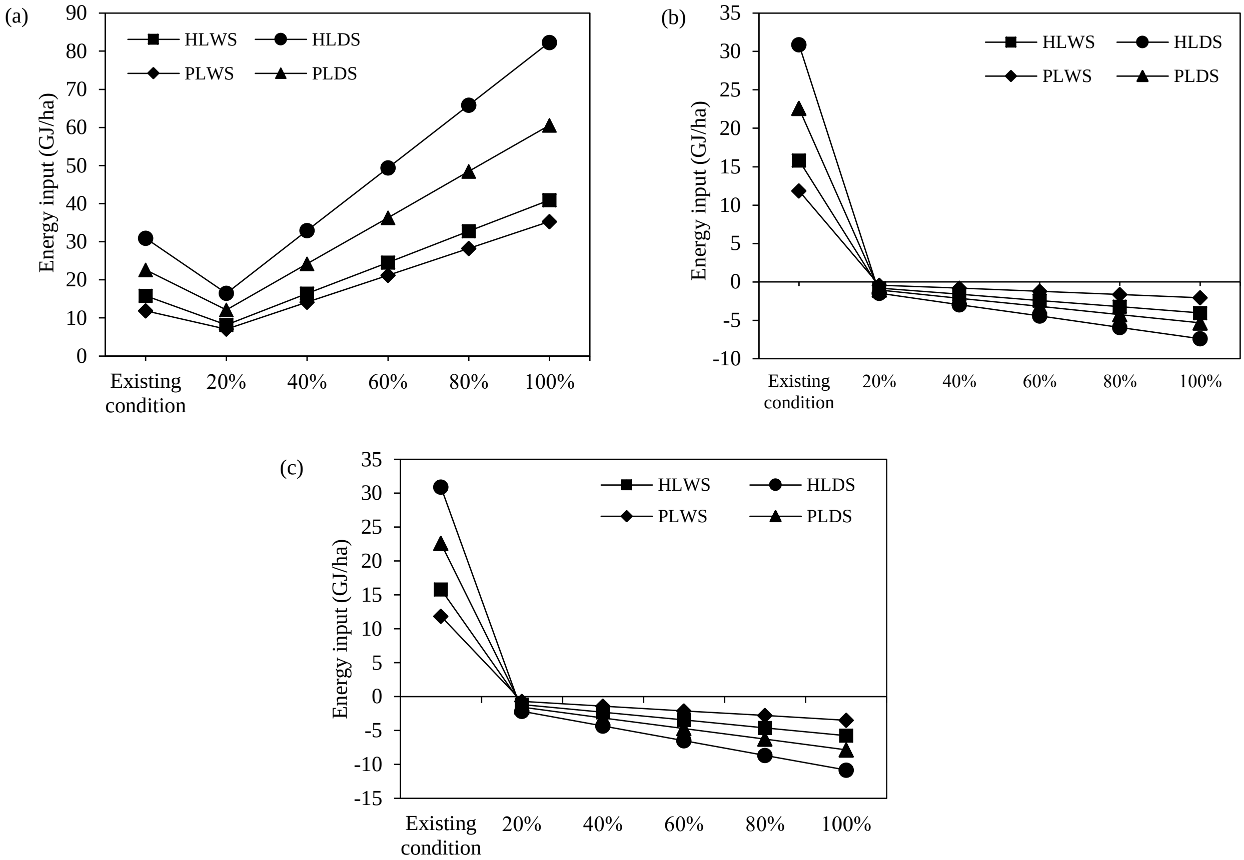

Figure 6. Methods to reduce energy consumption from organic material substitution; (a) cow manure; (b) chicken manure; (c) farmyard manure

4. CONCLUSION

The cultivations of maize fed to animal feed industry in Thailand depends on seasonal and geographical factors classified in four systems, HLWS, HLDS, PLWS, and PLDS. Regarding agricultural activity, consumption of chemical fertilizers created the highest energy input value followed by the consumption of fossil fuels for all methods. Following the concept of energy input-output analysis, the net energy value was found to be +77.0, +106.5, +191.6, and +228.5 GJ/ha, whereas ETE was computed to be 1.73, 2.01, 1.92, and 2.29%, respectively. The positive value of NEV presented a significantly energy gain from production processes. In terms of ETE, the values were quite lower than those found in previous studies because of the lack of further uses of co-products from the production processes, i.e., maize husk, straw, and cob. To determine a sustainable method to produce grain products together with lowering energy consumption, different scenarios were established. These included replacing chemical fertilizers with cow, chicken, and farmyard manures. Results showed that chicken manure and farmyard manure substitutions could achieve this goal. Although these results from chicken and farmyard manure appeared best and may achieve a lesser rate of energy input, only the use of farmyard manure provided profit returns to farmers.

Results from cost performance analysis showed that all systems produced profit returns of about 619.2 1,067.3 758.4 and 1,365.2 USD/ha for HLWS, HLDS, PLWS, and PLDS, respectively. The highest profit return was found in the PLDS system due to its huge amount of product, about 1.7 times compared with the lowest system.

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