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Agro-Ecosystems Conservation Through Efficient Energy Utilization in Crop Production: An Empirical Evidence of Maize Farmers' in Niger State, Nigeria

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ABSTRACT: *The research conducts an in-depth investigation on energy use efficiency in maize production in Niger State, Nigeria. The study employed multi-stage sampling technique to elicit information from 120 respondents through administration of pre-tested questionnaire. Data were collected during the 2014 cropping season. Production function analyses which incorporate the conventional neoclassical test of economic and technical efficiencies, and energy index models were used to analyze the data collected. Results showed that Total inputs energy in maize production was 2227.81 MJha^{-1}, with 85.2% of input energy contributed by agrochemical input or coming from biological energy and energy ratio was 4.5 in the production systems. Furthermore, findings revealed that the farmers were inefficient in the use of all the energy inputs, with energy inputs such as nitrogen MJ, K_2O MJ and family labour MJ been under-utilized. Results suggest that reduction in agrochemical consumptions are important for energy saving and decreasing the environmental risk problem in the area. Also policies that prevent global warming, soil and water pollution should be enacted thereby creating environmental friendly ecosystem.*

Keywords: *Energy; Efficiency; Conventional neoclassical approach; Maize; Niger state; Nigeria*

INTRODUCTION

Maize (*Zea mays L.*) is important cereal crop that is grown widely throughout the world in a range of agroecological environments. More maize is produced annually than any other grain. The crop was introduced into Africa in the 1500s and has since become one of Africa's dominant food crops and an important staple food for more than 1.2 billion people in SSA and latin America. It has a worldwide production of 785 million metric tons and consumption of about 116 million tons (IITA, 2014). The age old necessities of life are food, clothing and shelter. The 20th and 21th century dramatized a fourth-energy. Energy starvation of the technological complex that maintains modern society may soon be as crucial as feeding the world's hungry. Therefore, energy starvation could well precipitate more wide spread food starvation. Solution to the energy crisis is strongly dependent on the technology of how energy is used. As such to make a physical change in the world it is necessary to use four resources: energy, matter, space and time. Energy has been a key input of agriculture since the age of subsistence agriculture. It is an established fact worldwide that agricultural production is positively correlated with energy input (Taheri-Garavand *et al.*, 2010). Agriculture is both a producer and consumer of energy. It uses large quantities of locally available noncommercial and commercial energies as direct and indirect forms, such as seeds, manure and animals, diesel fuel, electricity (mostly for irrigation), fertilizer, biocides, chemical fertilizers, and machinery (Reza, *et al.*, 2012). Energy input–output analysis is usually used to evaluate the efficiency and environmental impacts of production systems (Ozkan *et al.*, 2004; Lorzadeh *et al.*, 2012). Energy use in agriculture has been increasing in response to increasing population, limited supply of arable land, and a desire for higher standards of living (Kizilaslan, 2009). Choudhary *et al.*, (2013), cited that modern agriculture system input energy is very much higher than in traditional agriculture system, but energy use efficiency has been reduced in response to not effective use of input energy. Efficient use of energies helps to achieve increased productivity and contributes to the economy, profitability and competitiveness of agriculture sustainability in rural

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areas (Lorzadeh *et al.*, 2012). Furthermore, in order to meet the ever increasing demand for food production, energy use in agriculture production has become more intensive. However, more intensive energy use has brought some important human health and environment issues forcing humans to make more efficient use of inputs to maintain a sustainable agriculture production (Maral *et al.*, 2012). In general, two competing approaches for the measurement of efficiency are the parametric and nonparametric approach (Pishgar *et al.*, 2011). The empirical studies that have made use of this model in determining efficiency in crop production in Nigeria is increasing, but there are relatively fewer studies which applied it in determining energy efficiency in crop production in the country, given that it has been applied in other parts of the world. In addition, no studies have been documented for energy efficiency using conventional neoclassical approach in maize production in Niger state, Nigeria. The objective of this study is to provide empirical information on energy efficiency and energy indicator in maize production in Niger State, Nigeria using the conventional neoclassical analytical approach with a view to derive policy implications for proper policy recommendations thereby exerting positive effect on managing the ecosystems in order to realize sustainability in agriculture, and also establishing a productive efficiency benchmark in maize production in Niger state.

THEORETICAL FRAMEWORK: IMPOSED ENERGY FUNCTION IN EFFICIENCY STUDIES

The modeling and estimation of energy efficiency of a firm relative to other firms or the 'best' practice in an industry has become an important area of economic study. Energy productivity is generally measured in terms of the efficiency with which energy inputs, such as fertilizer MJ, labour MJ, animal MJ, machine MJ, seed MJ, herbicides MJ, petrol MJ, diesel MJ, electricity MJ, etc are converted to output within the production process. There are two measures of energy productivity namely, partial energy input productivity and total energy input productivity. Partial energy input productivity is measured as the ratio of output to a single input. The ratio of output to all inputs combined is the total energy input productivity. Generally, two approaches are used in measuring total energy input productivity. These are the growth accounting or index number approach and the econometric or parametric method. The econometric method is based on an econometric estimation of the energy function or the underlying production, cost or profit function. In this study, the energy function is used to measure the productivity (or energy use efficiency of maize farmers). From the imposed energy function, the conventional neoclassical test of economic efficiency of energy was derived. The rule of this test is that the shape of the imposed energy function (MEP) should be equal to the inverse ratio of energy input price to output price at the profit maximization point. This is given as:

$$MEP\ x\ i = P\ x\ i/Py$$

Where:

Pxi = unit price MJ^{-1} input used
Py = output price MJ^{-1}
MEP = marginal energy product of resource input used
MEP x Py = MVEP
MVEP/UEFC = r

Where:

MVEP = marginal value energy product
UEFC = unit energy cost
r = allocation index

In an attempt to substitute the efficiency hypothesis, focus is centered on the estimated value of r and its closeness to unity (1). Efficiency is attained if MVEP = UEFC.

METHODOLOGY

Study Area

This study was based on the farm level data on small scale maize farmers in Niger State, Nigeria. Niger State is located in the Guinea Savannah zone of Nigeria and lies between latitudes 8°20′N and 11°30′N of equator and longitude 3°30′E and 7°20′E of the Greenwich Meridian .The land area is about 76,363 square kilometre with varying physical features like hills, lowland and rivers. The state enjoys luxuriant vegetation with vast Northern Guinea savannah found in the North while the fringe in mostly southern guinea savannah. The people are predominantly peasant farmers cultivating mainly food crops such as yam, maize, rice, millet for family consumption, market and cash. Farming activities are usually carried out using hand tools and other simple implements.

Sampling Technique

The study made used of multi-stage sampling technique. Data mainly from primary sources were collected from one out of the three Agricultural zones, namely, Kuta zone which was purposively selected given its conspicuous importance in maize crop production. The second stage involved purposive selection of three LGAs, namely, Shiroro, Bosso and Paikoro LGAs, respectively based on the preponderance of small-scale maize farmers' in the areas. The third stage involved random selection of four villages from each LGA. The final stage involved simple random selection of 10 farmers from each of the villages, thus giving 120 respondents. Data were collected with the aid of pre-tested questionnaire to collect input-output data of the farmers defined within production content. Both energy index models and inferential statistics were used to analyze the data collected.

Table 1.1
Energy sources grouped under different categories of energy

Category energy	*Sources of energy*
Direct Energy	Human, Animal, Fuel wood, Agricultural waste, Petrol, Diesel, Kerosene, Electricity, etc
Indirect Energy	Seeds, Farm yard manure, Chemicals, Fertilizer, Machinery, etc
Renewable Energy	Human, Animal, Fuel wood, Agricultural wastes, Seeds, Farm yard manure, etc
Non-Renewable	Petrol, Diesel, Electricity, Chemicals, Fertilizers, Machinery, etc
Commercial Energy	Petrol, Diesel, Electricity, Chemicals, Fertilizers, Machinery, Seeds, etc
Non-Commercial Energy	Human, Animal, Fuel wood, Agricultural wastes, Farm yard manure, etc
Biological Energy	Diesel, Pesticides, Fertilizers, Machinery, Electricity, etc
Industrial Energy	Human, Seeds and H_2O for Irrigation

Table 1.2
Equivalents for various sources of energy

Particulars	*Units*	*Equivalent energy, MJ*	*Remarks*
Adult man	Man-hour	1.96	
Women	Woman-hour	1.57	
Child	Child-hour	0.98	
Nitrogen	Kg	60.60	
P_2O_5	Kg	11.1	
K_2O	Kg	6.7	
Herbicides	litre	120	
Improved seed	Kg	15.2	Processed
Maize product	Kg (Dry mass)	14.7	The main output is grain

Model specification

Energy standard equations: Standard equations were used to determine the following energy model index:

Energy ratio = output energy ($MJha^{-1}$)/Total input energy ($MJha^{-1}$) ………………… (1)

Energy productivity = Grain yield ($kgha^{-1}$)/Total input energy ($MJha^{-1}$) ……………... (2)

Net energy = Total output energy ($MJha^{-1}$) – Total input energy ($MJha^{-1}$) ……………...(3)

Specific energy = Total input energy ($MJha^{-1}$)/ Grain yield ($kgha^{-1}$) …………… (4)

2. Energy production function

The analytical procedure employed was imposed energy production function analysis. This was used to obtain the parameters for the measurement of energy resource use efficiency of the maize farmers. Four functional forms were tried and the lead equation was selected based on economic, econometric and statistical criteria including signs and magnitudes of the coefficients, the magnitude of R^2, T-statistics, F-statistics. The function experimented with were linear, semi log, double log and exponential. The implicit function can be presented by the following equation:

$$Y = f(X1, X2, X3, X4, X4, X5, X6, X7) \quad \ldots (4)$$

Where:

Y = Output of Maize (MJ)
X_1 = Nitrogen (MJ)
X_2 = P_2O_5 (MJ)
X_3 = K_2O (MJ)
X_4 = Family labour used (MJ)
X_5 = Hired labour used (MJ)
X_6 = Improved seeds (MJ)
X_7 = Herbicides (MJ)

The following functional forms were evaluated

(a) Linear function

$$Y = b_0 + b_1 X_1 + b_2 X_2 \ldots + b_n X_n + e_i \quad \ldots (5)$$

MPP= b

Elasticity = b * X/ Y

(b) Semi–log function

$$Y = \log b_0 + b_1 log X_1 + b_2 log X_2 \ldots + b_n log X_n + e_i \quad \ldots (6)$$

MPP = b/ X

Elasticity = b/Y

(c) The Cobb Douglas (double log) function

$$Log\ Y = \log b_0 + b_1 log\ X_1 + b_2 log\ X_2 \ldots + b_n log\ X_n + e_i \quad \ldots (7)$$

MPP = b* Y/X

Elasticity = b

(d) Exponential function

$$Log\ Y = b_0 + b_1 X_1 + b_2 X_2 \ldots + b_n X_n + e_i \quad \ldots (8)$$

MPP = b*X

Elasticity = b*Y

Note:

b_0 = Intercept
b_1-b_n = Regression co-efficients

Determining technical efficiency of energy resource use

The elasticity of energy production which is the percentage change in output as a ratio of a percentage change in input was used to calculate the rate of return to scale which is a measure of a firm's success in producing maximum output from a set of input.

EEP = MEP/AEP

Where:

EP = elasticity of production
MEP = marginal physical product
AEP = average physical product

If

EEP = 1: constant return to scale
EEP < 1: decreasing return to scale
EEP > 1: increasing return to scale

Determining the economic efficiency of energy resource use

The following ratio was used to estimate the relative efficiency of energy resource use (r)

r = MVEP/UEFC

Where:

UEFC = unit cost of a particular energy resource
MVEP = value added to maize output due to the use of an additional unit of MJ input, calculated by multiplying the MEP by the unit price of MJ output . i.e. MEPxi x Py

Decision rule:

If r = 1, energy resource is efficiently utilized,
if r > 1, energy resource is underutilized, while,
if r < 1, energy resource is over utilized.

Economic optimum takes place where MVEP = UEFC. If r is not equal to 1, it suggests that energy resources are not efficiently utilized. Adjustments could therefore, be made in the quantity of energy inputs used and costs in the energy production process to restore r = 1 and the model is given as follows:

Divergence: % **=** (1-1/ri) x 100 or [(ri-1)/ri] x 100

RESULTS AND DISCUSSION

Source-wise energy consumption

Table 2 revealed source-wise energy consumed in maize production in the studied area. The total input energy requirement for producing maize crops was 2227.81 MJha^{-1}, with indirect energy used accounting for the highest share in total energy input consumed (11942.27MJha^{-1}). Among the different energy sources nitrogen fertilizer was the highest energy consumed, and the average use of the nitrogen fertilizer was 23.62 Kgha^{-1}. It is a common belief that increase in fertilizer use will lead to an increase in yield. Therefore, because of the high Nitrogen fertilizer used in the production, it account for the highest value in total energy input used in maize production (1431.07 MJha^{-1}). Comparatively, from this finding, the total input energy required for production of maize per hectare in Niger State Nigeria was lower than the reported total input energy (29307.74MJha^{-1}) required for maize using little high technology in Dezful in Iran (Lorzadeh *et al.*, 2011). Therefore, on the basis of maize output ratio, farmers in the study area in Nigeria will be judicious in energy use and output better-off if they will operate on the same technological level, given that they required just five times of their present total input energy to produce the same level of output obtained in Dezful, Iran, which used thirteen times energy input estimated equivalent used in maize production in Nigeria to obtained their present output level. However, other inputs applied in the growing process, and percentage of each input to the total energy inputs are given in the table.

Table 2
Source-wise energy consumption in maize production

Variables	*Quantity units ha^{-1}*	*Total energy equivalents (MJha^{-1})*	*% of Total energy*
a. Inputs			
Direct energy			
Family labour	84.88 manhours	166.37	7.5
Hired labour	60.80 manhours	119.17	5.5
Sub-total	285.54		
Indirect energy			
Seeds	2.67	40.58	1.8
Nitrogen	23.62	1431.07	64
Phosphorus (P_2O_5)	11.81	131.09	5.9
Potassium (K_2O)	11.81	79.13	3.6
Herbicides	2.17	260.40	11.7
Sub-total	1942.27		
Total input energy (MJha^{-1})	**2227.81**	**100**	
b. Output			
Maize	683.54	10048.04	
Total energy output (MJha^{-1})	**10048.04**		

Source: Field survey, 2014.

Yield and energy requirement in different form for maize production

Table 3 shows the energy requirement in different forms for maize production Agro-ecosystems. The energy productivity, energy ratio, specific energy, net energy and Agrochemical energy ratio of maize production in the study area were identified. Energy ratio in maize production was 4.51; therefore, raising the crop yield and decreasing energy inputs consumption the energy ratio can be increased. This findings is greater than the amount recorded for maize production by Canakci *et al.*, (2005) in Turkey (3.66) and Lorzadeh *et al.*, (2011) in Iran(1.86), respectively. This high energy ratio implies efficient use of energy in maize production. Energy productivity and specific energy in maize production systems were 0.31 KgMJ^{-1} and 3.26 MJKg^{-1} respectively. This means that produced maize grain yield per input energy unit was 0.13 kg/MJ, or in other word, in maize production, 3.26 MJ energy was used for producing one kg of grain yield. Also, Net energy per hectare for maize production was 7820.23 MJha^{-1}. Furthermore, the agrochemical energy ratio in maize production was 85 per cent which implies high energy quantum consumed from fertilizer and herbicides inputs in the production. However, distribution of other inputs used in the production according to the industrial and biological; renewable and non-renewable; and, commercial and non-commercial were also identified. The total biological energy input consumed was 85.4%, while industrial energy accounted for 14.6%. Moreover, several researchers reported the ratio of industrial energy to be greater than biological energy consumption in crops production (Ozkan *et al.*, 2007; Esengun *et al.*, 2007; Lorzadeh *et al.*, 2011). In modern crop production systems large amount of industrial energy has been replaced instead of biological energy therefore energy use efficiently has been reduced in response to use of agrochemical input with high energy cost and effective use of input energy.

Table 3
Yield and energy requirement in different form for maize production

Items	*Unit*	*Quantity*
Yield	Kgha^{-1}	683.54
Total input energy	MJha^{-1}	2227.81
Output energy	MJha^{-1}	10048.04
Energy ratio		4.5
Specific energy	MJkg^{-1}	3.26
Energy productivity	KgMJ^{-1}	0.31
Net energy	MJha^{-1}	7820.23
Agro-chemical energy ratio	%	85
Industrial energy	MJha^{-1}	326.12 (14.6)
Biological energy	MJha^{-1}	1901.69 (85.4)
Renewable energy	MJha^{-1}	326.12 (14.6)
Non-renewable energy	MJha^{-1}	1901.69 (85.4)
Commercial energy	MJha^{-1}	1942.27 (87.2)
Non-commercial energy	MJha^{-1}	285.54 (12.8)

Source: Field survey, 2014.

Energy inputs and maize output relationship

The functional relationship between different energy inputs and maize output was shown in Table 4a. The influence of energy inputs on maize output was determined with the aid of energy production function analysis. On the basis of *a priori* expectation, the statistical significance of the coefficients and the coefficient of determination, the semi logarithm functional form was chosen as the lead equation. The result reveals that almost all the energy inputs were positively related to the output. The value of the R^2 reveals that approximately 62% of the variations in output energy in the area were explained by the independent energy input variables included in the model, while 38% was due to systematic error which were unexplained by the energy function. However, Nitrogen, Phosphorus (P_2O_5), potassium (K_2O) and seed MJ respectively, significantly affected maize output at one percent level. On the other hand, family labour MJ affected the output at 10 percent level of significance. Hired labour MJ and herbicides MJ were not significant; as such need no further discussion. Since the coefficient of the semi-log divided by the mean of the given output is the MJ elasticity, the following MJ estimates were obtained (Table 4b); Nitrogen MJ(0.09), Phosphorus MJ(-0.23), potassium MJ(0.23), family labour MJ(0.15), hired labour MJ(0.03), seed MJ(0.33), and herbicides MJ(0.05) respectively. The MJ elasticity coefficient for constant was 11.00, which implies that at zero commitment of MJ inputs, 11.00 MJ will be contributed to the maize output. Therefore, it can be inferred that a unit increase in the level of MJ in Nitrogen, P_2O_5, K_2O, family labour, and seed will lead to 0.09, – 0.23, 0.23, 0.15, and 0.33 unit changes in maize output, respectively. The inputs with positive MJ coefficients imply an increase in maize output, while negative coefficient MJ implies a decrease in maize output. Except phosphorus MJ which was in the irrational energy production stage III (deminishing), all the significant inputs MJ were within the rational energy production stage II which is referred to as economic stratum in production theory. The summation value of MJ coefficients which is 0.65 indicates decreasing returns to scale. This suggests that maize farmers in the study area can increase their output by judiciously using of these four resources (Nitrogen, potassium, family labour and seed) and less of phosphorus (Table 4b). Measure of technical energy efficiency of energy resources used such as Average Energy Product (AEP), Marginal Energy Product (MEP), and Marginal Energy Value Product (MVEP) and Unit Energy Factor Cost (UEFC)

Table 4a
Functional relationship between output and different energy inputs in maize production

Variables	*Linear*	*Exponential*	*Semi-log (+)*	*Double log*
Nitrogen MJ	0.443^{NS}	-0.0002^{NS}	1927.80***	0.41^{NS}
	(1.05)	(-0.20)	(3.11)	(1.46)
P_2O_5 MJ	-142.58^{NS}	7.64^{NS}	-47032.27***	-1.46*
	(-1.17)	(1.17)	(-2.73)	(1.88)
K_2O MJ	287.29^{NS}	-12.65^{NS}	47112.51***	1.46*
	(1.42)	(-1.17)	(2.73)	(1.89)
Family labour MJ	2.17**	0.000034^{NS}	3151.11*	0.1^{NS}
	(2.89)	(0.10)	(1.74)	(1.33)
Hired labour MJ	0.12***	-0.00020^{NS}	601.85^{NS}	0.018^{NS}
	(6.37)	(-0.42)	(1.02)	(1.06)
Seed MJ	93.49***	0.0033***	6812.59***	0.30***
	(3.88)	(2.58)	(3.32)	(3.22)
Herbicides MJ	1.33^{NS}	0.000077^{NS}	940.60^{NS}	0.023^{NS}
	(1.062)	(0.59)	(1.06)	(0.43)
Constant	1775.17***	9.11***	22832.54***	-0.98^{NS}
	(1.56)	(54.44)	(2.63)	(-1.12)
R^2	0.69	0.58	0.62	0.58
R^2 adjusted	0.67	0.54	0.59	0.57
F- statistics	29..14***	17.79***	21.23***	22.02***

Source: Field survey, 2014.

Table 4b
Elasticity of energy production function

Variables	*Coefficients*
Constant	11.00
Nitrogen MJ	0.091
P_2O_5 MJ	-0.23
K_2O MJ	0.23
Family labour MJ	0.15
Hired labour MJ	0.03
Seed MJ	0.33
Herbicides MJ	0.05
RTS	0.65

Source: Field survey, 2014.

Table 4c
Technical energy efficiency parameters

Variables	*Mean*	*AEP*	*MEP*
Nitrogen MJ	2925.01	7.09	0.659
P_2O_5 MJ	270.66	76.66	17.38
K_2O MJ	163.37	127	28.84
Family labour MJ	339.16	61.18	9.29
Hired labour MJ	245.98	84.35	2.45
Seeds MJ	84.04	246.90	81.06
Herbicides MJ	536.40	38.68	1.75

Source: Field survey, 2014. Output mean = 20749.05 MJ.

Table 4d
Allocative energy efficiency estimates

Variables	*MEP*	*MVEP*	*UEFC*	*AEEI (r)*	*% Divergence*
Nitrogen MJ	0.659	2.91	0.74	3.93	74.56
P_2O_5 MJ	17.38	-76.82	4.05	-18.97	-94.73
K_2O MJ	28.84	127.47	4.05	31.47	96.8
Family labour MJ	9.29	41.06	51.02	0.81	23.46
Seed MJ	81.06	358.29	19.74	18.15	94.49

Source: Field survey, 2014.

were derived (Table 4c-d). The values of the MEP show that the farmers were more efficient in the use of seed MJ than the other resources. This suggests that if additional MJ were available, it would lead to an increase in maize yield by 81.06 among the farmers. This implies that the farmers were more technically energy efficient in the use of seed. Of all the energy resources used, P_2O_5 had the least MEP (-17.38 MJ). This shows inefficiency in the use of available P_2O_5. Given the level of technology and prices of both energy inputs and outputs, efficiency of energy resource use was further ascertained by equating the MVEP to the productive UEFC of resources. A resource is said to be energy optimally allocated if there is no significant difference between the MVEP and UEFC that is, if the ratio of MVEP to UEFC =1 (unit). Table 4c further reveals that the ratios of the MVEP to the UEFC were greater than unity (1) for all the energy input except P_2O_5 MJ and family labour MJ. This implies that nitrogen MJ, K_2O MJ, and seed MJ were under-utilized, while P_2O_5 MJ and family labour MJ were over utilized (less than one). This means that maize output was likely to increase and hence revenue if more of such inputs MJ (nitrogen, P_2O_5, K_2O, family labour and seed) had been utilized. The adjustment in the MVEPs for optimal energy resource use (% divergence) in indicates that for optimum allocation of energy resources more than 74% increase in Nitrogen was required, while approximately 97% increase in K_2O was needed. Similarly, over 23% and 94% increase in family labour MJ and seed MJ respectively are needed. P_2O_5 MJ was over -utilized, and required approximately 95% reduction for optimal energy use in maize production.

CONCLUSION AND RECOMMENDATION

This research investigated energy utilization efficiency in maize production in Niger state, Nigeria. The total energy consumption in maize production was 2227.81MJha^{-1}, with energy input from fertilizer recording the biggest share (73.5%) of total energy inputs. Averagely, 85.2% of total energy input used in maize production was biological energy, while the contribution of industrial energy was 14.8%. Findings revealed that maize farmers were technical inefficient in the use of energy input resources. The inefficiency of these farmers may be directly or indirectly linked to the inadequate knowledge on energy conservation consciousness; rising cost for energy, dire consequences in placing additional stresses on our biosphere, and energy scenario in crop production. Results suggest that reduction in agrochemical consumptions are important for energy saving and decreasing the environmental risk problem in the area. Therefore, excessive application of chemical fertilizers would result in increased energy consumption in production systems; inefficient energy use, thus, causing environmental challenges, including global warming, soil and water pollution thereby affecting human health. This trend indicates that environmental challenges will worsen in the near future if there is absence of managerial consideration in agrochemical application pattern in these agro-ecosystems. The research inferred that improvement in energy use efficiency among the farmers is the responsibility of the individual farmers, government and research institutions.

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