Investigations on energy input-output in below sea level rice production systems in Kuttanad region of Kerala

by

NIDHIN J K

(2015 – 18 – 005)

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KERALA, INDIA

2017

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THESIS

Submitted in partial fulfillment of the

requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Farm Power, Machinery and Energy)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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KERALA, INDIA

2017

DECLARATION

I hereby declare that this thesis entitled **"Investigations on energy input-output in below sea level rice production systems in Kuttanad region of Kerala"** is a *bonafide* record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Date: **(2015-18-005)**

CERTIFICATE

Certified that this thesis entitled **"Investigations on energy input-output in below sea level rice production systems in Kuttanad region of Kerala"** is a *bonafide* record of research work done independently by Mr. NIDHIN J K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mr. NIDHIN J K. (2015 -18 -005)** a candidate for the degree of Master of Technology in Agricultural Engineering majoring in Farm Power, Machinery and Energy agree that the thesis entitled **"Investigations on energy input-output in below sea level rice production systems in Kuttanad region of Kerala"** may be submitted by **Mr. NIDHIN J K. (2015-18-005)** in partial fulfillment of the requirement for the degree.

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ACKNOWLEDGEMENT

I avail this opportunity with immense pleasure to express my deep sense of gratitude and indebtedness to my Guide and Chairman of the Advisory Committee, ***Dr. Joby Bastian.,*** *Professor, FPME, RARS, Kumarakom for his exemplary guidance, incessant inspiration, immense patience, efficacious advice, perpetual and prolific encouragement and creative criticisms evinced throughout the course of this investigation and in the preparation of the thesis.*

I have boundless pleasure in recording my profound thanks to ***Dr. Santhi Mary Mathew,*** *Dean, K.C.A.E.T, Tavanur, for her helpful guidance, erudite manners and genial association throughout the framework of study.*

I wish to place on record my heartfelt thanks to my advisory committee members ***Dr. Jayan P. R,*** *Professor & Head, Department of Farm Power, Machinery and Energy, K.C.A.E.T, Tavanur,* ***Dr. Vandhana Venugopal,*** *Professor, Agromony, RARS, Kumarakom,* ***Er. Shivaji K P,*** *Assistant Professor, Department of Farm Power, Machinery and Energy, K.C.A.E.T, Tavanur for their esteemed guidance, constant inspiration encouragement, constructive suggestions and adroit peerless guidance throughout the course of the study.*

With deep sense of gratitude and obligation, I would like to remember the help rendered to me by ***Dr. K. P Sudheer.,*** *Professor, IIT Madras , for his unreserved help, incessant motivation and encouragement during the tenure of my study.*

I would like to acknowledge the valuable help rendered by the staff members of ***RARS Kumarakam*** *for their sincere help, support and co-operation for the completion of a part of my research work.*

Words would not suffice to express my gratitude to all phd scholars of IIT Madras especially ***Er. Vamsi krishna., Er. Cicily.*** *and* ***Er Mani prakash.*** *for their sincere help and co-operation during the entire project work., constant encouragement and moral support shown throughout and also I express my ineffable and glowing*

gratitude with great indebtedness to my friends and classmates for their helping hands and caring smiles went a long way in the fulfillment of this strenuous venture.

I express my thanks to all the faculty ***members of Library****, KCAET, Tavanur for their ever willing help and co-operation.*

I am greatly indebted to ***Kelappaji College of Agricultural Engineering & Technology*** *and* ***Kerala Agricultural University*** *for giving me an opportunity to undergo this Master programme.*

Last but not least I thank ***God, the almighty*** *who is behind every act in this universe. Words are inadequate to express my love and gratitude to my beloved* ***parents*** *for their unfathomable love and support throughout my study period.*

NIDHIN JK

Dedicated to

GOD & My Family

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SYMBOLS AND ABBREVIATIONS

Mha	:	million hectare
MT	:	million tonnes
et al.	:	and others
Cm	:	centimetre
Kg	:	kilogram
Rs.	:	Rupees
H	:	hour
/	:	per
ha/h	:	hectare per hour
h/ha	:	Hour perhectare
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
N	:	Nitrogen
P	:	Phosphorus
K	:	Pottasium
Ha	:	hectare
h/ha	:	hour per hectare
kg/ha	:	kilogram per hectare
Ml	:	millilitre
kg/cm^2	:	kilogram per square centimetre
Km	:	kilometre
KWH	:	Kilo watt hour
Rpm	:	Revolutions per minute
PTO	:	power takeoff
Mm	:	millimetre
%	:	per cent
AFC	:	Actual field capacity

TFC	:	Theoretical field capacity
E_f	:	Field efficiency
BCR	:	Benifit cost ratio
AWH	:	Annual working hours
M	:	metre
°	:	degree
G	:	gram
<	:	Less than
>	:	Greater than
=	:	Equal to
Min	:	minute
MJ	:	Mega joule
L	:	litre
l/ha	:	litre per hectare
KAU	:	Kerala Agricultural University

Chapter 1

INTRODUCTION

Energy is the basic driving force in human development. The energy starvation of the technological complex that maintains modern society may be soon as crucial a problem as feeding the world's population. Indeed energy starvation could well precipitate more widespread food starvation. Energy consumption of agricultural activity has developed in response to increasing populations, limited supply of arable land and desire for an increasing standard of living. In all societies, these factors have encouraged an increase in energy inputs to maximize yields, minimize labor-intensive practices, or both (Esengun *et al.*, 2007). Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resource preservation and air pollution reduction.

Agriculture is the most important sector in Indian economy and it is basically an energy conversion industry. The energy use pattern for crops has varied under different agro-climatic zones. The use of energy in crop production depends on the availability of energy sources and the capacity of the farmers. Agricultural productivity is proportional to energy input in the form of improved seeds, fertilizers, plant protection chemicals, irrigation and mechanization including water management practices.

Energy consumption in agriculture is one of the important and effective factors in sustainable agricultural production, because it reduces the fossil resources and reduce the amount of air pollution and greenhouse gas emissions (Ulhin, 1998). Recently, agricultural sector has become more energy intensive in order to supply more food to increasing population and provide sufficient and adequate nutrition.

Solution for the energy crisis is strongly dependent on the technology of how energy is used. Use of improved implements has generally reduced the energy consumption in the respective operations. Efficient use of the energy resources is vital in terms of increasing production, productivity, competitiveness of agriculture as well as sustainability of rural living. Energy auditing is one of the most common approaches to examine the energy efficiency and environmental impact of the production system. It enables researchers to calculate output-input ratio, relevant indicators, and energy use patterns in an agricultural activity.

Also, the energy audit provides sufficient data to establish functional forms to investigate the relationship between energy inputs and outputs. Estimating these functional forms is very useful for determining elasticity of inputs on yield and production (Adem *et al*. 2006).

Rice is the staple food of the people of Kerala. Rice is cultivated throughout the state; the important rice producing areas in the state are Kuttanad, Palakkad and Thrissur. Despite substantial improvement in productivity, rice production has been stagnating around 10 to 11 lakhs tonnes during the period of 1970-80's. The state had gross cropped area of 1.96 lakh hectares under paddy cultivation in 2015-16 contributing to an annual production of around 4 to 6 lakh tonnes of rice.

Kuttanad, the 'Holland of Kerala', is a low-lying area with backwaters, canals and stream networks extending over 874 km^2. There are garden lands at an average elevation of 1 m above mean sea level covering an area of 304 km^2. Kuttanad, the deltaic formation of five major river systems, Pampa, Muvattupuzha, Achencoil, Manimala and Meenachil, confluence into the Vembanad Lake, lies 0.6 to 2.2 m below mean sea level. The region extends from 9°17' to 9°40' N latitude and 76°19' to 76°33' longitude. Rice is the important agricultural produce, giving Kuttanad the moniker of "The rice bowl of Kerala".

In Kerala, paddy is cultivated in below sea level areas in Kuttanad. The cropping pattern of Kuttanad region is different from other rice growing areas because of its topography. As this region is lying below the mean sea level, salt water intrusion is one of the major problems faced by the farmers. To prevent this salt water intrusion, two bunds are made (Thottapally spillway and Thaneermukkam Bund) in this region.

The different farm operations like seed bed preparation, dewatering, fertilizer application, bund formation, lime application and harvesting are to be carried out for paddy production. Hence a high amount of energy is utilized here for the cultivation. In order to improve the productivity of farming in this area, energy auditing in paddy cultivation will be useful and it will help to identify the factors which consume more energy.

The aim of this study was to determine energy flow in farms of Kuttanad region and find out the energy use pattern of all operations related to paddy cultivation. In addition to these, it also aims to calculate energy efficiency, energy productivity, and specific energy used in paddy production. Artificial Neural Network modelling is used to predict the energy output in different zones in the region.

The energy inputs estimated in this study are those that go into on-farm production systems before the post-harvest processes. The study has considered only the energy used in rice production, without taking into account the environmental sources of energy (radiation, wind, rain, etc.).

With these factors in view, the project was undertaken in rice production areas of Kuttanad with special emphasis on Below Sea Level (BSL) areas with the following objectives

1. To assess the energy use pattern in the rice production systems in Kuttanad with special emphasis on Below Sea Level (BSL) areas
2. To carry out an energy audit for rice production systems with a view to suggest means for improving energy efficiency

3. To develop an Artificial Neural Network (ANN) model for predicting the energy and economic indices in rice production

CHAPTER II

REVIEW OF LITERATURE

The past research works relating to the relevant aspects of energy auditing on paddy cultivation are reviewed in this chapter. Numerous types of energy auditing on paddy cultivation is done in different countries. To comprehend the research towards the investigation of energy inputs and output in below sea level paddy cultivation, literature reviews were done and are grouped under the following headings.

2.1. Kuttanad Region

Kuttanad region is located at the Southernmost part of India. Primarily it is formed of five river systems: Meenachil, Pamba, Manimala, Muvattupuzha and Achencovil, located on the low-lying areas of the Vembanad Lake. The Kuttanad region (Fig 2.1) spread over the Alappuzha, Kottayam and Pathanamthitta districts. It comprises of 79 revenue villages and 10 Taluks Dwivedi, (2011) - Cherthala, Ambalapuzha, Chengannur, Kuttanad, Karthikappally and Mavelikara Taluks in Alappuzha District, Thiruvalla taluk in Pathanamthitta District and Changanassery, Vaikom and Kottayam taluks in Kottayam district covering a region of 870 sq. km, Hazard Center and People’s Science Institute, (2006). The Kuttanad lies at 9°17' to 9°40' N latitude and 76°19' to 76°33' E longitude Shari and Chitra, (2005).

Fig 2.1 Kuttanad

Kurup and Rangeet, (2002) describes the Kuttanad region is around 1,10,000 ha consisting of 28 per cent dry land, 60 per cent wetlands and 12 per cent other water bodies. Wetlands in Kuttanad are mostly used for paddy cultivation. Conventionally, rice is cultivated in two seasons: Punja (November to February) and Virippu (July to October). Punja contributes to the bulk of the paddy cultivated in Kuttanad region. Out of the total 55,000 ha utilized for paddy cultivation in Kuttanad, nearly 35,000 ha is utilized during the Punja season while only about 3,000 ha is used during the Virippu season. During recent years, farmers in Kuttanad have been inclined to abandon paddy cultivation either partly during any of the two seasons or to fully leave the padashekaram fallow.

Based on the soils, geomorphology and salt water intrusion, Kuttanad is subdivided into six agro-ecological zones (i) Upper Kuttanad (ii) Kayal lands (iii) Vaikom Kari (iv) Lower Kuttanad (v) North Kuttanad and (vi) Purakad Kari (Indo-Dutch Mission, 1989).

M S Swaminathan report (2007) divides the area of Kuttanad into six zones

Kayal lands comprise padashekharams recently domesticated from the Vembanad Lake with an elevation between 1.5 to 2.2 m below MSL. Kayal land has an area of 13000 ha all around the Kuttanad region. Kavalam, Mannar, Nedumudi, Perumpalam, Pulinkunnu, Kumarakam and Thiruvarppu villages come under the Kayal in Kuttanad region.

Lower Kuttanad is the center area of Kuttanad region, located at the South Eastern side of the Vembanad Lake. Lower Kuttanad has an area of 16,280 ha with a large amount of the area falling in Alappuzha district. Greater part of the padashekharams in this region have elevations ranging from 1.5 m below to 1.0 m above MSL and its bund levels at 0.3 to 1.3 m above MSL.

Upper Kuttanad comes on the South East of Kuttanad region, with a higher elevation of 0.5 m below to 6.0 m above MSL and the bund levels vary from 0.3 to 5.0 m above MSL. It has a vicinity of 10,576 ha, a large amount of it is further South of lower Kuttanad and East of Purakad Kari. Here the seven tributaries of Pamba River converge and a division of the Pamba joins Achenkovil before joining to the Vembanad Lake.

Northern Kuttanad is formed by the low lands on around the lower Meenachil river. It consists of an area of 6,556 ha. Northern Kuttanad contains Northern and Eastern side of the Vembanad Lake including some part of Kumarakom town.

Purakad Kari is a minute area measuring 3,500 ha along the South-West coast spread across 43 padasekharams of Ambalappuzha and Karthikappally panchayats. Purakadu region is located 1.5 to 2.0 m below MSL. Purakad region is susceptible to flooding and salt water intrusion through Thottapally spillway and Ambalappuzha-Thakazhy canals.

Vaikom Kari has an area of 7,748 ha and this area lies in Kottayam district located at the North of North Kuttanad and includes Vaikom.

2.2. Cultivation practice in Kuttanad

The traditional paddy cropping pattern of Kuttanad region has been detailed in Swaminathan report (2007) on Kuttanad Package. The practices adopted in the rice cultivation in Kuttanad are as follows;

Wet ploughing:

This wet ploughing is done by the locally assign ploughman. Now a days ploughing is carried out with tractor and cage wheel without involving ploughman

Dewatering:

The dewatering of fields commence soon after the wet ploughing and the completion of repairs to the outer bunds. Dewatering is done with special pump called petti and para, driven by electric motors in each padasekharam. Electric pump sets of 15 - 60 HP are used for pumping. The pumping out of water continues till the fields get totally drained off and the process continues for about 15 to 20 days

Strengthening of outer bunds;

It is done if the bund is damaged by flood and usually begins in August/September. The resources used for this operation are clay, shrubs, straw, etc. Clay is dug out from the neighboring canals and rivers by katta kuth, which involves pitching to the Kayal-bed for clay. Other materials are also brought from closeby places by country canoes.

Seedbed preparation:

Preparation of seedbed includes draining out of water after ploughing and on exposure of field to sunlight for 3 days. Then the water is again let in for 10-15 days to decay the weeds. This is a helpful practice to control weeds like “Kavada” (*Echinochloa colona*).

Seed rate and Sowing:

The seed needed for the sowing in the Kuttanad region is 100 $kgha^{-1}$. The seed supply is done by the Agricultural Department and the National Seeds Corporation. Usually direct sowing of sprouted seeds in 5-10 cm of standing water is practised.

Fertilizer application:

Chemical fertilizers are widely used, particularly with the improved varieties. Usually fertilizer is applied in 3 split doses, two doses each with 1/3 N half P and 1/3 K at 12-15 and 30-35 days after sowing, and the remaining N and K at 45-50 days after sowing. The recommended dose of nutrients is 90:45:45 NPK as direct fertilizers for Uma and Jyothi varieties. But farmers regularly apply higher doses of more costly complex fertilizers to get higher yield.

Gap filling:

It is done on twenty five to thirty days after sowing, the highly populated portions are thinned out and the gaps filled. Along with this, one more weeding is carried out. Top-dressing with fertilizers is also done at this stage.

Weed control:

Application of weedicide is very frequent in Kuttanad. Virtually one weedicide, 2-4 D sodium salt, is widely used at a dose of 1.2 $kgha^{-1}$ at 17-20 days after sowing. This mainly controls broad leaved weeds and sedges.

Water Management:

Water management is the process of letting in and draining out of water being continuous all the way through the cropping season for washing out the salts and regulating soil pH to the optimum for better crop growth. Irrigation is generally at 10 days intervals by opening the sluices in the outer bunds. The usual water management schedule is as follows: (a) Draining the paddy field before preparation of land, (b) Letting in water for destroying the weeds, (c) Maintain 2 - 5 cm deep water during sowing, (d) Draining out 2 days after sowing process, (e) Letting the water in on 5 days after and then maintaining 2 - 5 cm water until first fertilizer is applied, (f) Drain the water for first fertilizer application and then letting water in, (g) Draining out the water at the active tillering stage for second top dressing and letting in water, (h) Maintaining 5 cm of water level after the maximum tillering stage, (i) Draining out for the giving third top dressing and letting in till the heading stage, (j) Drain out 15 days prior to the crop harvest.

Harvesting:

Harvest is largely carried out by combine harvesters in recent times, although there is an opposition from farm labourers against mechanization. The harvest charges are paid around 16 per cent of the output. In the case of combine harvester, harvesting charges may come to Rs. 1,800 h^{-1} of operation.

2.3. Sample size.

Ashkan *et al.* (2014) had carried out a study on energy consumption for rice production using artificial neural networks in Guilan province, Iran. Initial data were collected from 120 rice farmers of the Astaneh Ashrafiyeh city through face-to-face questionnaire in March 2013. For determination the sample size for the studies, the random sampling method was used. Based on the farm sizes, samples were classified into three groups: small farms (<1 hectare), medium farms (between 1 and 3 hectare) and large farms (>3 hectare). After the determination of input consumption of energy and rice yield, the input and output energy was calculated by multiplying the amount to the standard coefficient.

Ashkan *et al.* (2014) studied about applying artificial neural networks and multi-objective genetic algorithm to modeling and optimization of energy inputs and greenhouse gas emissions for peanut production and then they found out energy input and output values, the energy ratio (energy use efficiency), energy productivity, specific energy, net energy and energy intensiveness various farm size in the selected region. Then these values are calculated and analyzed based on the farm size classification.

Alipour *et al.* (2011) studied about the determination of energy consumption to produce conventional rice of the Guilan province. They collected data from 127 paddy farmers in 13 zones by interviewing the farmers using a specially designed and pre-tested questionnaire for one year in 2010. These selected zones are located in the Guilan province of Iran, where rice cultivation is the major source of income for the farmers. The questionnaire incorporated all kinds of inputs such as chemicals, fertilizers, farmyard manure, power sources (human and prime movers) and agricultural machinery (power tiller, weeder, sprayer and thresher).

Safa and Samarasinghe (2010) conducted a study on modeling of energy consumption in wheat production using neural networks and the data was collected from three different sources: questionnaire, literature review, and field measurements. The energy input data estimated in this study are which goes into on-farm production systems before the post-harvest processes. The study has measured only the energy used in wheat production, without taking into relation the environmental sources of energy (radiation, wind, rain, etc).

2.4. Energy equivalents

The energy equivalent values mentioned in many literatures are given in the table 2.1

Table 2.1. Energy coefficient used in energy calculation

Energy Source	Energy equivalent values (MJ/unit)	Reference
Machinery	62.70 $MJkg^{-1}$	Gundogmus (2006)
Human	1.96MJh^{-1}	Gundogmus (2006)
Diesel	56.31MJL^{-1}	Gundogmus (2006)
Fertilizer		
Potassium	11.15$MJkg^{-1}$	Nabavi-Pelesaraei *et al.* (2014)
Phosphorus	12.44 $MJkg^{-1}$	Rafiee *et al.* (2010)
Nitrogen	66.14 $MJkg^{-1}$	Mousavi-Avval *et al.* (2011)
Pesticide	101.2 $MJkg^{-1}$	Banaeian and Zangeneh (2011)
Lime	1.15 $MJkg^{-1}$	Gundogmus (2006)
Electricity	11.93 $MJKwh^{-1}$	Gundogmus (2006)
Paddy	14.57 $MJkg^{-1}$	Iqbal (2007)
Straw	12.50 $MJkg^{-1}$	Iqbal (2007)

2.5. Source wise energy

Surendra Singh and Mittal (1992) classified the energy inputs in source wise, nature wise and economic value wise in their study of production energy of agriculture in India. The classification includes, direct and indirect energies (source wise) renewable and non renewable energies (nature wise) and commercial and non commercial energies (economic value wise).

Table 2.2. Classification of source of energy

Category of energy	Source of energy
Direct energy	Human, animal, petrol, diesel, electricity, kerosene, Fuel wood, agriculture waste, etc.
Indirect energy	Seed, farmyard manure, chemical, fertilizer, Machinery, etc.
Renewable energy	Human, animal, agriculture waste, Seed, farmyard manure, fuel wood, etc.
Non renewable energy	Petrol, diesel, electricity, kerosene, fertilizer, Machinery, etc.
Commercial energy	Petrol, diesel, electricity, kerosene, fertilizer, Machinery, etc.
Non commercial energy	Human, animal, agriculture waste, Seed, manure, fuel wood, etc.

Alipour *et al.* (2012) studied about the determination of energy consumption to produce conventional rice of the Guilan province and they classified the energy into direct and indirect energy source. Direct energy sources were labour energy, implement/machinery used for the particular operation and electric/diesel motor to run water pump, while indirect energy sources included seed of high yielding varieties, fertilizers and plant protection chemicals used in the production process. Energy sources were also classified into renewable and non-renewable. Renewable energy included human, labour, manure and seed, while non-renewable sources included diesel, electricity, plant protection chemicals, fertilizers, machinery. The results showed the share of direct input energy was 33.5 per cent in the total energy input compared to 66.5 per cent for the indirect energy. Also, renewable and non-renewable energy contributed to 4.41 and 95.59 per cent of the total energy input, respectively. It is clear that the proportion of indirect and non-renewable input energy use in surveyed farm's rice is very high.

Prasanna Kumar and Hugar (2011) conducted a study on economic analysis of energy use in paddy cultivation under irrigated situations and concluded that fertilizer was found to be the leading source of energy contributed 3,154 mega joules per acre which contributed for 55.53 per cent of the total energy utilized for the paddy cultivation. The total energy used for paddy cultivation by small farmers (6,237MJacre^{-1}) was notably superior to that of medium (5,501MJacre^{-1}) and large (5,303MJacre^{-1}) farmers.

Yadav and Khandelwal (2013) conducted a study on effect of various energy inputs on energy requirement for wheat production in the Agro-Climatic Region Kamore plateau and Satpura Hill, Madhya Pradesh in India and found out that wheat production in year of 2010- 11 consumed a total of 14345MJha^{-1} of which chemical fertilizer, diesel fuel and electric energy consumption was 31.1 per cent, 20.5 per cent and 24.2 per cent, respectively. Direct and indirect energy were 49.6 per cent and 50.4 per cent respectively in the wheat cultivation in that region.

2.6. Operation wise energy.

Kalbande and More (2008) did a study on assessment of energy requirement for cultivation of Kharif and Rabi Sorghum and found out the operation wise and source wise energy input in mechanical, conventional and shallow tillage method. The maximum farm operational energy use average of Kharif and Rabi was find to be 8664.12 MJha^{-1} in mechanical tillage followed by conventional tillage (4548.52 MJha^{-1}) and shallow tillage (3876.08 MJha^{-1}). The maximum crop wise mean farm operational energy was found to be in farm operational energy for raising Kharif sorghum in mechanical tillage method (8750.4 MJha^{-1}). The maximum farm operational energy for Kharif Sorghum in mechanical tillage method occurred due to over use of higher fertilizer doses at the rate of 5560 MJha^{-1}.

Yadav and Khandelwal (2013) studied about the effect of various energy inputs on energy requirement for wheat production in agro-climatic region Kamore plateau and Satpura Hill, Madhya Pradesh in India and calculated the energy values operations wise and in that, irrigation was the highest energy consuming operation and consumed (3670 $MJha^{-1}$) followed by seedbed preparation (2038$MJha^{-1}$), harvesting and threshing (1752 $MJha^{-1}$) and transportation (800$MJha^{-1}$) for wheat crop production in 2010-11.

Prasanna Kumar and Hugar (2011) conducted a study on economic analysis of energy use in paddy cultivation under irrigated situations and found out the operation wise energy use pattern in paddy cultivation. The result showed that among all the operations, ploughing consumed highest amount of energy (308$MJacre^{-1}$) which accounted to 20.58 per cent of the total energy utilized for all operations in paddy cultivation

2.7. Energy indices and economic indices.

Benyamin *et al.* (2013) conducted a study on application of Artificial Neural Networks for prediction of output energy and greenhouse gas emissions in potato production in Iran and found out the energy indices as energy use efficiency and energy productivity were 1.03 and 0.29 $kgMJ^{-1}$, respectively for the potato production in Iran region.

Cherati *et al.* (2011) conducted a study on energy survey of mechanized and traditional rice production system and found out the energy indices for the rice, energy output and energy expenditure. Energy ratio of rice in traditional methods and semi-mechanized are found to be 3 and 3.08 respectively. Energy productivity (EP) of grain for both traditional and semi-mechanized cultivation systems, is found out as, 0.111 and 0.116 $kgMJ^{-1}$. Specific energy shows that the energy utilization for each kilogram of paddy production in the traditional and mechanization production system was 98.8 and 62.8 MJ, respectively. Net energy gain of 134.77 and 139.67 $GJha^{-1}$ in traditional and semi-mechanized systems has been calculated during the research.

Yadav and Khandelwal (2013) studied about the effect of various energy inputs on energy requirement for wheat production and calculated the energy output–input ratio and specific energy of production and productivity as 3.9, 3.7 $MJkg^{-1}$ and 0.27 $kgMJ^{-1}$, respectively.

Ashkan *et al.* (2014) studied about applying Artificial Neural Networks and multi-objective genetic algorithm to modeling and optimization of energy inputs and greenhouse gas emissions for peanut production and found out the energy indices in peanut production as energy use efficiency, energy productivity, specific energy, net energy and energy intensiveness were 4.53, 0.18 $kgMJ^{-1}$, 5.52 $MJkg^{-1}$, 67937.21 $MJha^{-1}$ and 1.58 $MJha^{-1}$, respectively.

Ali *et al.* (2013) conducted a study on neural network based modeling of energy inputs for predicting economic indices in seed and grain corn production and found out that economic indices in seed and grain corn production. The benefit cost ratio is more in seed corn rather than grain corn due to the higher price of seed corn.

2.8. Artificial neural networking model

Sudheer *et al.* (2008) did a modelling work on models for estimating evapotranspiration using artificial neural networks, and their physical interpretation. It was conducted to develop ANN based models to estimate ET0 from limited climatic data. The motivation for the study was the cumbersome procedure and large data requirement (not easily available in many situations) for estimating ET0 using the FAO recommended Penman–Monteith method. The results of the study show that an ANN technique can be used successfully to estimate ET0 from climate data. It is observed that for accurate estimation of ET0 using an ANN, temperature and radiation data are the most crucial inputs.

Safa and Samarasinghe (2010) did a study in New Zealand on Modelling of Energy Consumption in Wheat Production Using Neural Networks and found out ANN the model ability to predict energy consumption in wheat production by using different heterogeneous data. Using dissimilar variables, such as farm conditions and social factors would improve the ability of decision makers to look at the problems from different aspects.

Benyamin *et al.* (2013) conducted a study on application of Artificial Neural Networks for prediction of output energy and GHG emissions in potato production in Iran and found out that the best model consisted of an input layer with twelve input variables, one hidden layer with eight neurons in it, and an output layer with two output variables (12-8-2 structure). This topology had the least MAE for output energy and total GHG emission, the highest R^2 and the least RMSE for total GHG emission. Therefore, this model was selected as the best solution for estimating the potato output energy and GHG emission on the basis of input energies in the studied region

CHAPTER III

MATERIALS AND METHODS

3.1. Locale of study

The present study is carried out in regions where rice is cultivated in Below Sea Level (BSL) areas especially in Kuttanad. Kuttanad is a delta region of about 1100 sq.km in area (110000 ha) situated in the West coast of Kerala between 9°17' to 9°40' N latitude and 76°19' to 76°33' E longitude.

3.2. Selection of locations

The below sea level area in Kuttanad region comprise of 64 panchayats under Alappuzha, Kottayam and Pathanamthitta revenue districts. The panchayats were identified, which are having below sea level paddy cultivation aggressively. These panchayats were classified based on the revenue districts and the agro-ecological zones in this region. The different panchayats were selected randomly for the survey such that an appropriate representation is existing from the different agro-ecological zones and also among the revenue districts.

3.3. Selection of respondents

The rice cultivation in the Kuttanad is oriented on polders (padasekarams). Each panchayat has different number of polders based on the different hydrological and geographical entity of that region. Four padasekarams are selected from each identified panchayats in consultation with the Agricultural Officer concerned. The farms were classified into four groups based on the farm sizes. They are small farms (less than 0.5 ha), marginal farms (between 0.5 and 1 ha), medium farms (between 1 and 2 ha) and large farms (greater than 2 ha). Three farmers from each group of farm size were identified from the selected padasekarams of different panchayats in consultation with the Secretary of the padasekara committee

3.4. Methodology used for survey.

The survey was conducted in the 3 districts in Kerala *viz.*, Alappuzha, Kottayam and Pathanamthitta through face to face interviewing with farmers by using questionnaire. The questionnaire is prepared based on the cultivation practices of paddy in the Kuttanad region. The questionnaire was validated in consultation with the agricultural officers of the selected panchayats. The questionnaire included the personal details, the machinery used and the details of cultivation practices adopted by them. The questionnaire is given in Appendix I.

The personal data includes name, address, contact number, area of cultivation, name of padasekaram, agro- ecological zone and panchayat name of the location.

The machinery details includes name of the equipment/ machinery used, its Make, Capacity (HP), Power source (Type), Type of Fuel and Fuel consumed (per hr).

The operational details included the unit operations and the quantity of man power, machinery and materials used in the different stages of paddy cultivation at different stages of cultivation.

The data collection was done during October 2016- February 2017, the Punja season, which is the major cropping season in Kuttanad. A total number of 731 farmers in Kuttanad region were surveyed by using this questionnaire during this season and data were collected and recorded.

3.5. Energy equivalents' calculation

The inputs used for the paddy cultivation are seeds, human power, plant protection chemicals, fertilizers, diesel, electricity, and machinery. The usage of different inputs was calculated on per hectare basis for each farmer. These input data are converted to energy equivalents by multiplying with the corresponding energy coefficient (Table 2.1).

3.6. Input-energy use pattern

The energy use pattern in below sea level paddy cultivation were investigated based on the different classification of energy input *viz*., Source of energy, Economic value of energy, and Nature of energy as illustrated on Table 2.2. The energy use pattern within the different agro-ecological zones and the different farm size groups were studied. The significance of energy input between agro-ecological zones and farm size groups were tested statistically.

3.7. Operation-wise energy use pattern

The paddy cultivation comprises of different unit operations. They were identified, quantified and recorded in the face to face interviewing with farmers by using questionnaire. These unit operations were grouped into five major operations *viz*., Land preparation, Seeding, Water management, Fertilizer and chemical application, and Harvesting.

The operation wise energy use pattern within the different agro-ecological zones and the different farm size groups were calculated. The significant between agro-ecological zones and farm size groups were tested statistically.

3.8. Input-wise energy use pattern

The paddy cultivation comprises of different unit operations. These unit operations are accomplished by using different inputs *viz*., Human, Diesel, Machinery, Seed, Fertilizer, Plant protection chemicals, and Electricity. These inputs are identified, quantified and recorded in the face to face inter viewing with farmers by using questionnaire. These inputs vales were converted to energy equivalents and grouped based on the input.

The input-wise energy use pattern within the different agro-ecological zones and the different farm size groups were calculated. The significance between agro-ecological zones and farm size groups were tested statistically.

3.9. Energy indices

Agriculture area is not only an energy consumer but also a producer of energy in the form of energy output. Different energy indices were used to compare how efficiently crops convert input energy into output energy. Based on the energy equivalents of the inputs and output, the indicators of energy use including Energy use efficiency (energy ratio), energy productivity, specific energy, and net energy were calculated (Benyamin *et al.*, 2013).

The energy indices of the below sea level rice production systems in Kuttanad region of Kerala within the different agro- ecological zones and the different farm size groups were calculated. The significance between agro-ecological zones and farm size groups were tested statistically.

3.9.1. Energy use efficiency

The indicator is composed of a measure of the energy used or going into agricultural production, and the amount of energy contained in various agricultural commodities produced in the primary agricultural sector. The ratio of energy output to energy input is a measure of energy use efficiency

$$\text{Energy efficiency} = \frac{\text{Total energy output}(\text{MJha}^{-1}) \text{ X } 100}{\text{Total energy input}(\text{MJha}^{-1})}$$

3.9.2. Energy productivity

Energy Productivity, which is defined as the ratio of output divided by energy consumption, is a useful indicator for understanding the energy efficiency. It is a measure of quantity of products produced per unit input energy ($kgMJ^{-1}$).

$$\text{Energy productivity } (kgMJ^{-1}) = \frac{\text{crop yield(kg)}}{\text{input energy(MJ)}}$$

3.9.3. Specific energy

Specific energy ($MJkg^{-1}$) has been widely used in the energy studies or analysis to express the quantity of energy invested to produce a unit quantity of product or output. This specific energy is the inverse of the energy productivity.

$$\text{Specific energy } (MJkg^{-1}) = \frac{\text{input energy(MJ)}}{\text{crop yield(kg)}}$$

3.9.4. Net energy

Net Energy is a concept used in energy economics that refers to the difference between the energy expended and the amount of energy gained. Net energy is the amount of energy which we gain from a process.

$$\text{Net energy } (MJha^{-1}) = \text{Total energy output } (MJha^{-1}) - \text{Total energy input } (MJha^{-1})$$

3.10. Economic Indices

The economic analysis of paddy cultivation under below sea level was investigated. The economic indices such as net profit of the system, gross profit of the farmers and benefit cost ratio was calculated for different agro ecological zones and for the different farm area groups. The net return of the system was calculated by subtracting the total cost of production from the total value of production per hectare. Unit cost for different energy input such as electricity, plant protection chemicals, human power, diesel, fertilizer, machinery and seed were calculated.

$$\text{Total value of production} = \text{Paddy Yield } (Kgha^{-1}) \times \text{Paddy Price } (Rskg^{-1})$$

$$\text{Net Return (of the system)} = \text{Total value of production } (Rsha^{-1}) - \text{Total cost of production } (Rsha^{-1})$$

The gross return of the farmers was calculated by subtracting the farmer level cost of production from the gross value of production per hectare.

$$\text{Gross Return (of the farmers)} = \text{Total value of production } (Rsha^{-1}) - \text{Farmer's level cost of production } (Rsha^{-1})$$

The Benefit Cost Ratio was calculated by dividing the net return of production by the total cost of production per hectare.

$$\text{Benefit Cost Ratio} = \frac{\text{Net return of production } (Rsha^{-1})}{\text{Total cost of production } (Rsha^{-1})}$$

The economic productivity is expressed as the ratio of output to inputs used in a production process

$$\text{Economic Productivity} = \frac{\text{Paddy Yield } (Kgha^{-1})}{\text{Total cost of production } (Rsha^{-1})}$$

3.11. Artificial Neural Network model and model development

Artificial Neural Networks (ANNs) are data driven models whose operation is inspired from neurons in the brain. ANNs are used in all engineering fields for a wide range of applications like non-linear function approximation, data classification, clustering and non-parametric regression. Neural network modeling has shown incredible capability for prediction, analysis, emulation and association. They have the ability to learn and generalize from examples to produce meaningful solutions to problems even when input data contain errors or are incomplete, and to adapt solutions over time to compensate for changing circumstances and to process information. In general, an ANN model tries to fit a non-linear functional relationship between the input and output variables. The functional form of this type of model is:

$\mathbf{y} = f\ (\mathbf{X^n})$

Where, f is the unknown function mapped by the model and X^n is an n-dimensional input vector consisting of the variables described above.

ANN models are used exclusively in the recent years for a wide range of applications in the field of agriculture. Fang *et al.* (2000) developed a neural network model to estimate energy requirements for the size reduction of cultivated wheat based on physical and mechanical characteristics of the wheat and the operational parameters of the roller mill. The developed ANN model was trained using back propagation algorithm and sensitivity study was also conducted to check the influence of input variables on the output variables. Safa and Samarasinghe (2012) calculated fuel and energy consumption for wheat production based on 140 direct and indirect parameters on irrigated as well as dry land. Another study was carried out in Esfahan province in Iran to model output energy and greenhouse gas (GHG) emissions of potato production on the basis of input energies using artificial neural networks.

3.11.1. ANN Architecture and Design

While setting up an ANN model, the main task is to identify the relevant input variables and to identify the optimal network architecture ie, number of hidden neurons in the hidden layer. Determination of an appropriate architecture for a neural network is a prominent issue as the network topology directly affects its computational complexity and its generalization capability. From the literature studies it is found that, in case of energy consumption studies the input variables considered mainly are human power, machinery, fertilizer, diesel, seeds, plant protection plant protection plant protection chemicals and electricity consumption. In this study, the output from the ANN model was the total energy required for the rice production. The final structure of ANN model has shown in fig 3.1.

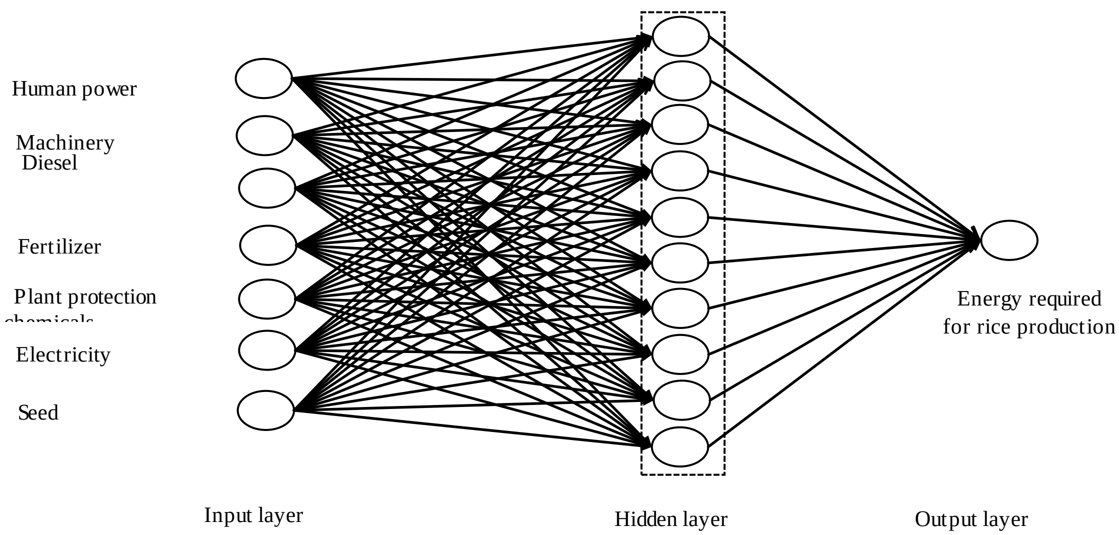

Fig.3.1. ANN architecture

In ANN, the number of hidden layers can vary from single layer to multiples, but the complexity of the model increases as increase the number of hidden layers. Current study uses a single layer of hidden neurons and the number of hidden neurons in the hidden layer was decided based on a trial and error procedure, in which the performance of the ANN model was evaluated using statistical method by varying number of neurons from 1 to 15 with a step size of 1. The activation function, defines the output of the neuron in terms of the activity level at its input. It is a mathematical representation, in terms of spatial or temporal frequency, of the relation between the input and output. There are various transfer functions used in the literature. In this study, tangential sigmoid transfer function (tansig) is used, which converts the inputs values to a scale varying between -1 to +1. In mathematical terms tangential sigmoid function is expressed as

$$a = tansig(n) = \frac{2}{1 + e^{-2n}} - 1$$

Where, n is the variable which is to be converted. *Tansig (n)* is mathematically equivalent to *tanh(n)*. The training algorithm adopted in this study was standard back propagation algorithm. The training of the ANN model was done using NN toolbox in the Matlab 2012 version. Out of the total 731 data points which has been collected from various fields (which is already mentioned in the above sections) across the study area, 100 data patterns were randomly picked from the validation of the model. Out of the remaining 631 points, 400 and 231 data points were used for training and testing of the ANN model respectively. The data used for the ANN model is collected from different fields across the study area containing varying land holdings. Choosing the data points for the training, testing and validation of the model should be done carefully to ensure that every land classes should be represented in all 3 data sets. To ensure this 500 ensembles of training and testing data sets for the ANN model were created.

In order to check any over-fitting during training, cross-validation was performed by keeping track of the efficiency of the fitted model. The training was stopped when there was no significant improvement in the efficiency. The model was simultaneously tested for its generalization properties by examining the computational accuracy of the trained model on the validation data set. The parsimonious structure that resulted in minimum error and maximum efficiency during training as well as testing was selected as the final form of the ANN model.

3.11.2. Indices for ANN performance

The performance of the ANN model in training and testing was evaluated using two different criteria. The goodness-of-fit statistics considered were coefficient of determination (r^2) and the root mean square error (RMSE) which was calculated using the following equations.

$$r^2 = \left[\frac{\sum_{i=1}^{n}(Y_{oi} - \overline{Y_{oi}})(Y_{si} - \overline{Y_{si}})}{\sqrt{n\sum Y_{oi}^2 - (\sum Y_{oi})^2}\ \sqrt{n\sum Y_{si}^2 - (\sum Y_{si})^2}}\right]^2$$

$$RMSE = \left[\sqrt{\frac{\sum_{i=1}^{n}(Y_{oi} - Y_{si})^2}{N}}\right]$$

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Locale of study

The energy study of below sea level (BSL) rice cultivation was carried out in the six agro-ecological zones of Kuttanad region of Kerala. The agro-ecological zones are Kayal, Lower Kuttanad, Upper Kuttanad, Purakad Kari, Northern Kuttanad and Vaikom Kari.

4.2.Selection of locations

The Kuttanad region is spread over in Alappuzha, Kottayam and Pathanamthitta revenue districts. Thirty two panchayats in Alappuzha district, 27 panchayats in Kottayam district and five panchayats in Pathanamthitta district comes under the Kuttanad region.

Out of these 64 panchayats, 54 panchayats have active rice production in the recent years. These rice producing panchayats were classified based on the revenue district and on the agro-ecological zones. The Table 4.1 and Table 4.2 shows the number of panchayats based on the revenue district and on the agro-ecological zones respectively.

The panchayats for the study were selected randomly such that, it will represent a minimum of 20 per cent among revenue districts and agro-ecological zones. The details of the panchayats selected in each agro-ecological zones are shown in Table 4.3.

Table 4.1. Number of rice cultivating panchayats in Kuttanad region based on revenue districts

	Number of panchayats
Alappuzha	27
Kottayam	23

Pathanamthitta	4
Total	**54**

Table 4.2. Number of rice cultivating panchayats in Kuttanad region based on agro ecological zone

Agro-ecological zones	**Number of panchayats**
Kayal	6
Lower Kuttanad	9
Upper Kuttanad	24
Purakad Kari	1
Northern Kuttanad	11
Vaikom Kari	3
Total	**54**

Table 4.3. List of panchayats selected in different agro ecological zone

Zones	**Name of panchayats**
Kayal	Kavalam, Kumarakam, Thiruvarppu
Lower Kuttanad	Muttar, Nedumudi
Upper Kuttanad	Edathuva, Muttar, Thalavadi, Kurichi, Payippadu, Niranam
Purakad Kari	Purakad
Northern Kuttanad	Kallara, Kumarakam, Thiruvarppu
Vaikom Kari	Kallara

4.3.Selection of respondents

The rice cultivation in the Kuttanad is oriented on polders (Padasekarams). In consultation with the Agricultural officers of the selected panchayats four active padasekarams were identified. Hence, 64 padasekarams were selected for study coming under different agro-ecological zones of Kuttanad.

The respondents for the survey – farmers were selected in consultation with the respective secretary of the padasekara committee. The farmers were selected such that equal representation is retained between the different farm size group classifications. Three farmers among each farm size groups were selected from each padasekaram for the survey. A total of 731 farmers were surveyed for the data collection.

4.4.Methodology used for survey.

This study was conducted among the 731 farmers in below sea level rice production system in Kuttanad region of Kerala. The personal data including the name, address, contact number, area of cultivation, name of padasekaram, agro-ecological zone and panchayat name of the location were collected and recorded from each farmer.

The machinery details collected include name of the equipment/ machinery used, its Make, Capacity (hp), Power source (Type), Type of Fuel and Fuel consumed (liters per h). The operational details such as unit operations and the quantity of man, machinery and materials used in the different stages of paddy cultivation at different times of cultivation are collected and recorded. The summary of the survey is tabulated Table 4.4.

Table 4.4. Levels of different inputs in below sea level paddy cultivation

	Inputs	**unit**	**Quantity**
1.	**Human power**		
	a) Land preparation	hha^{-1}.	356.51

	b) Planting	hha^{-1}.	368.85
	c) Water treatment	hha^{-1}.	30.57
	d) Fertilizer & Chemical application	hha^{-1}.	20.05
	e) Harvesting	hha^{-1}.	6.37
2.	**Machine power**		
	a) Land preparation	hha^{-1}.	8.65
	b) Harvesting	hha^{-1}.	6.37
3.	**Diesel**		
	a) Land preparation	lha^{-1}.	30.27
	b) Harvesting	lha^{-1}.	22.29
4.	**Fertilizer**		
	a) Phosphorus	$kgha^{-1}$.	45.57
	b) Nitrogen	$kgha^{-1}$.	143.20
	c) Potassium	$kgha^{-1}$.	135.22
5.	**Chemical**		
	a) Lime	$kgha^{-1}$.	273.58
	b) Pesticide	lha^{-1}.	0.27
6.	**Electricity**	$Kwhha^{-1}$.	623.33
7.	**Seed**	$kgha^{-1}$.	116.15

4.5. Energy equivalents' calculation

The inputs used for the paddy cultivation are seeds, human power, plant protection chemicals, fertilizers, diesel, electricity, and machinery and the output is paddy and straw. The energy equivalent values of input and output are calculated for further energy analysis by multiplying with the respective energy coefficients corresponding to different inputs.

4.6. Input energy use pattern

The input energy use pattern in paddy cultivation of Kuttanad region is studied based different classification of input energy. The variation in the energy use based on different agro-ecological zones and farm sizes were investigated.

4.6.1. Source-wise energy input.

Source-wise energy inputs are divided into direct energy and indirect energy. The different energy input variables are classified into direct energy and indirect energy and are tabulated based on the different agro- ecological zones and the different farm size groups.

The source-wise energy utilization in different agro-ecological zones was shown in Table 4.5 and a comparison is represented in Fig.4.1.

Table 4.5. Source-wise energy input in agro-ecological zones

Zones	**Direct energy ($MJha^{-1}$)**	**In direct energy ($MJha^{-1}$)**	**Total energy ($MJha^{-1}$)**
Kayal	11546.71	13090.18	24636.89
Lower Kuttanad	15439.12	14406.33	29845.45
Upper Kuttanad	14371.70	14275.97	28647.67
Purakad Kari	14116.65	18701.89	32818.54
Northern Kuttanad	10112.57	13384.72	23497.29
Vaikom Kari	10806.09	13703.54	24509.63

The total energy consumption in different agro-ecological zone was found to be varying between 23497.29 $MJha^{-1}$ to 32818.54 $MJha^{-1}$. The topmost total energy was consumed in the Purakad Kari and the lowest in Northern Kuttanad among the different agro-ecological zones

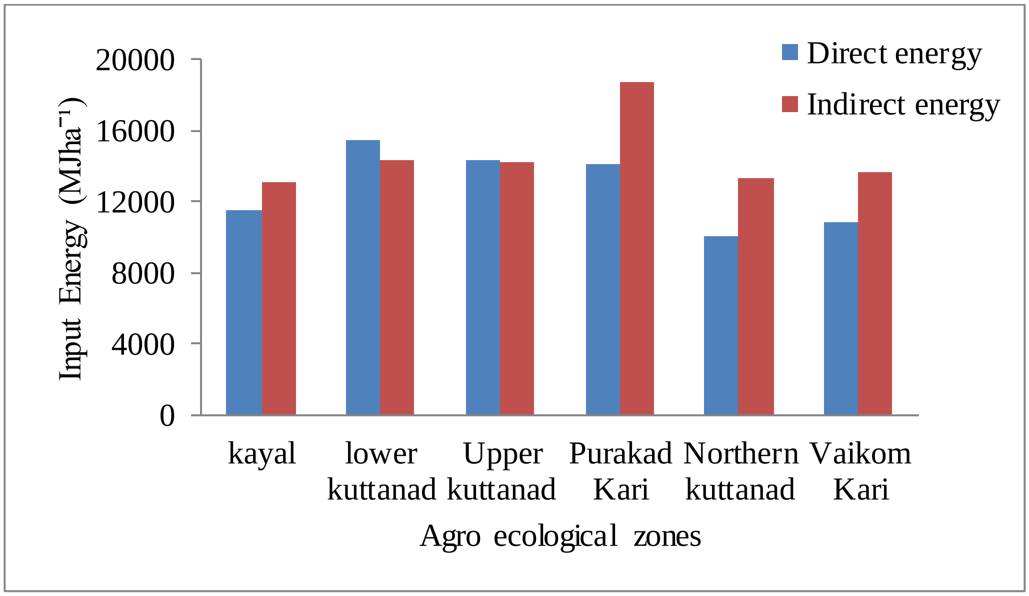

Fig 4.1. Source-wise energy input in agro-ecological zones

The indirect source of energy is found to be used more than the direct source of energy in all the agro-ecological zones except in the Lower Kuttanad zone. The high use of direct energy in Lower Kuttanad zone is due to high energy requirement for the water management operation in Lower Kuttanad. The major energy source consumed in water management activity is electricity which comes under the direct energy classification.

The uppermost direct energy of 15439.12 MJha^{-1} is consumed in the lower Kuttanad and the lowest direct energy of 10112.57 MJha^{-1} is consumed in Northern Kuttanad among the different agro-ecological zones.

The uppermost indirect energy of 18701.89 MJha^{-1} was consumed in the Purakad Kari and the lowest indirect energy of 13090.18 MJha^{-1} was consumed in Kayal among the different agro-ecological zones.

The source-wise energy utilization in different farm size groups are shown in Table 4.6 and a comparison is represented in Fig.4.2.

Table 4.6. Source-wise energy input in farm size groups

Groups	Direct energy ($MJha^{-1}$)	Indirect energy ($MJha^{-1}$)	Total energy ($MJha^{-1}$)
Large	8911.21	10326.64	19237.85
Medium	10527.19	13020.75	23547.94
Marginal	12302.70	14135.82	26438.52
Small	22477.46	19582.77	42060.23

The total energy consumption in different farm size groups was found to be varying between 19237.85 $MJha^{-1}$ to 42060.23 $MJha^{-1}$. The total energy consumed in the farm size group increases with the decrease in the farm size.

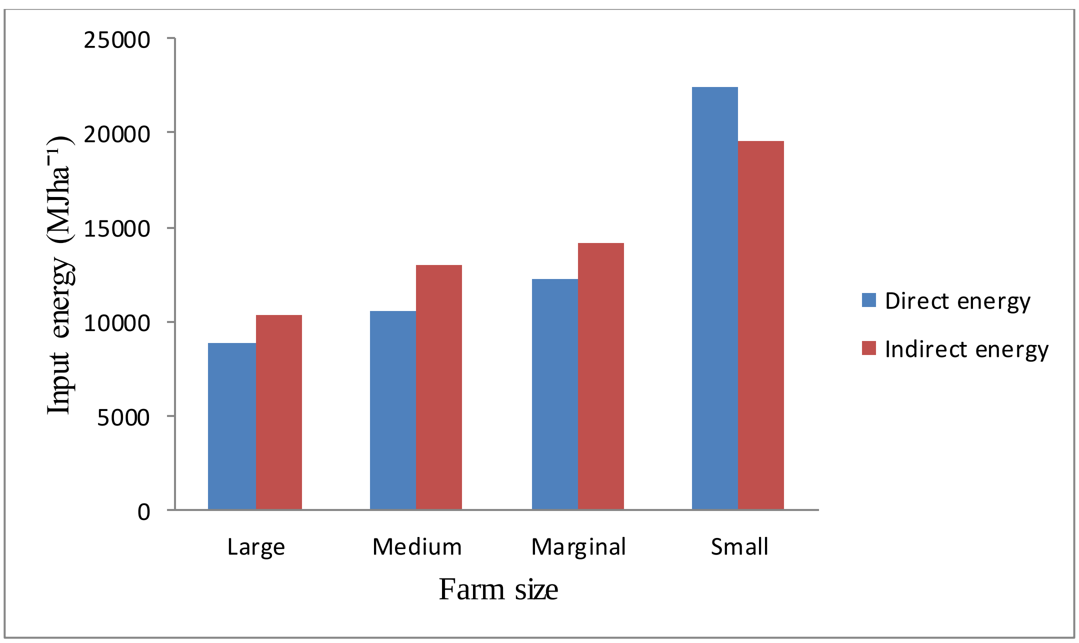

Fig 4.2. Source-wise energy input in farm size groups

The indirect source of energy is found to be used more than the direct source of energy in all the farm size groups except the small size farm group.

The uppermost direct energy of 22477.46 $MJha^{-1}$ was consumed in the small farms and the lowest direct energy of 8911.21 $MJha^{-1}$ was consumed in large farm.

The highest indirect energy of 19582.77 $MJha^{-1}$ was consumed in the small farms and the lowest indirect energy of 10326.64 $MJha^{-1}$ was consumed in large farm size among the different farm size groups.

The below sea level paddy cultivation in Kuttanad region shows that the direct energy use was up to 46.5 per cent and the indirect energy was 53.5 per cent. The higher use of the indirect energy in the region was mainly contributed from the energy input from the fertilizers.

4.6.2. Nature-wise energy

Nature-wise energy inputs are divided into renewable energy and non-renewable energy. The different energy input variables are classified into renewable energy and non-renewable energy and are tabulated based on the different agro-ecological zones and the different farm size groups.

The nature-wise energy utilization in different agro-ecological zones is shown in Table 4.7 and a comparison is represented in Fig.4.3.

Table 4.7. Nature-wise energy input in agro-ecological zones

Zones	**Renewable energy ($MJha^{-1}$)**	**Non-renewable energy ($MJha^{-1}$)**	**Total energy ($MJha^{-1}$)**
Kayal	5424.50	19212.39	24636.89
Lower Kuttanad	7068.48	22776.97	29845.45

Upper Kuttanad	6954.47	28647.68	28647.67
Purakad Kari	8581.56	24236.98	32818.54
Northern Kuttanad	5522.16	17975.13	23497.29
Vaikom Kari	5507.22	19002.41	24509.63

The total energy consumption in different agro ecological zone was found to be varying between 23497.29 MJha^{-1} to 32818.54 MJha^{-1}. The topmost total energy was consumed in the Purakad Kari and the lowest in Northern Kuttanad in the different agro-ecological zones.

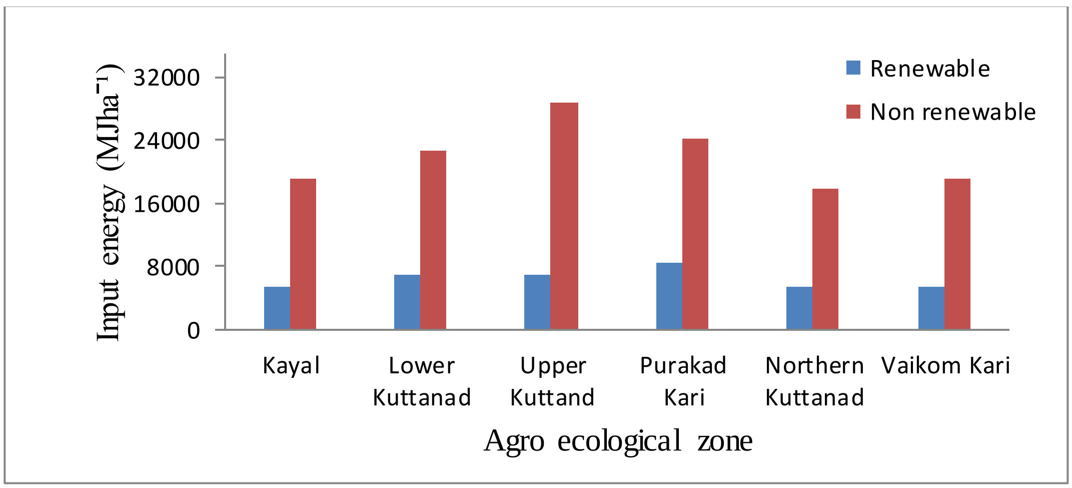

Fig 4.3. Nature-wise energy input in agro-ecological zones

The non-renewable energy is found to be used more than the renewable source of energy in all the agro-ecological zones. This was because, the high energy inputs like electricity and fertilizers are coming under non-renewable energy classification.

The uppermost renewable energy of 8581.56 MJha^{-1} was consumed in the Purakad Kari and the lowest renewable energy of 5424.50 MJha^{-1} was consumed in Kayal in the different agro-ecological zones.

The uppermost non-renewable energy of 28647.68 MJha^{-1} was consumed in the upper Kuttanad and the lowest non-renewable energy of 17975.13 MJha^{-1} was consumed in Northern Kuttanad in the different agro-ecological zones.

The nature-wise energy utilization in different farm size groupS is shown in Table 4.8 and a comparison is represented in Fig.4.4.

Table 4.8. Nature-wise energy input in farm size group

Farm size	**Renewable energy (MJha^{-1})**	**Non-renewable energy (MJha^{-1})**	**Total energy (MJha^{-1})**
Large	3734.21	15503.63	19237.85
Medium	4785.88	18762.06	23547.94
Marginal	5945.43	20493.12	26438.52
Small	12480.44	29579.78	42060.23

The total energy consumption in different farm size group varied between 19237.85 MJha^{-1} to 42060.23 MJha^{-1}. The total energy consumed in the farm size group increases with the decrease in the farm size.

The uppermost renewable energy of 12480.44 MJha^{-1} was consumed in the small farms and the lowest renewable energy of 3734.21 MJha^{-1} was consumed in large farm among the different farm size groups.

The uppermost non-renewable energy of 29579.78 MJha^{-1} was consumed in the small farms and the lowest non-renewable energy of 15503.63 MJha^{-1} was consumed in large farm size in the different farm size groups.

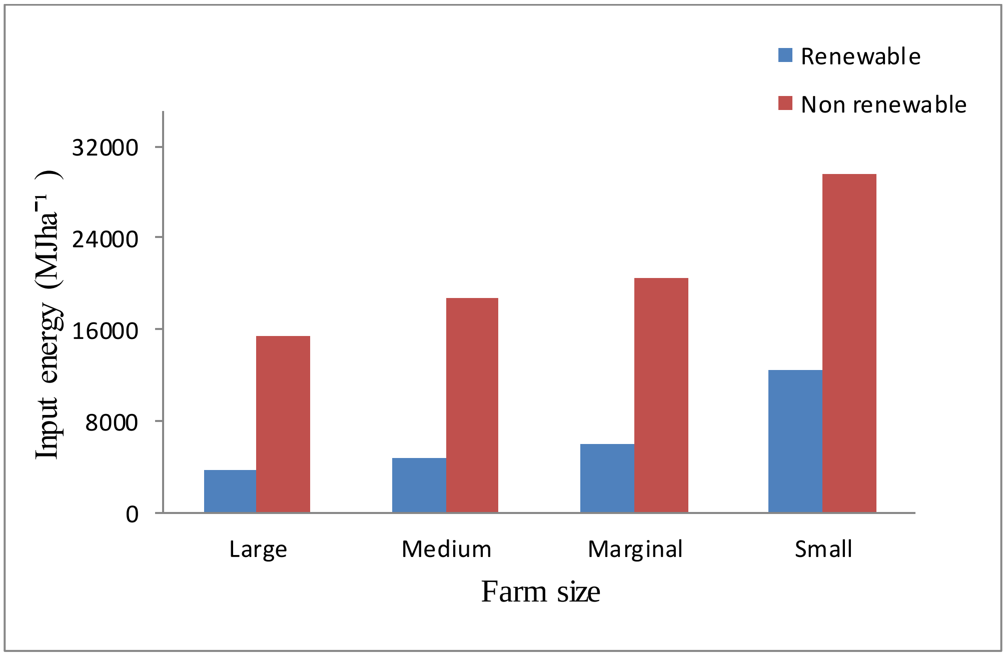

Fig 4.4. Nature-wise energy input in farm size

The non-renewable source of energy is found to be used more than the renewable source of energy in all the farm size groups.

The share of renewable and non-renewable energy is 22.80 per cent and 77.2 per cent respectively, which clearly shows the use of non-renewable energy is more than the renewable energy in this region. This higher usage was mainly due to the input energy from the fertilizers, electricity and diesel.

4.6.3. Economic value-wise energy

Economic value-wise energy inputs are divided into commercial energy and non commercial energy. The different energy input variables are classified into commercial energy and non commercial energy and are tabulated based on the different agro- ecological zones and the different farm size groups.

The nature-wise energy utilization in different agro-ecological zones was shown in Table 4.9 and a comparison is represented in Fig.4.5.

Table 4.9. Nature-wise energy input in agro-ecological zones

Zones	**Commercial energy ($MJha^{-1}$)**	**Non commercial energy ($MJha^{-1}$)**	**Total Energy ($MJha^{-1}$)**
Kayal	19212.39	5424.50	24636.89
Lower Kuttanad	22776.97	7068.48	29845.45
Upper Kuttanad	28647.68	6954.47	28647.67
Purakad Kari	24236.98	8581.56	32818.54
Northern Kuttanad	17975.13	5522.16	23497.29
Vaikom Kari	19002.41	5507.22	24509.63

The total energy consumption in different agro-ecological zone found to be varies between 23497.29 $MJha^{-1}$ to 32818.54 $MJha^{-1}$. The topmost total energy was consumed in the Purakad Kari and the lowest in Northern Kuttanad in the different agro-ecological zones.

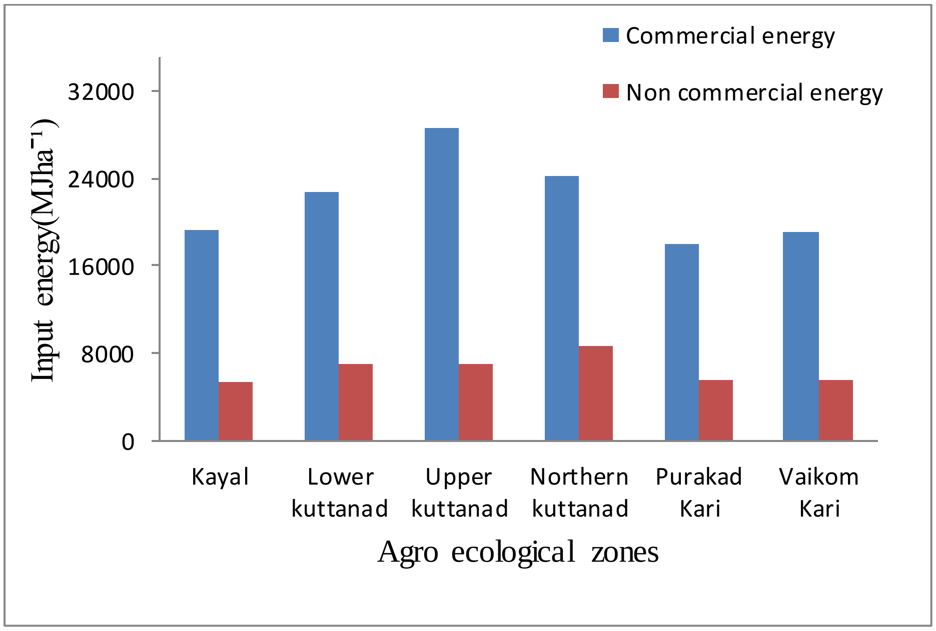

Fig 4.5. Economic value-wise energy input in agro-ecological zones

The commercial energy is found to be used more than the non commercial energy in all the agro-ecological zones.

The uppermost commercial energy of 28647.68 MJha^{-1} was consumed in the upper Kuttanad and the lowest commercial energy of 17975.13 MJha^{-1} was consumed in Northern Kuttanad in the different agro-ecological zones.

The uppermost non commercial energy of 8581.56 MJha^{-1} was consumed in the Purakad Kari and the lowest non commercial energy of 5424.50 MJha^{-1} was consumed in Kayal in the different agro-ecological zones.

The nature-wise energy utilization in different agro-ecological zones was shown in Table 4.10 and a comparison is represented in Fig.4.6.

Table 4.10. Nature-wise energy input in farm size group

Farm size	Non Commercial ($MJha^{-1}$)	Commercial energy ($MJha^{-1}$)	Total energy ($MJha^{-1}$)
Large	3734.21	15503.63	19237.85
Medium	4785.88	18762.06	23547.94
Marginal	5945.43	20493.12	26438.52
Small	12480.44	29579.78	42060.23

The total energy consumption in different farm size groups were found to be varying between 19237.85 $MJha^{-1}$ to 42060.23 $MJha^{-1}$. The total energy consumed in the farm size group increases with the decrease in the farm size.

The commercial source of energy is found to be used more than the non commercial source of energy in all the farm size.

The uppermost non commercial energy of 12480.44 $MJha^{-1}$ was consumed in the small farms and the lowest non commercial energy of 3734.21 $MJha^{-1}$ was consumed in large farm in the different farm size.

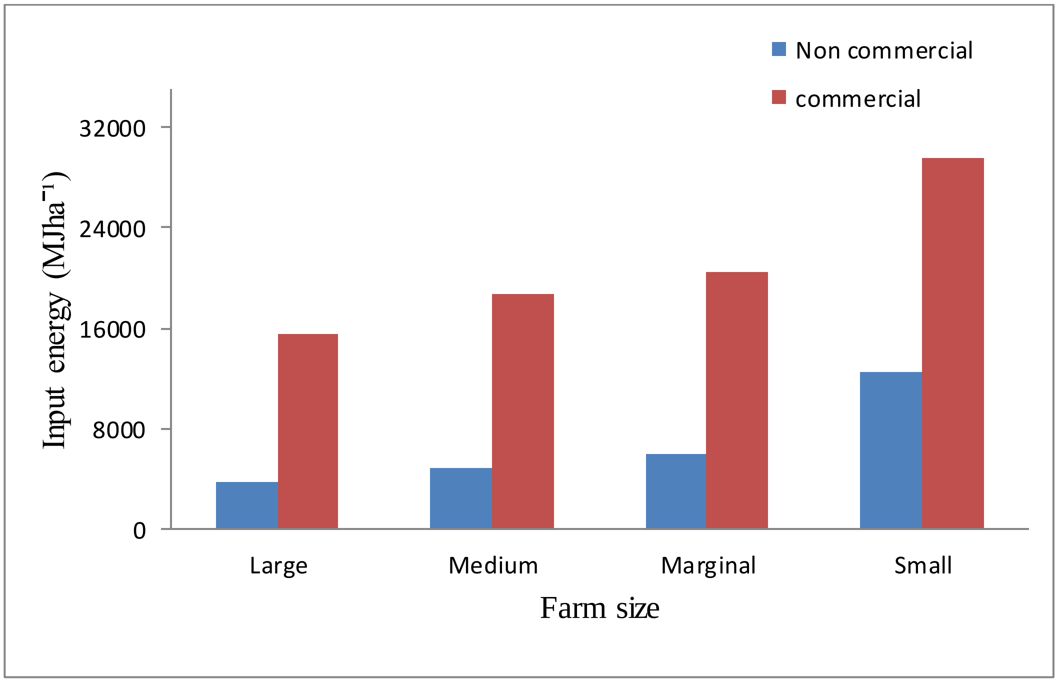

Fig 4.6. Economic value-wise energy input in farm-wise

The uppermost commercial energy of 29579.78 $MJha^{-1}$ was consumed in the small farms and the lowest commercial energy of 15503.63 $MJha^{-1}$ was consumed in large farm size in the different farm size.

The share of non commercial and commercial energy is 22.80 per cent and 77.2 per cent respectively, which clearly shows the use of commercial energy is more than the non commercial energy in the region. This is mainly due to the input energy from the fertilizers, electricity and diesel.

The statistical analysis of the energy inputs based on different agro-ecological zones and farm sizes were done.

The analysis of variance for the energy input with respect to six different agro-ecological zones is given in Table 4.11.

Table 4.11. The analysis of variance for the energy input with respect to agro-ecological zones

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Treatments	5	689368428.047	137873685.609	2.814	0.024
Error	60	2939566622.716	48992777.045	-	-
Total	65	-	-	-	-

Coefficient of Variation = 25.340
Treatments found significant at 5 per cent level of Significance
CD (0.05)= 11430.110

From the results it was inferred that the interaction effect due to different agro-ecological zones is significant.

The analysis of variance for the energy input with respect to four farm size groups is given in Table 4.12.

Table 4.12. The analysis of variance for the energy input with respect to four farm size groups

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Treatments	3	1828761995.621	609587331.874	15.567	0.000
Error	20	783182678.781	39159133.939	-	-
Total	23	-	-	-	-

Coefficient of Variation = 15.366
Treatments found significant at 1 per cent and 5 per cent level of significance
CD(0.01) = 10278.700 CD(0.05) = 7536.509

From the results it was inferred that the interaction effect due to different farm size groups is significant.

Operation-wise energy use pattern

The major unit operations of paddy cultivation are Land preparation, Seeding, Water management, Fertilizer and chemical application, and Harvesting. The different energy input are grouped into major unit operations of paddy cultivation and are tabulated based on the different agro- ecological zones and the different farm size groups. The unit operations wise energy utilization in different agro-ecological zones was shown in Table 4.13 and a comparison is represented in Fig.4.7.

Table 4.13. Operation-wise energy in agro ecological zone (MJha^{-1})

Zone	**Land preparation**	**Seeding**	**Water management**	**Fertilizer and chemical application**	**Harvesting**	**Total**
Kayal	2330.32	2183.03	7446.78	11293.95	1382.80	24636.89
Lower Kuttanad	2381.62	2596.50	11299.68	12182.35	1385.27	29845.42
Upper Kuttanad	2415.63	2397.82	10164.68	12231.61	1437.93	28647.67
Purakad Kari	2770.46	3784.72	9047.86	15683.72	1531.62	32818.38
Northern Kuttanad	2452.38	2284.13	5750.58	11513.03	1497.15	23497.27
Vaikom Kari	2493.15	2259.68	6442.71	11780.13	1533.94	24509.61

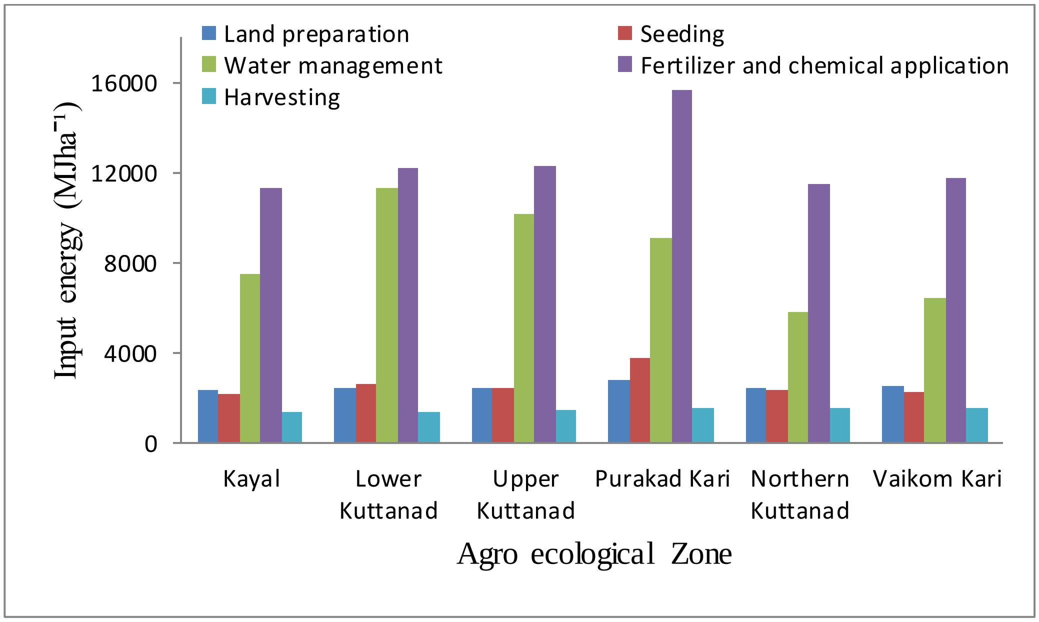

Fig. 4.7. Operation-wise energy in agro ecological zone (MJha^{-1})

Among the five units operation in paddy cultivation, the fertilizer and chemical application is the most energy consuming unit operation in all six agro-ecological zones. This is because of the high energy input value of the fertilizers applied in the fields. The different unit operation except water management shows uniform energy expenditure in different agro-ecological zones.

The unit operation water management shows a maximum energy consumption of 11299.68 MJha^{-1} in the Lower Kuttanad region and a minimum of 5750.58 MJha^{-1} in the Northern Kuttanad. The Lower Kuttanad zone has the lowest elevation among the different zones this may be the cause of the high expenditure in that unit operation.

The unit operations-wise energy utilization in different farm size groups is shown in Table 4.14 and a comparison is represented in Fig.4.8.

Table 4.14. Operation-wise energy in different farm size ($MJha^{-1}$)

Farm size	Land preparation	Seeding	Water management	Fertilizer and chemical application	Harvesting	Total
Large	1462.61	2073.45	6362.03	8686.41	653.34	19237.85
Medium	1886.00	2385.49	7047.18	11305.12	924.14	23547.94
Marginal	2171.43	2291.59	8571.96	12042.71	1360.84	26438.52
Small	4597.94	3018.95	14505.19	16795.00	3143.34	42060.23

Among the five unit operation in paddy cultivation in four farm size groups, the fertilizer and chemical application consumes the maximum energy as compared to the other operations and the harvesting consumes the less amount of energy among these five operations.

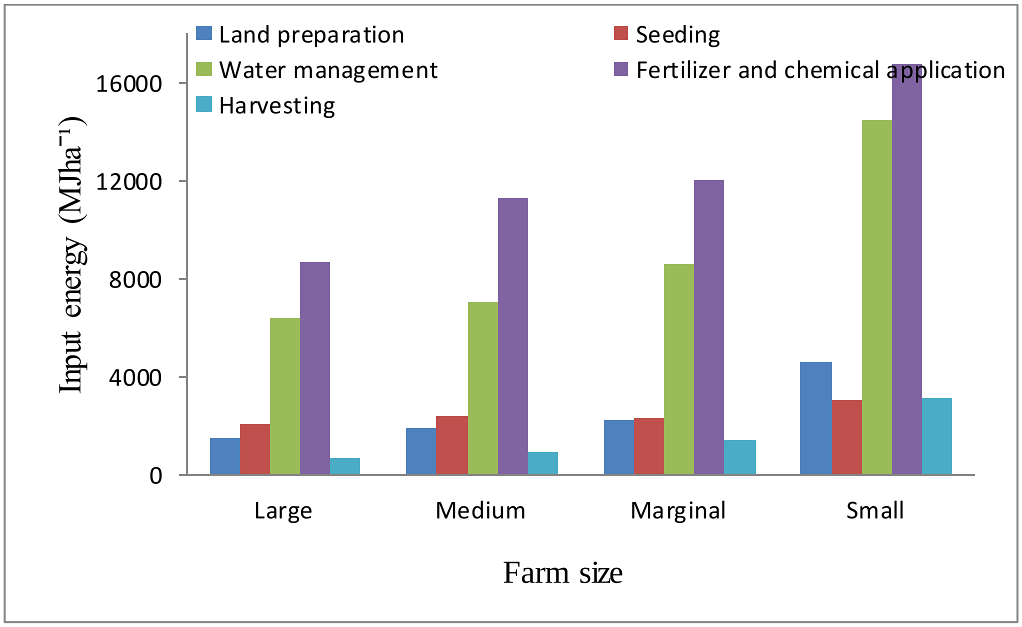

Fig.4.8. Operation-wise energy in different farm size

The energy input pattern in all unit operations of different farm size groups shows a uniform pattern. It shows that the energy input decreases as the area of the holding increases.

4.7. Input-wise energy use pattern

The data was collected from the farmers by using a questionnaire and the value is converted to energy equivalents and grouped on the basis of agro ecological zone and farm size and given in the Table 4.15 and Table 4.16.

Table 4.15. Input-wise energy use pattern within the different agro-ecological zones (MJha^{-1})

	Kayal	Lower Kuttanad	Northern Kuttanad	Purakad Kari	Upper Kuttanad	Vaikom Kari
Input						
Human	3937.60	5227.86	3928.24	5897.26	5265.15	3885.46

Machinery	391.683	463.932	365.54	425.59	440.46	390.12
Diesel	2868.23	2829.97	3079.63	3095.22	2968.24	3126.29
Nitrogen	8912.61	9588.54	9127.00	12434.78	9572.31	9343.13
Phosphorus	518.02	584.16	521.91	766.29	570.93	546.68
Potassium	1391.50	1568.62	1404.88	2060.48	1533.98	1470.39
Chemical	389.44	360.44	371.44	330.44	468.94	331.44
Seed	1486.90	1840.61	1593.91	2684.29	1689.31	1621.76
Electricity	4740.88	7381.28	3104.68	5124.16	6138.31	3794.32
Output						
Paddy	78003.37	85816.15	82503.68	103454.80	83116.70	84935.95
Straw	22149.13	32545.55	25583.59	23784.20	38374.70	49468.25
Total	**100152.50**	**118361.70**	**108087.37**	**127239.00**	**121491.40**	**110749.40**

Table 4.16. Input-wise energy use pattern within the different farm size ($MJha^{-1}$)

	Large	Medium	Marginal	Small
Input				
power	2324.44	3332.11	4178.65	10252.98
Machinery	267.85	318.02	404.00	749.36
diesel	1308.55	1801.96	2845.15	6577.92
Nitrogen	6628.74	8902.37	9475.67	13439.19
phosphorus	438.67	525.40	563.35	744.14
potassium	1175.59	1412.82	1514.89	2000.98
chemical	405.99	408.35	411.11	421.65
seed	1409.77	1453.76	1766.78	2227.46
electricity	5278.21	5384.11	5278.92	5646.56
Total	**19237.81**	**23538.9**	**26438.52**	**42060.24**
Output				
Paddy	72912.51	75507.54	82150.38	107667.1
Straw	19037.7	24193.78	36947.43	45044.12

Total	92220.20	99701.32	119097.8	152710.2

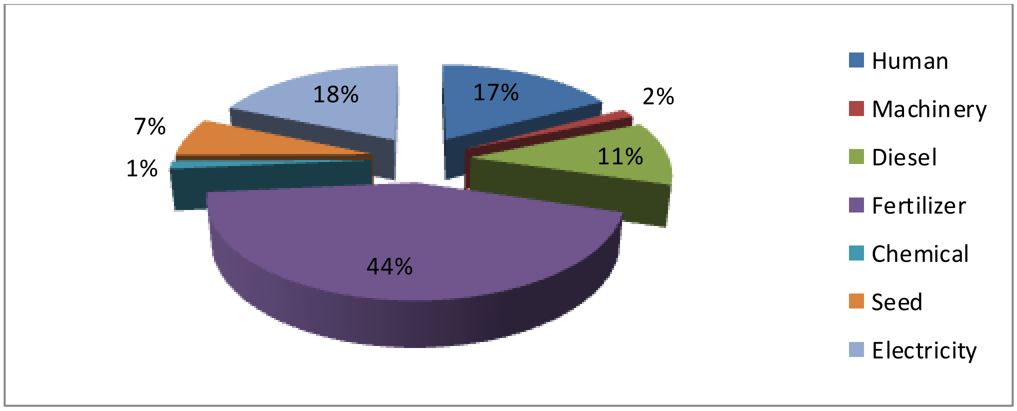

Fig 4.9. Input-wise energy use pattern within the Kuttanad region.

The input-wise energy use pattern in the Kuttanad region reveals that the fertilizer comes on top with 43 per cent and followed by electricity with 18 per cent and human power with 17 per cent (Fig. 4.9.). This clearly shows that the fertilizer is consuming the most energy in the all inputs used in paddy cultivation in Kuttanad region.

4.8.Energy indices

The energy indices of the below sea level rice production systems in Kuttanad region of Kerala within the different agro- ecological zones and the different farm size groups were calculated and tabulated. The energy indicators used in the study are energy use efficiency (energy ratio), energy productivity, specific energy and net energy.

The energy indices of the below sea level rice production systems in Kuttanad region of Kerala and the same within the different agro- ecological zones and the different farm size groups were calculated.

4.9.1. Energy use efficiency

The indicator is composed of a measure of the energy used or going into agricultural production and the amount of energy contained in various agricultural commodities produced in the primary agricultural sector. The ratio of energy output to energy input is a measure of energy use efficiency. The energy efficiency was calculated within the different agro- ecological zones and the different farm size groups and are tabulated as Table.4.17 and Table 4.18 respectively.

Table 4.17. Energy efficiency in different farm size groups

Farm size	**Energy efficiency**
Large	478
Medium	478
Marginal	423
Small	362

Table 4.18. Energy efficiency in different agro- ecological zones

Zones	**Energy efficiency (%)**
Kayal	406
Lower Kuttanad	396
Upper Kuttanad	424
Purakad Kari	387
Northern Kuttanad	459
Vaikom Kari	451

4.9.2. Energy productivity

Energy Productivity is the ratio of output divided by energy consumption. Energy productivity was calculated within the different agro- ecological zones and the different farm size groups and are tabulated as Table.4.19 and Table 4.20 respectively.

Table 4.19. Energy productivity in different agro- ecological zones

Zones	**Energy productivity (kgMJ^{-1}).**
Kayal	0.22
Lower Kuttanad	0.18
Upper Kuttanad	0.18
Purakad Kari	0.15
Northern Kuttanad	0.23
Vaikom Kari	0.21

Table 4.20. Energy productivity in different farm size groups

Farm size	**Energy productivity (kgMJ^{-1}).**
Large	0.25
Medium	0.25
Marginal	0.22
Small	0.17

4.9.3. Specific energy

Specific energy (MJkg^{-1}) is the quantity of energy invested to produce a unit quantity of product or output. The specific energy were calculated within the different agro- ecological zones and the different farm size groups and are tabulated as Table.4.21. and Table 4.22. respectively.

Table 4.21. Specific energy in different agro- ecological zones

Zones	Specific energy (MJ /kg).
Kayal	4.50
Lower Kuttanad	5.47
Upper Kuttanad	5.41
Purakad Kari	6.29
Northern Kuttanad	4.26
Vaikom Kari	4.56

Table 4.22. Specific energy in different farm size groups

Farm size	Specific energy (MJ /kg).
Large	3.80
Medium	3.83
Marginal	4.23
Small	5.69

4.9.4. Net energy (MJha^{-1})

Net Energy is the difference between the energy expended and the amount of energy gained. Net energy was calculated within the different agro- ecological zones and the different farm size groups and are tabulated as Table.4.23 and Table 4.24 respectively.

Table 4.23. Net energy in different agro- ecological zones

Zones	Net energy ($MJkg^{-1}$)
Kayal	75515.60
Lower Kuttanad	88516.29
Upper Kuttanad	92843.72
Purakad Kari	94420.49
Northern Kuttanad	84589.97
Vaikom Kari	86239.75

Table 4.24. Net energy in different farm size groups

Farm size	Net energy ($MJkg^{-1}$)
Large	72746.47
Medium	72746.47
Marginal	76191.35
Small	110314.50

4.9. Economic indices

The economic indices of the below sea level rice production systems in Kuttanad region of Kerala within the different agro- ecological zones and the different farm size groups were calculated and tabulated.

4.10.1. Gross profit.

The gross profit in the paddy cultivation of Kuttanad region is analyzed on agro-ecological zone-wise and farm size-wise and its value is given in Table 4.25 and Table 4.26 respectively.

Table 4.25. Gross profit in different agro- ecological zones

Zones	Total value of production ($Rsha^{-1}$.)	Farmers level cost of production ($Rsha^{-1}$.)	Gross profit ($Rsha^{-1}$.)
Kayal	123135.00	60059.76	63075.24
Lower Kuttanad	135468.20	99982.82	35485.38
Northern Kuttanad	130239.20	61197.38	69041.78
Purakad Kari	163312.39	84679.80	77663.31
Upper Kuttanad	131206.97	63328.31	68010.16
Vaikom Kari	134078.72	62362.40	71716.32

Table 4.26. Gross profit in different Farm size groups

Farm size	Total value of production ($Rsha^{-1}$.)	Farmers level cost of production ($Rsha^{-1}$.)	Gross profit ($Rsha^{-1}$.)
Large	115098.70	55387.58	59711.12
Medium	119195.10	69311.58	49883.48
Marginal	129681.40	59455.18	70226.22
Small	169961.00	92282.63	77679.27

The zone wise and farm size-wise gross profit is calculated. From this result the Purakad Kari region has more gross profit than that of other zones and smaller farm size groups having the upper gross profit than the other farm size groups in the Kuttanad region. The less gross profit in Lower Kuttanad region, may be due to the overuse of input energy for water management in this region. The medium size farms show less gross profit in the farm size-wise calculations.

4.10.2 Net profit

The Net profit in the paddy cultivation of Kuttanad region is analyzed on agro ecological zone-wise and farm size-wise and its value is given in Table 4.27 and Table 4.28 respectively.

Table 4.27. Net profit in different Farm size groups

Farm size	**Total value of production (Rsha^{-1}.)**	**Total cost of production (Rsha^{-1}.)**	**Net profit (Rsha^{-1}.)**
Large	115098.70	74142.08	40956.62
Medium	119195.10	88326.86	30868.76
Marginal	129681.40	80628.08	49053.32
Small	169961.00	116465.94	53495.94

Table 4.28. Net profit in different agro- ecological zones

Zones	**Total value of production (Rsha^{-1}.)**	**Total cost of production (Rsha^{-1}.)**	**Net profit (Rsha^{-1}.)**
Kayal	123135.00	78869.82	44265.18
Lower Kuttanad	135468.14	122543.90	12924.24
Northern Kuttanad	130239.20	79822.87	50416.27
Purakad Kari	163312.32	110358.70	53138.32
Upper Kuttanad	131206.90	84573.00	46635.10
Vaikom Kari	134078.70	82155.39	51923.31

The net profit from each agro-ecological zone wise and farm size-wise is calculated. From these results it is seen that the Purakad Kari region has more net profit than that of other zones and smaller farms having the upper gross profit than the other farm size groups in the Kuttanad region. The less gross is found in Lower Kuttanad region. It is due to the overuse of input energy for water management in this region. The medium size farms show less gross profit in the farm size-wise calculations.

4.10.3. Productivity.

The productivity in the paddy cultivation of Kuttanad region is analyzed agro ecological zone-wise and farm size-wise and given in Table 4.29 and Table 4.30 respectively.

Table 4.29. Productivity in different farm size groups

Farm size	**Productivity ($KgRs^{-1}$)**
Large	0.06
Medium	0.06
Marginal	0.08
Small	0.07

Table 4.30. Productivity in different agro- ecological zones

Zones	**Productivity ($KgRs^{-1}$)**
Kayal	0.07
Lower Kuttanad	0.06
Northern Kuttanad	0.07
Purakad Kari	0.06
Upper Kuttanad	0.07
Vaikom Kari	0.07

The productivity from each zone and farm size group is calculated. From these results, the Vaikom Kari region is found to have more productivity than that of other zones and marginal farms have more productivity than the other farm size groups in the Kuttanad region. The less productivity obtained in the Lower Kuttanad region is due to the overuse of input energy for water management in this region. The medium size farms show the less productivity in the farm size-wise calculations.

4.10.4. Benefit cost ratio (BCR)

The benefit cost ratio in paddy cultivation of Kuttanad region is analyzed agro ecological zone-wise and farm size-wise and given in Table 4.31 and Table 4.32 respectively.

Table 4.31. BCR in different agro- ecological zones

Zones	**Total value of production (Rsha⁻¹.)**	**Total cost of production (Rsha⁻¹.)**	**Net profit (Rsha⁻¹)**	**BCR**
Kayal	123135.00	78869.82	**44265.18**	0.65
Lower Kuttanad	135468.14	122543.90	**12924.24**	0.42
Northern Kuttanad	130239.20	79822.87	**50416.27**	0.66
Purakad Kari	163312.32	110358.70	**53138.32**	0.56
Upper Kuttanad	131206.90	84573.00	**46635.10**	0.65
Vaikom Kari	134078.70	82155.39	**51923.31**	0.74

Table 4.32. BCR in different farm size groups

Farm size	**Total value of production (Rsha⁻¹)**	**Total cost of production (Rsha⁻¹)**	**Net profit (Rsha⁻¹)**	**BCR**
Large	115098.70	74142.08	40956.62	0.60
Medium	119195.10	88326.86	30868.76	0.42
Marginal	129681.40	80628.08	49053.32	0.84
Small	169961.00	116465.94	53495.94	0.62

The benefit cost ratio from each zone and farm size groups is calculated. It is found that the Vaikom Kari region has more benefit cost ratio than that of other zones and marginal farm having the upper benefit cost ratio than the other farm size groups in Kuttanad region. The less benefit cost ratio is in the Lower Kuttanad region among the agro-ecological zones. Among the farm size groups, medium farm shows the less benefit cost ratio.

Table.4.33. ANOVA Table for agro-ecological zone-wise BCR

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Treatments	5	0.1.9	0.02	0.735	0.60
Error	59	1.74	0.03	-	-
Total	64	-	-	-	-

Coefficient of Variation = 10.52 , Treatments found to be non significant

Table.4.34. ANOVA Table for farm size wise BCR

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Treatments	3	0.35	0.11	4.27	0.017
Error	20	0.55	0.02	-	-
Total	23	-	-	-	-

Coefficient of Variation = 10.337

Treatments found significant at 5 per cent level of significance CD(0.05)= 0.200

The benefit cost ratio in the agro ecological zones and farm size groups is tested statistically by using CRD ANOVA and it shows that the benefit cost ratio in each agro-ecological zone is not significant to each other. In case of farm size groups the CRD ANOVA shows that the benefit cost ratio is significant between each farm size groups.

Cost of expenditure for unit energy input is calculated during the survey and given in the Table 4.35.

Table 4.35. Cost for unit input energy.

Energy inputs	Price(Rs)	Price/MJ
1. Machinery		
Tractor	$750h^{-1}$	38.69
Combine harvester	$1800h^{-1}$	55.77
2. Human	$100h^{-1}$	51.00
3. Diesel	$61.00l^{-1}$	1.08
4. Fertilizer		
➢ Potassium (Muriate of Potash)	$11kg^{-1}$	1.00
➢ Phosphorus (Factomphos)	$26kg^{-1}$	2.10
➢ Nitrogen (Urea)	$6kg^{-1}$	0.10
5. Plant protection chemicals	$8000kg^{-1}$	82.00
6. Seed (paddy)	$23kg^{-1}$	1.57
7. Electricity	$5kwh^{-1}$	0.04

4.11. ANN model and model development

ANN model is developed for six agro-ecological regions of the Kuttanad region, Kerala to estimate the energy output from the Padasekhams. In this study, seven input variables *viz* machinery, human power, seed, fertilizer, plant protection plant protection chemicals, diesel, and electricity are considered to estimate the energy output. All the input data variables were converted to the energy equivalents using appropriate coefficients obtained from the literature. The 731 data points for input and output variables are collected from the farmers across the six agro ecological regions and for different farm holdings.

After determining the input and output variables of the ANN model, second step is to determine the number of hidden neurons in the ANN model architecture. The number of hidden neurons in the ANN model is decided by trial and error method. The trial and error procedure for identification of the hidden neurons is applied by employing to 400 and 231 randomly selected data points from the whole data set as training and testing data sets respectively. The ANN model is trained on the 400 data points and tested on the 231 data points. The training and testing statistic (NSE) is evaluated for all the ANN models with different number of hidden neurons starting from 1 to 15 hidden neurons. The number of hidden neurons is selected such that the training and testing statistic are similar or close to each other. For the developed model, it was observed that the hidden neurons 7, 10 and 12 showed similar performances for the training and testing data sets as can be seen from the fig 4.10. To further analyze the performance of the number of hidden neurons of 7, 10, and 12, residuals were plotted for the training data set Fig. 4.11. The residual plot for 10 hidden neuron showed more uniformity and homoscedasticity compared to the 7 and 12 hidden neurons. Therefore, the number of hidden neurons selected for the ANN model is 10. The architecture of the developed ANN model consisted of seven input variables, ten hidden neurons, and 1 output variable. Schematic diagram of the ANN architecture is shown below Fig.4.11.

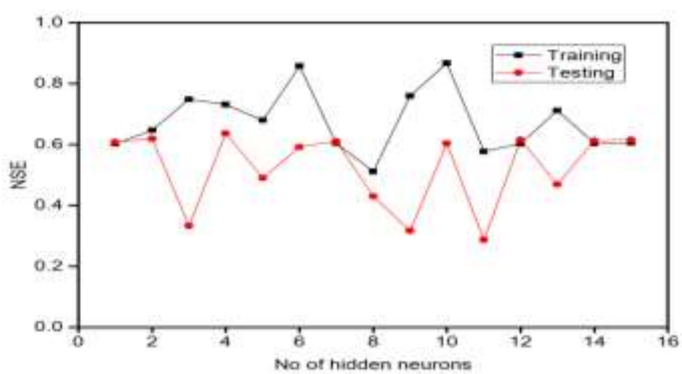

Fig 4.10. Trial and error procedure for finding number of hidden neurons for the ANN architecture

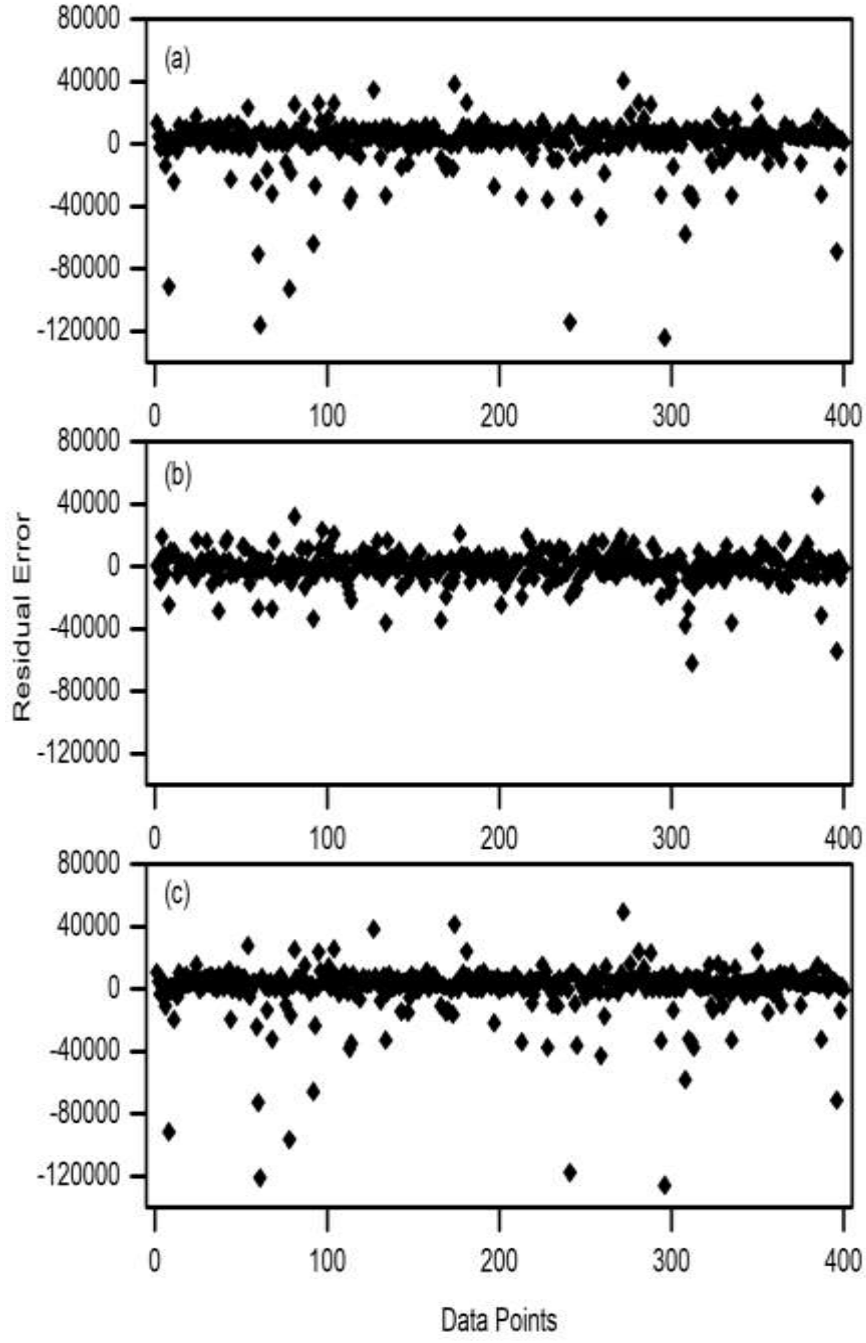

Fig 4.11. Scatter plot of residual error for the training data set of 400 data points for ANN architecture consisting of (a) 7, (b) 10, and (c) 12 hidden neurons

As mentioned before, the scaled input and output is used to train the ANN model using the back propagation algorithm. ANN training involves determination of the weights and biases of the transfer function employed in the ANN architecture. The ANN weights are determined on the training set and same weights are used to estimate the energy output for the testing dataset and compared with the observed energy output. Training of ANN model involves selection of suitable error function, whose values is determined by the actual and desired output and an iterative process is followed in back propagation algorithm to minimize the error function. In this study, mean square error (MSE) is used as the error function. The iterative process of minimization of error function estimates the weights and biases of the connections between input layer and hidden layer and also between hidden layer and output layer. The weights and biases estimated for the ANN model are significantly biased by the input data used for training the ANN model. Therefore the weights and biases estimated from a sample of data may not be similar to those estimated from another sample data from the same population.

ANN model performs as good as the data it is trained on. For good performance of ANN model, it should be trained on significant data with data representing different clusters. In this study, we have 631 data points from 6 agro ecological areas and 4 different land holdings; the data is not uniformly distributed among different clusters. Training of ANN model with one set of random sample may bias the model towards a particular cluster and model may not be the best model. To account for the variability in the weights and biases due to different input data points and to obtain a generalized model, 500 random sets were generated with 400 data points for training the ANN model and 231 data points for testing the model. The 500 random sets used for training the ANN model created 500 different models. These 500 models were used to predict the energy output from the validation data set and the output was compared to the observed output.

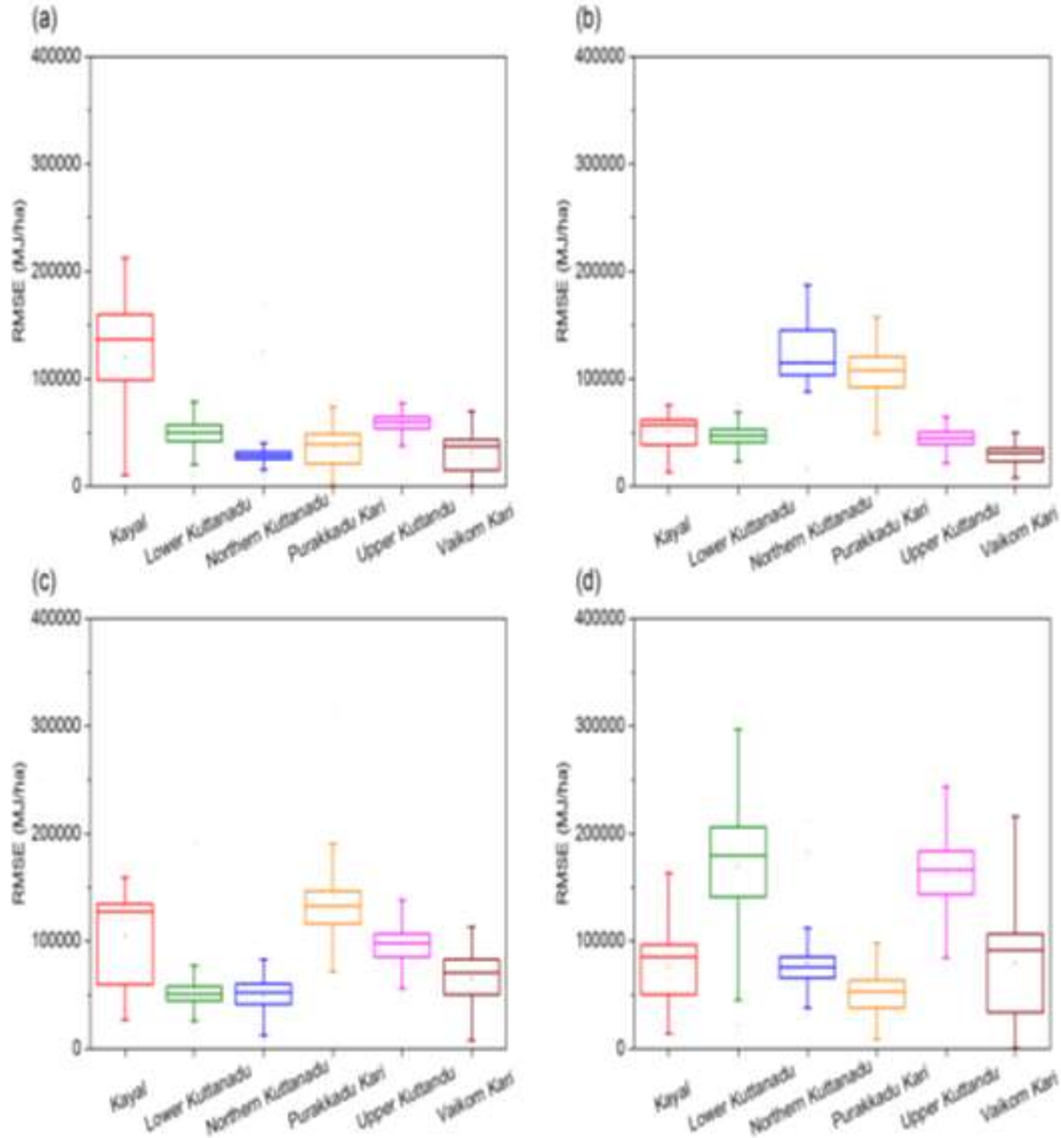

Fig 4.12. Variability of RMSE for the training dataset in different agro-ecological zones for: (a) Large farm holdings, (b) Medium farm holdings, (c) Small farm holdings, and (d) Marginal farm holdings

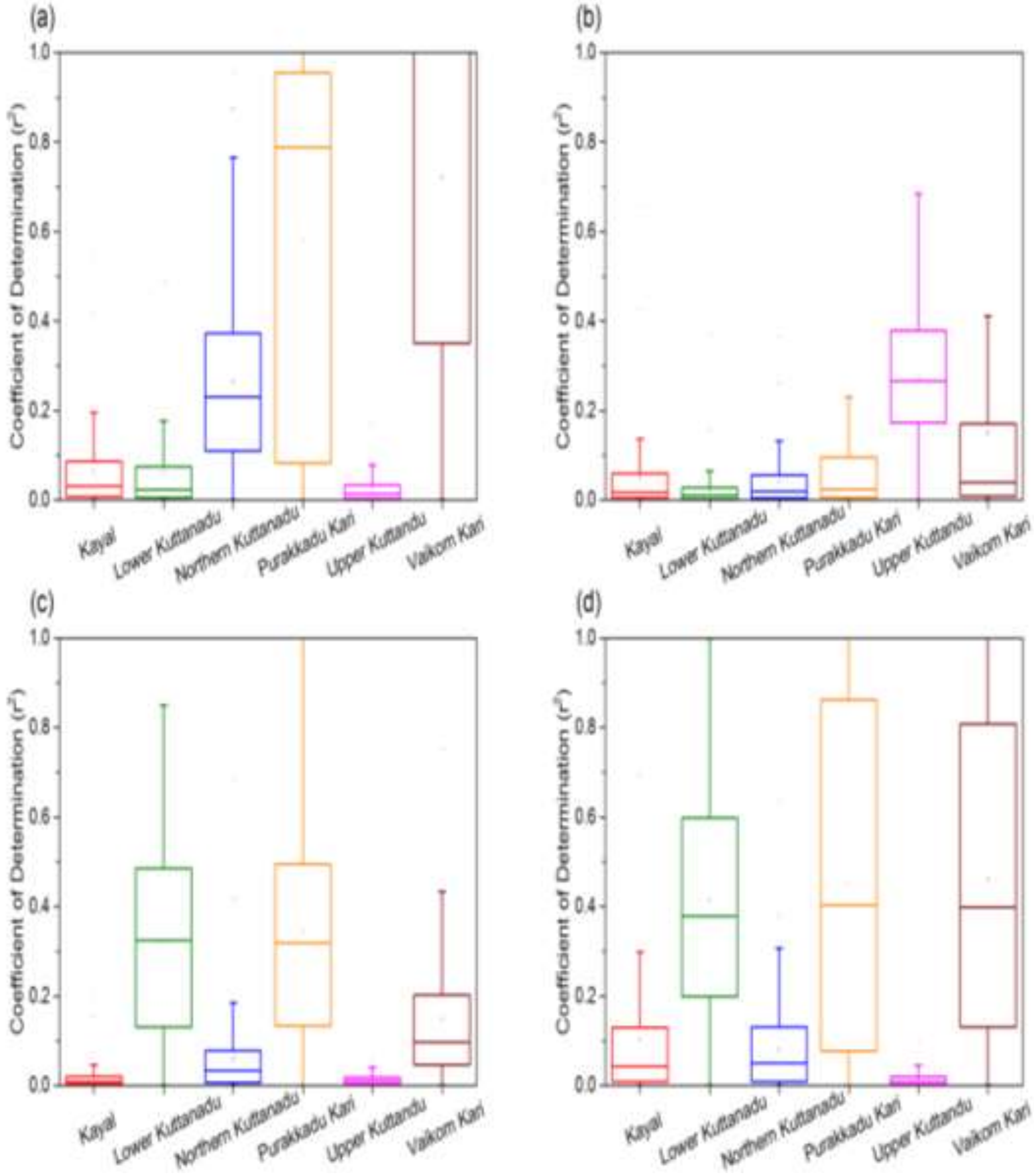

Fig 4.13. Variability of r-square for the training dataset in different agro-ecological zones for: (a) Large farm holdings, (b) Medium farm holdings, (c) Small farm holdings, and (d) Marginal farm holdings

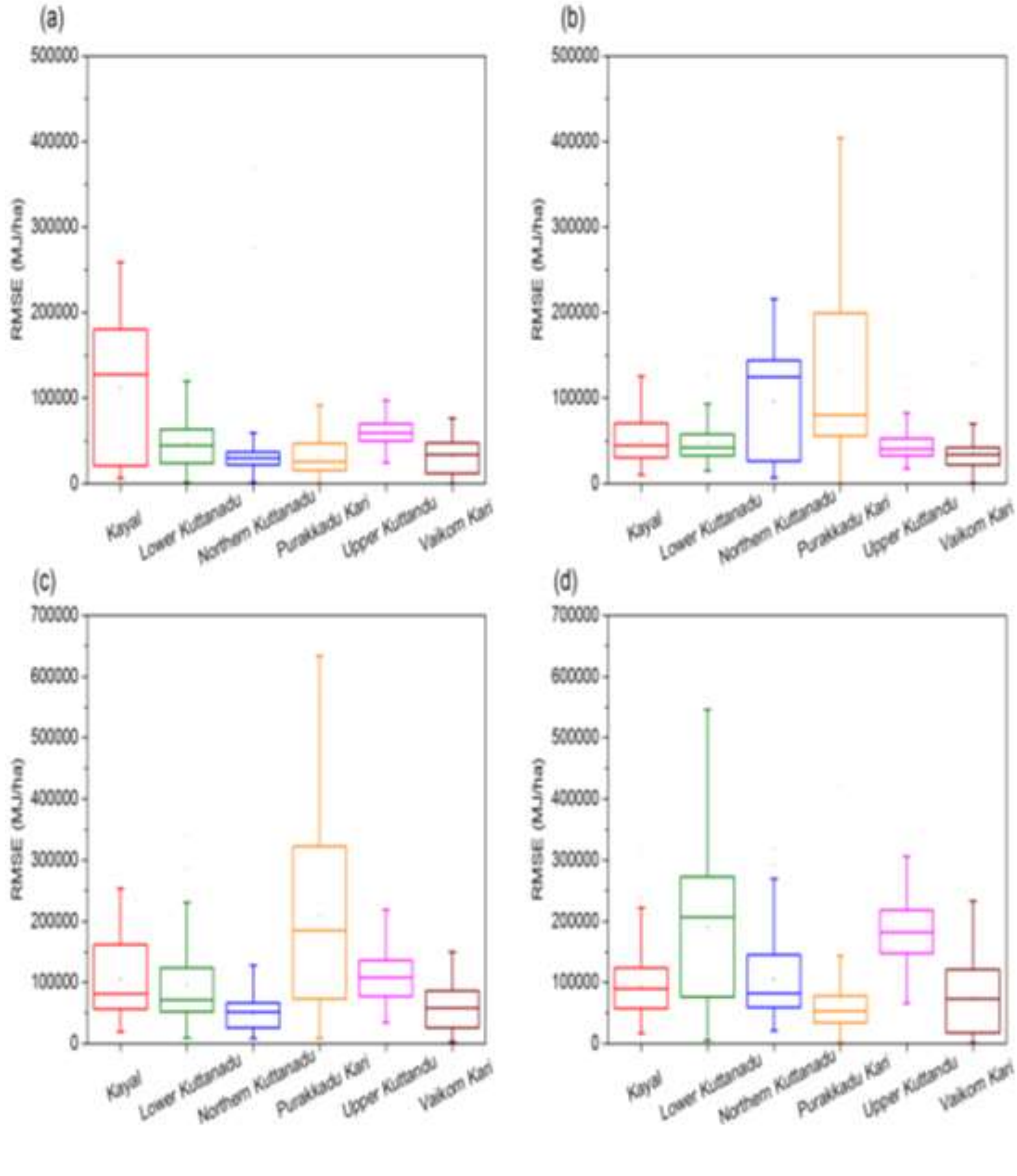

Fig.4.14. Variability of RMSE for the testing dataset in different agro-ecological zones for: (a) Large farm holdings, (b) Medium farm holdings, (c) Small farm holdings, and (d) Marginal farm holdings

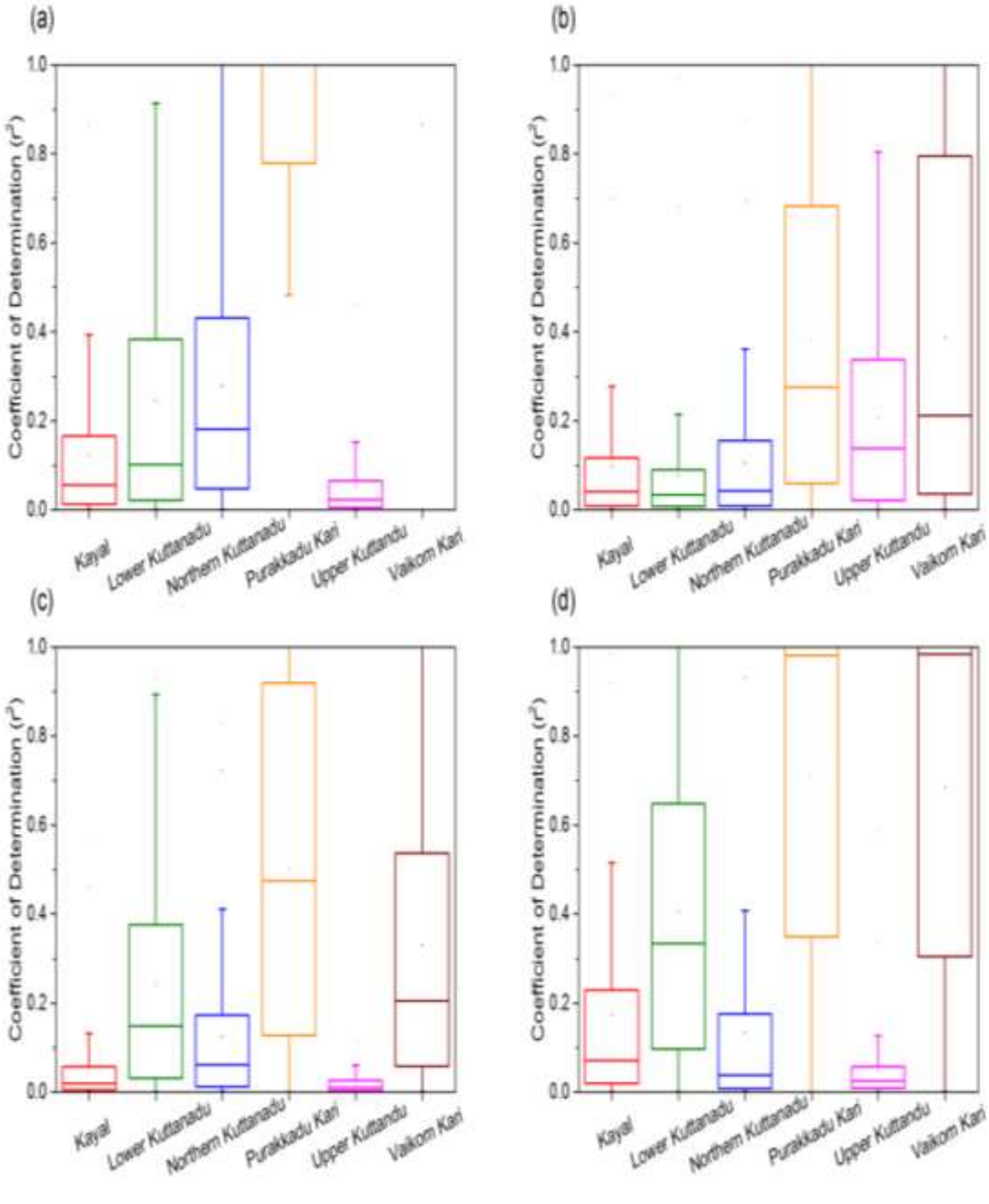

Fig.4.15. Variability of r-square for the testing dataset in different agro-ecological zones for: (a) Large farm holdings, (b) Medium farm holdings, (c) Small farm holdings, and (d) Marginal farm holdings

The outputs from the simulations of 500 models on the training, testing, and validation data sets were separated into different classifications of agro-ecological regions and land holdings. The performance statistics (RMSE, r-square) of these models for different clusters of training, testing and validation data sets are plotted as box plots and presented in the fig.4.12, fig.4.13, fig.4.14, fig.4.15, fig.4.16, fig.4.17. For the training data sets, the variation of the RMSE was found to be more in Kayal, Purakad Kari and Vaikom Kari compared to other 3 regions, for all 4 different land holdings. It is also observed that the error increases as the land holdings decreases with average RMSE for all regions above 5000 for marginal land holdings. The developed ANN models perform best for the Northern Kuttanad region in all the land holdings with minimum variability in all the land holding classes except for the medium land holding class. In the medium land holding class, lower Kuttanad and Vaikom Kari regions perform best. However, variation in training data sets showed slightly different trend, with Lower Kuttanad, Purakad Kari, and Vaikom Kari showing the maximum variation in large, small and marginal land holdings. The r-square of different areas were consistent with the RMSE of the training data sets with areas having high RMSE had lower r-square compared to other areas. In the testing data set, all the models in general performed well for large and medium farm holdings for all the regions. However, the variability in the model outputs of the ANN models was observed to be differing for regions in the 4 land holding classes. Kayal region has the most variability for the large land holdings, Lower Kuttanad in the marginal land holdings and Purakad Kari in the small and medium land holdings. Overall, Vaikom Kari region showed minimum variability for all the 4 land holdings and in general RMSE is lower compared to other areas for the testing data sets. Similar results can be seen from the r-square plots, where Vaikom Kari regions, r-square variability is less and close to 1 in all the land holding systems. The variability and performance of the Purakad Kari and Vaikom Kari showed similar results and the median of the rest of the outputs for the models for the remaining areas were found to be less than 0.5.

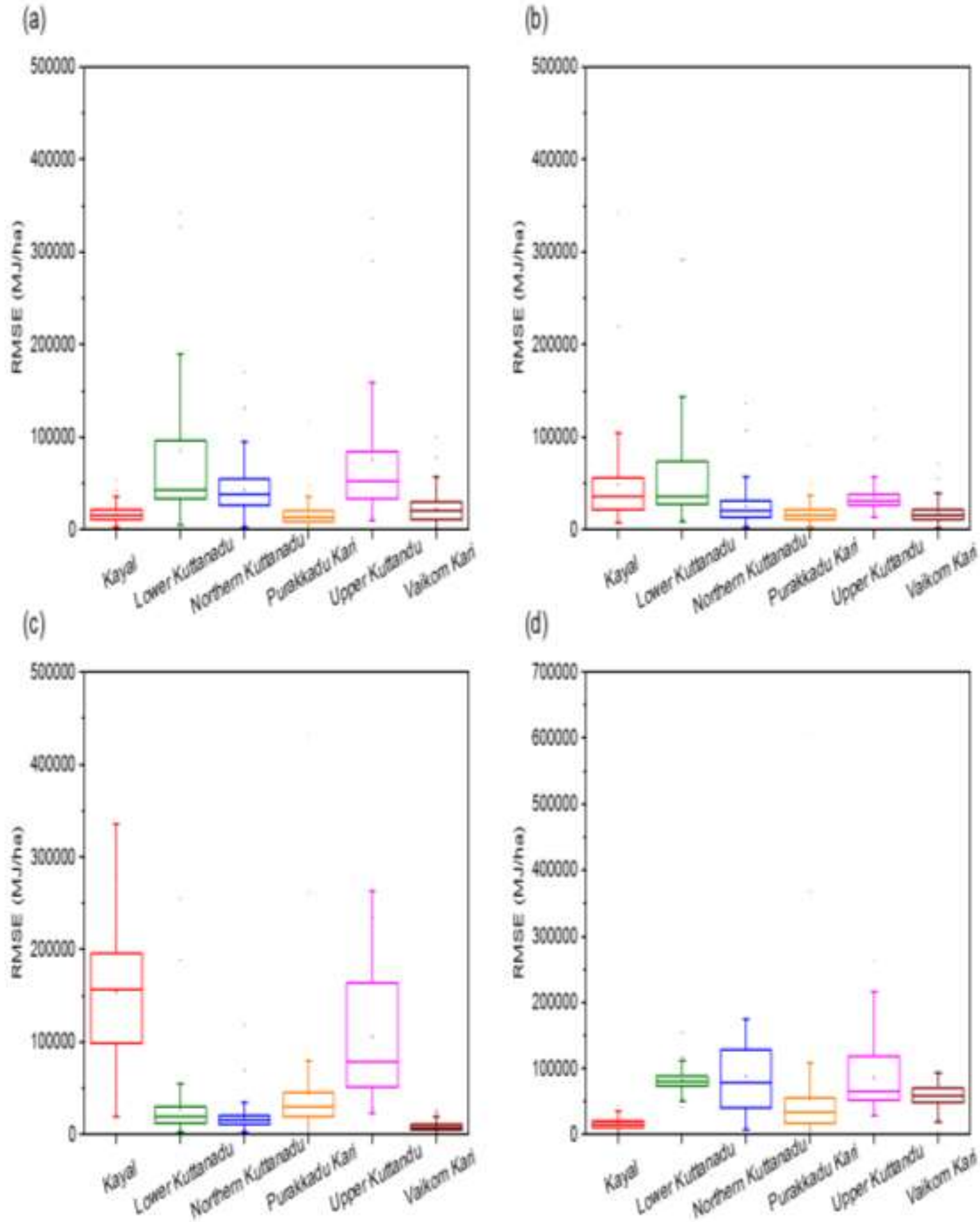

Fig 4.16. Variability of RMSE for the validation dataset in different agro-ecological zones for: (a) Large farm holdings, (b) Medium farm holdings, (c) Small farm holdings, and (d) Marginal farm holdings

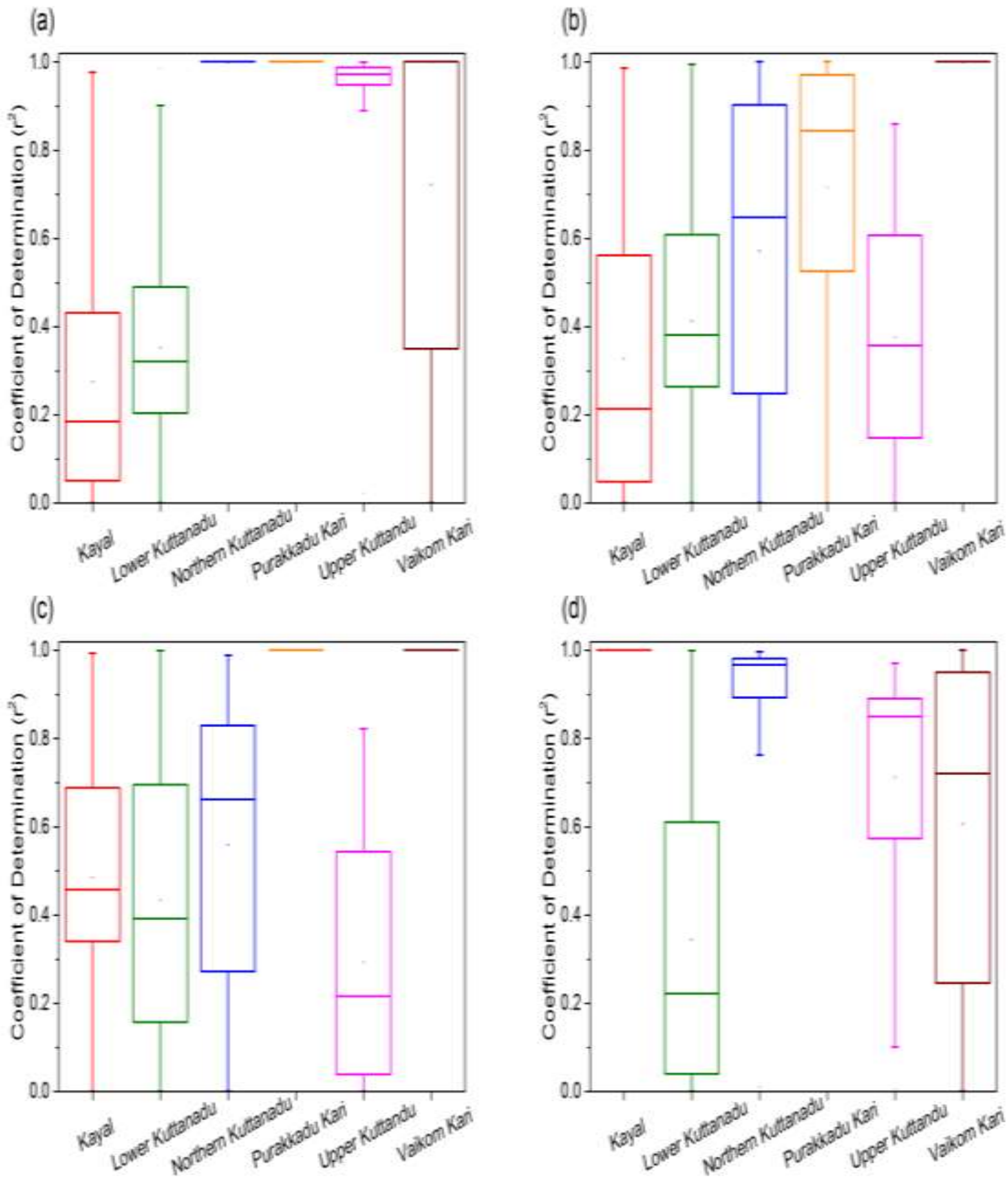

Fig 4.17. Variability of r-square for the validation dataset in different agro ecological zone for: (a) Large farm holdings, (b) Medium farm holdings, (c) Small farm holdings, and (d) Marginal farm holdings

The 500 ANN models developed using the 500 random sets was applied to the validation data set consisting of 100 data points which were not used either in the training or testing data set. The validation data set was also divided into different clusters in a similar fashion as was done in training and testing data sets. All the models performed relatively well in all the regions compared to the training and testing data sets, with relatively less variability in RMSE fig.4.16 Model performance was best for Kayal region with very less variability in large holding and marginal holdings group, while models performed well for Vaikom Kari in medium and small holdings. The performance of the models in the remaining four regions is similar in all the holdings. The r-square performance measure for different regions showed that Northern Kuttanad, Purakad Kari and Upper Kuttanad performed well in large holding farms with majority of the simulations having r –square closer to 1. While Kayal and Vaikom Kari had relatively less RMSE in large land holdings, the variability in r-square was found to be more. However, performance was good with less variability for both Kayal and Vaikom Kari for marginal and medium land holdings respectively. In small land holdings, models performed well in Purakad Kari region with r-square close to one.

In general, the models showed significant variability in performance in all the regions and for different land holdings. The variability in the performance of different models reflects the ANN model bias towards the training data set. One of the possible solutions to reduce the output variability of the models and development of a robust model is to develop individual models for each region and for different land holdings. However, to develop models for individual region and different land holdings, more data is required. To select a model from 500 models developed in this study, different methodologies are available for selecting the best model from ensemble like selecting the median or taking a weighted average etc. It can be concluded that no single ANN model can perform well in all the regions and different land holdings.

4.12. Suggestions for improving energy efficiency.

The one of the objective of this study is to suggest means for improving the energy efficiency. To improve the energy efficiency, the input energy should be reduced. In this study the input energies are human power, machinery, fertilizer, seed, diesel, chemical and electricity. Out of these, fertilizers, electricity and human power comes first, second and third respectively in energy consumption.

So in order to reduce the input energy to an extent we want to focus on these three energy inputs.

- Use of power drum seeder

  The human power is mostly used in the planting and thinning operations in Kuttanad region. For planting and thinning process the human energy used per ha is 368.2 hha^{-1}. By using a power drum seeder we can avoid the thinning out process in planting operation. So energy of around 288 hha^{-1} of human power in thinning out process can be reduced. It will reduce the human energy to around 75 per cent in planting operation thereby reducing around Rs.28,800.00 from human labour. This will improve energy efficiency and economic profit of the farmer.

- Use of fertilizers recommended in Package of Practices (PoP).

  There is a recommended level of fertilizer application for the paddy cultivation as per the package of practices recommendations crop (2016) in Kuttanad. By analyzing the amount of fertilizer using in the paddy field of Kuttanad during the survey, it is noted that the amount used is higher than the recommended level. By using the recommended level of fertilizers in the field can reduce the energy consumption and increase the energy efficiency. By using the recommended amount of fertilizer, the energy of around 4080

MJha^{-1} can be reduced from the total fertilizer input energy of 11554.78 MJha^{-1}. By reducing the energy it can also reduce the cost of production of farmers by an amount of around Rs.1,900.00 from each hectare of land from the total of Rs. 5,750.00 expend for fertilizer.

- Use of more efficient pump for water management.

Electricity is the one of the main factor which affects the input energy. The electricity is mainly used for the petti and para pump for water management activity. The efficiency of petti and para pump is only about 30 per cent. By adopting 10 per cent more efficient pumps the electrical energy consumption can be reduced by 25 per cent.

CHAPTER V

SUMMARY AND CONCLUSION

This study was conducted to investigate on energy input-output in below sea level rice production systems in Kuttanad region of Kerala. The study area selected belongs to below sea level paddy cultivating area coming under the three revenue districts namely Alappuzha, Kottayam and Pathanamthitta.

Sixteen Krishibhavans for the study were selected randomly such that, it will represent a minimum of 20 per cent among revenue districts and agro- ecological zones. Sixty four padasekarams were selected for study coming under different agro-ecological zones of Kuttanad such that a minimum of four active padasekarams each from selected Krishibhavans. Three farmers from each farm size group are selected from each padasekaram for the survey. A total of 731 farmers were surveyed for the data collection.

The survey was conducted through face to face interviewing with the farmers. The survey included personal details, machinery details and operational details.

The inputs used for the paddy cultivation are seeds, human power, plant protection chemicals, fertilizers, diesel, electricity, and machinery and the output is straw and paddy. The energy equivalent values of input and output were calculated and recorded.

The total energy consumption in different agro ecological zones was found to be varying between 23497.29 $MJha^{-1}$ to 32818.54 $MJha^{-1}$. The topmost total energy was consumed in the Purakad Kari and the lowest in Northern Kuttanad in the different agro-ecological zones.

The indirect source of energy was found to be used more than the direct source of energy in all the agro-ecological zones except in the Lower Kuttanad zone.

The non renewable energy is found to be used more than the renewable source of energy and commercial energy is found to be used more than the non commercial energy the in all the agro ecological zones.

The total energy consumption in different farm size groups were found to be varying between 19237.85 $MJha^{-1}$ to 42060.23 $MJha^{-1}$. The total energy consumed in the farm size group increases with the decrease in the farm size.

The indirect source of energy is found to be used more than the direct source of energy in all the farm size groups except the small size farm group.

The major unit operations of paddy cultivation are Land preparation, Seeding, Water management, Fertilizer and chemical application, and Harvesting.

Among the five units operation in paddy cultivation the Fertilizer and chemical application is the most energy consuming unit operation in all six agro ecological zones. In different unit operations except in water management shows uniform energy expenditure in different agro ecological zones.

Among the five unit operation in paddy cultivation in four farm size groups the fertilizer consumes the maximum energy as compared to the other operations and the harvesting consumes the less amount of energy among these five operations.

It consists of 43 per cent fertilizers, 18 per cent electricity, 17 per cent human power, 11 per cent fuel (diesel energy was mainly consumed for land preparation, harvesting), 7 per cent seed inputs, 2 per cent machinery and 1 per cent plant protection chemicals. The highest energy inputs are fertilizer and electricity.

The energy input pattern in all unit operations of different farm size groups shows a uniform pattern. It shows that the energy input decreases as the area of the holding increases.

The amount of net energy in Kuttanad region was approximately 87020.97 MJha^{-1}. The energy expenditure in Purakad Kari region is much higher than the other regions on Kuttanad. The marginal farm also shows a higher expenditure in energy than other farm size groups.

The energy productivity index of the rice cultivation in Kuttanad was found as 0.195. The higher energy productivity index was reported in Northern Kuttanad region among the different agro- ecological zones of Kuttanad. Among the farm groups large and medium farms shows higher energy productivity index.

The energy efficiency of the rice cultivation in Kuttanad was found as 4.20. The higher energy efficiency was reported in Northern Kuttanad region among the different agro- ecological zones of Kuttanad. Among the farm groups large and medium farms shows higher energy efficiency.

Specific energy which shows how much energy was used to produce one unit of the product. The present study found that 5.08 MJ energy was required to produce one kg of paddy in Kuttanad region. Among the agro-ecological zone it varies between 4.2 to 6.29 MJ and among the farm size group it varies in the range of 3.8 to 5.MJ.

Economic indices of each agro ecological zone and farm size are calculated. The Purakad Kari zone and small farm group's shows a higher gross and net profit. The Lower Kuttanad zone and medium farm group's shows a lesser gross and net profit in Kuttanad region. The Northern Kuttanad and marginal farm groups shows higher productivity and benefit cost ratio in Kuttanad region and Lower Kuttanad and medium farm groups shows lesser productivity and benefit cost ratio in Kuttanad region.

ANN modeling is done on the data collected to find out the changes occurring in zone wise and farm size wise and find out that all the models performed relatively well in all the regions compared to the training and testing data sets, with relatively less variability in RMSE. Model performance was best for Kayal region with very less variability in large holding and marginal holdings group, while models performed well for Vaikom Kari in medium and small holdings. The performance of the models in the remaining four regions is similar in all the holdings. The r-square performance measure for different regions showed that Northern Kuttanad, Purakad Kari and Upper Kuttanad performed well in large holding farms with majority of the simulations having r^2 closer to 1. While Kayal and Vaikom Kari had relatively less RMSE in large land holdings, the variability in r-square was found to be more. However, performance was good with less variability for both Kayal and Vaikom Kari for marginal and medium land holdings respectively. In small land holdings, models performed well in Purakad Kari region with r-square close to one.

Suggestions are made to improve the energy efficiency of the region during this study and they are using power drum seeder, application of fertilizers as per recommendation of the KAU pop and increasing the efficiency of the pump used for water management.

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APPENDIX I

QUESTIONNAIRE

Farmers Details

Name	
Address	
Phone number	
Area of cultivation	
Owned/ Hired	
Padasekharam	
KrishiBhavan	

Machinery Used

SL no	Equipment/ Machinery	Make	Capacity (HP)	Power source (Type)	Type of Fuel	Fuel consumed (per hr) .
1	Tractor					
2	Power tiller					
3	Tillage attachments					
4	Seeders/ planter					
5	Pump for Dewatering					

Operation Details

Sl no	Unit operations	Human	Machine	Diesel	Electricity	Chemicals	Seeds (kg)	Time tak (hrs)
6	Spraying							
7	Harvesting							
8	Threshing							
9	Winnowing							
10	Combine Harvester							

		Men	Women						
1	Cleaning								
2	Wet ploughing								
3	Lime application								
4	Outer bund repair								
5	Dewatering								
6	Inner bund repair								
7	Water intake								
8	Sowing /planting /Broadcasting								
9	Dewatering								
10	Water intake								
11	Fertilizer application								
12	Weedicide application								
13	Tinned out								
14	Fertilizer application								
15	Dewatering								
16	Fertilizer application								
17	Water intake								
18	Dewatering								
19	Water intake								
20	Dewatering								
21	Harvest								

22	Threshing								
23	Winnowing								
24	Combine harvester								

APPENDIX II

Calculation of input energies

Energy equivalents = Observed data from survey x energy co efficient values

Output	**Human labour**	**Machinery**	**diesel**	**Fertilizer**	**Chemicals**	**seed**	**Electricity**
93219.88	1703.719	210.5049	1038.273	6946.776	314.9487	1315.833	4137.407
85906.71	1573.174	221.3146	1078.207	6524.842	378.9487	1138.702	4393
86715.6	2142.371	340.3541	1168.057	7815.123	336.9487	1480.312	8335.436
99233.57	1212.24	169.8921	584.0286	7100.176	326.9487	1233.593	4157.588
99233.57	1212.24	169.8921	584.0286	7153.542	327.9487	986.8747	4157.588
105945.7	1976.877	191.7192	1274.244	7711.177	429.9487	1614.886	2709.017
84605.09	1043.654	128.0981	637.1221	7745.647	368.9487	1345.738	2500.631
84605.09	2036.618	231.8974	1274.244	7711.177	315.9487	1345.738	4137.407
89255.6	2069.023	330.2711	1401.669	8482.294	452.9487	1480.312	7224.044
89255.6	2176.556	318.8106	1201.43	7388.621	453.9487	1480.312	7224.044
107868.7	2200.453	304.8711	1401.669	8482.294	440.9487	1776.374	6321.039
89255.6	2200.453	304.8711	1401.669	8482.294	441.9487	1480.312	6321.039
89255.6	2168.591	191.8106	1201.43	7388.621	428.9487	1480.312	2709.017

111678.7	2995.005	204.0487	1401.669	8482.294	420.9487	1480.312	2736.66
111678.7	2989.031	192.5882	1201.43	7295.373	421.9487	1480.312	2736.66
89255.6	2260.194	254.0711	1401.669	8482.294	399.9487	1480.312	4515.028
89255.6	2200.453	254.0711	1401.669	8482.294	400.9487	1480.312	4515.028
89255.6	1134.08	185.4556	700.8343	8520.212	389.9487	1480.312	4334.427
89255.6	1985.386	248.9911	1401.669	8482.294	390.9487	1480.312	4334.427
111678.7	2045.127	250.6387	1401.669	8482.294	379.9487	1480.312	4393
107868.7	2475.26	308.6064	1401.669	8482.294	358.9487	1480.312	6453.834
91160.6	2415.52	308.6064	1401.669	8482.294	359.9487	1480.312	6453.834
89255.6	2260.194	236.7991	1401.669	8482.294	348.9487	1480.312	3900.984
89255.6	2200.453	236.7991	1401.669	8482.294	349.9487	1480.312	3900.984
89255.6	2511.105	361.5327	1401.669	8482.294	337.9487	1480.312	8335.436
93065.6	2304.004	244.017	1401.669	8482.294	328.9487	1480.312	4157.588
78491.64	2444.948	318.9901	1557.409	9424.772	442.9487	1315.833	6321.039
119854.1	2444.948	238.172	1557.409	9424.772	409.9487	1973.749	3447.839
99172.89	2444.948	238.172	1557.409	9424.772	410.9487	1644.791	3447.839
78491.64	2444.948	238.172	1557.409	9424.772	411.9487	1315.833	3447.839
124087.5	2272.363	264.7577	1557.409	9424.772	380.9487	1644.791	4393
93065.6	1275.577	140.9335	778.7047	9538.056	370.9487	1315.833	2500.631
90948.93	2790.117	375.6517	1557.409	9424.772	338.9487	1480.312	8335.436
93065.6	2489.2	257.5683	1557.409	9424.772	316.9487	1480.312	4137.407

89890.6	2731.897	378.9617	1877.235	9919.322	454.9487	1480.312	7224.044
89890.6	2721.94	251.9617	1877.235	9919.322	430.9487	1480.312	2709.017
107080.1	3747.491	252.7392	1877.235	9919.322	422.9487	1480.312	2736.66
89573.1	2638.552	271.5133	1501.788	8552.231	401.9487	1480.312	4515.028
89890.6	1435.024	201.3395	876.0428	10730.31	391.9487	1480.312	4334.427
116332	2481.732	229.1774	1752.086	10602.87	369.9487	1850.39	2500.631
89573.1	2638.552	254.2413	1501.788	8552.231	350.9487	1480.312	3900.984
89573.1	2623.617	378.9748	1501.788	8552.231	339.9487	1480.312	8335.436
88529.89	2717.495	313.9476	1501.788	11518.11	443.9487	1480.312	6321.039
88529.89	2717.495	233.1294	1501.788	11518.11	412.9487	1480.312	3447.839
102369.3	3288.589	346.6934	1716.329	9773.978	360.9487	1691.785	6453.834
87078.46	3161.284	370.6092	1501.788	11518.11	340.9487	1480.312	8335.436
93065.6	2774.391	252.5258	1501.788	11518.11	318.9487	1480.312	4137.407
76504.8	2774.391	252.5258	1501.788	11518.11	319.9487	1268.839	4137.407
89255.6	3269.979	362.0389	1752.086	13437.79	455.9487	1480.312	7224.044
86715.6	1717.548	309.0926	1168.057	6205.474	456.9487	740.156	7224.044
89255.6	3170.411	336.6389	1752.086	13437.79	444.9487	1480.312	6321.039
89255.6	3276.617	235.0389	1752.086	13437.79	431.9487	1480.312	2709.017
89255.6	4663.931	235.8165	1752.086	13437.79	423.9487	1480.312	2736.66
89255.6	3170.411	255.8207	1752.086	13437.79	413.9487	1480.312	3447.839
89255.6	3170.411	285.8389	1752.086	13437.79	402.9487	1480.312	4515.028

94758.93	3159.625	314.6044	2002.384	11402.97	392.9487	1480.312	4334.427
114926.5	2911.534	282.4065	1752.086	13437.79	381.9487	1480.312	4393
99415.6	3159.625	263.0229	2002.384	11402.97	371.9487	1480.312	2500.631
89255.6	3528.856	340.3742	1752.086	13437.79	361.9487	1480.312	6453.834
89255.6	3170.411	268.5669	1752.086	13437.79	351.9487	1480.312	3900.984
89255.6	3688.165	393.3004	1752.086	13437.79	341.9487	1480.312	8335.436
94758.93	3670.74	309.6302	2002.384	11402.97	329.9487	1480.312	4157.588
119430.8	3020.229	309.0626	2002.384	11402.97	317.9487	1973.749	4137.407
105563.4	3481.123	387.2206	2833.562	15876.08	394.9487	1536.173	4334.427
105563.4	4059.744	382.2464	2833.562	15876.08	331.9487	1536.173	4157.588
104058.7	2061.058	330.2711	1401.669	7446.569	459.9487	888.1872	7224.044
98907.6	3982.72	409.0213	2402.86	8482.294	447.9487	1480.312	6321.039
98907.6	3982.72	328.2031	2402.86	8482.294	416.9487	1480.312	3447.839
91478.1	3446.048	317.6067	2102.503	11169.85	403.9487	1480.312	4515.028
91478.1	3446.048	317.6067	2102.503	11169.85	404.9487	1480.312	4515.028
137911.8	3493.841	314.1742	2102.503	16125.35	384.9487	1776.374	4393
91478.1	3876.182	372.142	2102.503	11169.85	362.9487	1480.312	6453.834
91478.1	3876.182	372.142	2102.503	11169.85	363.9487	1480.312	6453.834
91478.1	3446.048	300.3347	2102.503	11169.85	352.9487	1480.312	3900.984
91478.1	3446.048	300.3347	2102.503	11169.85	353.9487	1480.312	3900.984
111569.5	2576.322	362.0389	1752.086	8130.115	457.9487	1110.234	7224.044

98507.55	2501.646	362.0389	1752.086	8130.115	458.9487	1110.234	7224.044
89890.6	2329.891	399.1356	2502.98	9119.216	445.9487	1480.312	6321.039
89890.6	2329.891	399.1356	2502.98	9119.216	446.9487	1480.312	6321.039
94697.55	2568.854	235.0389	1752.086	8130.115	432.9487	1480.312	2709.017
94697.55	2506.624	235.0389	1752.086	8130.115	433.9487	1480.312	2709.017
89890.6	2329.891	318.3174	2502.98	9119.216	414.9487	1480.312	3447.839
89890.6	2329.891	318.3174	2502.98	9119.216	415.9487	1480.312	3447.839
96875.6	4068.597	360.1784	2628.128	16855.52	393.9487	1480.312	4334.427
130619.5	3469.945	412.5942	3003.575	13787.48	382.9487	1480.312	4393
25126.95	2688.336	344.9032	2502.98	9119.216	383.9487	1480.312	4393
139871.5	4612.488	421.8618	3754.469	21035.81	372.9487	2035.429	2500.631
102590.6	4068.597	308.5968	2628.128	16855.52	373.9487	1480.312	2500.631
89890.6	3046.781	455.7971	2502.98	9119.216	342.9487	1480.312	8335.436
89890.6	3046.781	455.7971	2502.98	9119.216	343.9487	1480.312	8335.436
96875.6	4865.141	355.2042	2628.128	16855.52	330.9487	1480.312	4157.588
89890.6	2329.891	337.7138	2502.98	9119.216	320.9487	1480.312	4137.407
89890.6	2329.891	337.7138	2502.98	9119.216	321.9487	1480.312	4137.407
87027.66	3299.968	356.0377	3432.658	8243.94	374.9487	1268.839	2500.631
131343.4	3169.581	414.9852	2336.114	9191.65	461.9487	1480.312	7224.044
89255.6	2817.774	389.5852	2336.114	9424.772	448.9487	1480.312	6321.039
99051.53	3026.867	287.9852	2336.114	9128.455	436.9487	1480.312	2709.017

99051.53	3026.867	287.9852	2336.114	5390.659	437.9487	1480.312	2709.017
89255.6	5844.642	288.7628	2336.114	10840.15	424.9487	1480.312	2736.66
89255.6	5844.642	288.7628	2336.114	10840.15	425.9487	1480.312	2736.66

APPENDIX III

Operation wise energy equivalents

Seed bed preparation	Fertilizer	Planting	Harvesting	Water management
1252.69037	7291.226	1846.862	509.5691556	4767.11383
1178.325538	6934.427	1690.155	529.1679692	4976.112205
1376.087333	8185.261	2077.72	573.2653	9406.268677
546.989	7443.72	1499.108	286.63265	5008.018199
546.989	7498.085	1252.389	286.63265	5008.018199
1401.618182	8177.332	2266.604	625.3803273	3436.934498
596.7152727	8132.699	1635.391	312.6901636	3092.343498
1483.082909	8063.332	1997.456	625.3803273	4883.779366
1501.9528	8975.07	2083.694	687.91836	8191.92672
1288.2626	7878.414	2197.202	687.91836	8191.92672
1591.564	8963.07	2493.264	687.91836	7191.8322
1591.564	8964.07	2197.202	687.91836	7191.8322
1328.0898	7853.414	2197.202	687.91836	3502.10628
1501.9528	8943.07	2197.202	687.91836	4390.794378
1288.2626	7753.166	2197.202	687.91836	4390.794378
1651.3048	8922.07	2197.202	687.91836	5335.02108
1591.564	8923.07	2197.202	687.91836	5335.02108
656.3868	8930.074	1784.99	343.95918	5029.858368
1591.564	8913.07	2077.72	687.91836	5053.754688
1531.8232	8902.07	2197.202	687.91836	5113.975589
1651.3048	8881.07	2197.202	687.91836	7543.429309
1591.564	8882.07	2197.202	687.91836	7543.429309
1651.3048	8871.07	2197.202	687.91836	4703.705299
1591.564	8872.07	2197.202	687.91836	4703.705299
1591.564	8860.07	2197.202	687.91836	9573.542917

1591.564	8851.07	2077.72	687.91836	5190.559533
1768.404444	9911.973	2112.377	764.3537333	7268.831453
1768.404444	9878.973	2770.293	764.3537333	4314.813762
1768.404444	9879.973	2441.335	764.3537333	4314.813762
1768.404444	9880.973	2112.377	764.3537333	4314.813762
1702.025778	9849.973	2441.335	764.3537333	5180.354256
729.3186667	9931.131	1669.852	382.1768667	3208.204443
1768.404444	9807.973	2276.856	764.3537333	9685.059077
1812.656889	9785.973	2276.856	764.3537333	5023.778008
1877.441	10426.54	2376.424	1003.214275	8383.09728
1927.225	10402.54	2376.424	1003.214275	3681.32868
1877.441	10394.54	2376.424	1003.214275	4785.083658
1647.66625	8998.985	2376.424	859.89795	5478.399
820.4835	11147.15	1878.584	429.948975	5173.236288
1989.455	11022.6	2597.15	859.89795	3317.729243
1647.66625	8947.985	2376.424	859.89795	4847.083219
1647.66625	8936.985	2003.044	859.89795	9764.713477
1655.463143	12013.26	2402.027	737.0553857	7488.82932
1655.463143	11982.26	2402.027	737.0553857	4534.811629
1883.047143	10186.13	2715.913	982.7405143	7864.322749
1655.463143	11910.26	2402.027	737.0553857	10003.67668
1712.359143	11888.26	2402.027	737.0553857	5243.775875
1712.359143	11889.26	2190.554	737.0553857	5243.775875
1831.805667	13953.48	2555.646	859.89795	8781.36928
828.4633333	6695.612	1022.265	573.2653	8701.71488
1931.373667	13942.48	2555.646	859.89795	7653.82772
1898.184333	13929.48	2575.56	859.89795	4059.68708
1831.805667	13921.48	2555.646	859.89795	5561.714058
1931.373667	13911.48	2555.646	859.89795	4699.810029
1931.373667	13900.48	2555.646	859.89795	5797.0166
2196.888333	11855.66	2475.992	1146.5306	5412.199488
1831.805667	13879.48	2555.646	859.89795	5512.247589
2196.888333	11834.66	2475.992	1146.5306	3526.822043
1931.373667	13859.48	2555.646	859.89795	8148.802749
1931.373667	13849.48	2555.646	859.89795	5165.700819
1931.373667	13839.48	2555.646	859.89795	10242.63988

2196.888333	11792.66	2475.992	1146.5306	5741.502466
2196.888333	11780.66	2670.725	1146.5306	5368.947075
3002.950943	16349.93	2437.921	1514.285698	5538.444197
3002.950943	16286.93	2437.921	1514.285698	5935.253027
994.156	7946.345	1226.718	687.91836	8956.60896
2636.266	9001.932	2675.128	1375.83672	7837.03284
2636.266	8970.932	2675.128	1375.83672	4883.015149
1959.2036	11645.49	2770.713	1031.87754	6028.01436
1959.2036	11646.49	2770.713	1031.87754	6028.01436
2198.1668	16581.99	3066.776	1031.87754	5711.383589
1959.2036	11604.49	2770.713	1031.87754	8451.489469
1959.2036	11605.49	2770.713	1031.87754	8451.489469
1959.2036	11594.49	2770.713	1031.87754	5396.698579
1959.2036	11595.49	2770.713	1031.87754	5396.698579
1242.695	8637.847	1533.398	859.89795	9338.95008
1242.695	8638.847	1458.722	859.89795	9338.95008
1801.8125	9624.905	1853.692	1146.5306	8171.58132
1801.8125	9625.905	1853.692	1146.5306	8171.58132
1354.709	8612.847	1903.476	859.89795	4577.44068
1317.371	8613.847	1878.584	859.89795	4577.44068
1801.8125	9593.905	1853.692	1146.5306	5217.563629
1801.8125	9594.905	1853.692	1146.5306	5217.563629
2897.0605	17339.08	2645.258	1289.846925	5949.866688
2399.2205	14260.04	2600.452	1719.7959	5950.346789
1801.8125	9562.905	2451.1	1146.5306	5950.346789
3978.91	21513.31	3230.245	2006.42855	4004.748443
2897.0605	17319.08	2645.258	1289.846925	4064.489243
1801.8125	9521.905	1853.692	1146.5306	10959.52948
1801.8125	9522.905	1853.692	1146.5306	10959.52948
2897.0605	17276.08	2645.258	1289.846925	6564.597933
1801.8125	9499.905	1853.692	1146.5306	5926.527875
1801.8125	9500.905	1853.692	1146.5306	5926.527875
3466.301714	8698.543	1724.007	1310.320686	4277.849243
1590.548	9719.978	1845.395	1146.5306	9976.18528
1656.926667	9940.099	1745.827	1146.5306	8729.16212
1640.332	9631.783	1812.205	1146.5306	5174.84868

1640.332	5894.986	1812.205	1146.5306	5174.84868
1656.926667	11331.48	1745.827	1146.5306	8070.827658
1656.926667	11332.48	1745.827	1146.5306	8070.827658

APPENDIX IV

Energy classification.

Direct energy	**Indirect energy**	**Renewable energy**	**Non renewable energy**	**Commercial energy**	**Non commerci energy**
6879.399382	8788.062	3019.552	12647.90974	12647.90974	3019.552
7044.380975	8263.807	2711.875938	12596.31175	12596.31175	2711.875938
11645.86451	9972.738	3622.683467	17995.91869	17995.91869	3622.683467
5953.857049	8830.61	2445.833733	12338.63379	12338.63379	2445.833733
5953.857049	8638.257	2199.115067	12392.99919	12392.99919	2199.115067
5960.138171	9947.73	3591.7632	12316.10546	12316.10546	3591.7632
4181.406509	9588.432	2389.391855	11380.44648	11380.44648	2389.391855
7448.269584	9604.761	3382.356364	13670.67426	13670.67426	3382.356364
10694.73604	10745.83	3549.33504	17891.22727	17891.22727	3549.33504
10602.03112	9641.693	3656.86848	16586.85523	16586.85523	3656.86848
9923.16024	11004.49	3976.8272	16950.82171	16950.82171	3976.8272
9923.16024	10709.43	3680.7648	16951.82171	16951.82171	3680.7648
6079.03788	9489.693	3648.90304	11919.82743	11919.82743	3648.90304
7133.333667	10587.6	4475.31744	13245.62005	13245.62005	4475.31744
6927.121227	9390.222	4469.34336	11847.99953	11847.99953	4469.34336
8176.88992	10616.63	3740.5056	15053.01059	15053.01059	3740.5056
8117.14912	10617.63	3680.7648	15054.01059	15054.01059	3680.7648
6169.340468	10575.93	2614.39152	14130.87678	14130.87678	2614.39152
7721.481128	10602.55	3465.69792	14858.32948	14858.32948	3465.69792
7839.795262	10593.19	3525.43872	14907.55038	14907.55038	3525.43872
10330.76286	10630.16	3955.57248	17005.35194	17005.35194	3955.57248
10271.02206	10631.16	3895.83168	17006.35194	17006.35194	3895.83168
7562.846139	10548.35	3740.5056	14370.69481	14370.69481	3740.5056
7503.105339	10549.35	3680.7648	14371.69481	14371.69481	3680.7648
12248.20942	10662.09	3991.41696	18918.88027	18918.88027	3991.41696
7863.260139	10535.57	3784.31552	14614.51672	14614.51672	3784.31552

10323.39594	11502.54	3760.780444	18065.15883	18065.15883	3760.780444
7450.196433	12046.64	4418.696889	15078.14114	15078.14114	4418.696889
7450.196433	11718.68	4089.738667	15079.14114	15079.14114	4089.738667
7450.196433	11390.73	3760.780444	15080.14114	15080.14114	3760.780444
8222.772511	11715.27	3917.154133	16020.8875	16020.8875	3917.154133
4554.912226	11365.77	2591.4096	13329.27335	13329.27335	2591.4096
12682.96203	11619.68	4270.428622	20032.21739	20032.21739	4270.428622
8184.01676	11479.6	3969.512	15694.10539	15694.10539	3969.512
11833.17611	12233.54	4212.209	19854.51177	19854.51177	4212.209
7308.191505	12082.54	4202.2522	15188.48397	15188.48397	4202.2522
8361.384932	12075.32	5227.8026	15208.90454	15208.90454	5227.8026
8655.3675	10706	4118.864	15242.50831	15242.50831	4118.864
6645.493313	12803.91	2915.3358	16534.07022	16534.07022	2915.3358
6734.448832	13052.38	4332.1224	15454.71055	15454.71055	4332.1224
8041.323719	10637.73	4118.864	14560.19253	14560.19253	4118.864
12460.84044	10751.47	4103.9288	19108.37799	19108.37799	4103.9288
10540.32182	13756.32	4197.8072	20098.83193	20098.83193	4197.8072
7667.122311	13644.5	4197.8072	17113.81424	17113.81424	4197.8072
11458.75146	12173.41	4980.373943	18651.78277	18651.78277	4980.373943
12998.50764	13709.98	4641.596	22066.89049	22066.89049	4641.596
8413.586193	13569.9	4254.7032	17728.77849	17728.77849	4254.7032
8413.586193	13359.42	4043.230057	17729.77849	17729.77849	4043.230057
12246.1092	15736.09	4750.291067	23231.91154	23231.91154	4750.291067
10109.64958	7711.671	2457.704	15363.61689	15363.61689	2457.704
11243.53564	15699.69	4650.723067	22292.50598	22292.50598	4650.723067
7737.719263	15585.09	4756.928933	18565.88374	18565.88374	4756.928933
9152.676424	15577.87	6144.243067	18586.30432	18586.30432	6144.243067
8370.336128	15587.88	4650.723067	19307.48829	19307.48829	4650.723067
9437.524517	15606.89	4650.723067	20393.69486	20393.69486	4650.723067
9496.434821	13590.84	4639.936533	18447.3378	18447.3378	4639.936533
9056.619938	15582.46	4391.846267	20247.23465	20247.23465	4391.846267
7662.638915	13518.26	4639.936533	16540.96035	16540.96035	4639.936533
11734.77537	15620.43	5009.167867	22346.03621	22346.03621	5009.167867
8823.480736	15538.62	4650.723067	19711.37908	19711.37908	4650.723067
13775.68626	15653.35	5168.476667	24260.56454	24260.56454	5168.476667
9830.711966	13522.87	5151.052267	18202.52504	18202.52504	5151.052267

9160.020226	14003.74	4993.978667	18169.77659	18169.77659	4993.978667
10649.1111	18194.43	5017.295547	23826.2408	23826.2408	5017.295547
11050.8941	18126.45	5595.917132	23581.42804	23581.42804	5595.917132
10686.7706	9124.976	2949.2448	16862.50163	16862.50163	2949.2448
12706.61924	10819.58	5463.032	18063.16367	18063.16367	5463.032
9833.419731	10707.76	5463.032	15078.14598	15078.14598	5463.032
10063.57906	13371.72	4926.36048	18508.93917	18508.93917	4926.36048
10063.57906	13372.72	4926.36048	18509.93917	18509.93917	4926.36048
9989.343922	18600.85	5270.21552	23319.97832	23319.97832	5270.21552
12432.51888	13385.26	5356.49424	20461.28052	20461.28052	5356.49424
12432.51888	13386.26	5356.49424	20462.28052	20462.28052	5356.49424
9449.535279	13303.45	4926.36048	17826.62339	17826.62339	4926.36048
9449.535279	13304.45	4926.36048	17827.62339	17827.62339	4926.36048
11552.45213	10060.34	3686.556	17926.23229	17926.23229	3686.556
11477.77613	10061.34	3611.88	17927.23229	17927.23229	3611.88
11153.90962	11444.61	3810.2032	18788.31868	18788.31868	3810.2032
11153.90962	11445.61	3810.2032	18789.31868	18789.31868	3810.2032
7029.95673	10278.41	4049.1664	13259.20449	13259.20449	4049.1664
6967.72673	10279.41	3986.9364	13260.20449	13260.20449	3986.9364
8280.710111	11332.79	3810.2032	15803.30099	15803.30099	3810.2032
8280.710111	11333.79	3810.2032	15804.30099	15804.30099	3810.2032
11031.15256	19089.96	5548.9094	24572.20477	24572.20477	5548.9094
10866.52022	16063.33	4950.2568	21979.5939	21979.5939	4950.2568
9584.315522	11328.38	4168.648	16744.04735	16744.04735	4168.648
10867.58763	23866.05	6647.9166	28085.7206	28085.7206	6647.9166
9197.356657	19018.38	5548.9094	22666.82733	22666.82733	5548.9094
13885.19624	11398.27	4527.0928	20756.37724	20756.37724	4527.0928
13885.19624	11399.27	4527.0928	20757.37724	20757.37724	4527.0928
11650.85797	19021.99	6345.4534	24327.39202	24327.39202	6345.4534
8970.277993	11258.19	3810.2032	16418.26524	16418.26524	3810.2032
8970.277993	11259.19	3810.2032	16419.26524	16419.26524	3810.2032
9233.256382	10243.77	4568.806857	14908.21487	14908.21487	4568.806857
12729.74001	11548.9	4649.893333	19628.74299	19628.74299	4649.893333
11474.92752	11743.62	4298.0864	18920.45863	18920.45863	4298.0864
8071.99808	11333.7	4507.1792	14898.51999	14898.51999	4507.1792
8071.99808	7596.905	4507.1792	11161.72372	11161.72372	4507.1792

10917.41551	13034.18	7324.9536	16626.6381	16626.6381	7324.9536
10917.41551	13035.18	7324.9536	16627.6381	16627.6381	7324.9536

APPENDIX V

Energy requirement in each operation.

Human Power h/ Ha					**Machine Power h/ Ha**		
land Preparation	**planting**	**water treatment**	**Fertilizer**	**harvesting**	**land Preparation**	**water treatment**	**harvesting**
319.0993	270.9333	10.71418	6.773333	2.257778	3.01037	6.650182	2.257778
268.8492	281.3538	13.72973	7.033846	2.344615	3.126154	8.787027	2.344615
342.0533	304.8	49.23692	7.62	2.54	3.386667	32.82462	2.54
99.06	135.4667	37.42267	3.81	1.27	1.693333	24.80733	1.27
99.06	135.4667	37.42267	3.81	1.27	1.693333	24.80733	1.27
322.3491	332.5091	40.64	8.312727	2.770909	3.694545	31.15733	2.770909
108.0655	147.7818	4.501662	4.156364	1.385455	1.847273	3.001108	1.385455
363.9127	332.5091	10.71418	8.312727	2.770909	3.694545	6.650182	2.770909
334.264	307.848	81.28	9.144	3.048	4.064	60.96	3.048
333.248	365.76	81.28	9.144	3.048	3.048	60.96	3.048
379.984	365.76	58.928	9.144	3.048	4.064	36.576	3.048
379.984	365.76	58.928	9.144	3.048	4.064	36.576	3.048
353.568	365.76	40.64	9.144	3.048	3.048	31.15733	3.048
334.264	365.76	4.105469	9.144	3.048	4.064	2.799184	3.048
333.248	365.76	4.105469	9.144	3.048	3.048	2.799184	3.048
410.464	365.76	42.09143	9.144	3.048	4.064	26.12571	3.048

379.984	365.76	42.09143	9.144	3.048	4.064	26.12571	3.048
118.872	155.448	24.384	4.572	1.524	2.032	16.256	1.524
379.984	304.8	25.4	9.144	3.048	4.064	16.256	3.048
349.504	365.76	13.72973	9.144	3.048	4.064	8.787027	3.048
410.464	365.76	17.03294	9.144	3.048	4.064	11.65412	3.048
379.984	365.76	17.03294	9.144	3.048	4.064	11.65412	3.048
410.464	365.76	10.10194	9.144	3.048	4.064	6.270171	3.048
379.984	365.76	10.10194	9.144	3.048	4.064	6.270171	3.048
379.984	365.76	49.23692	9.144	3.048	4.064	32.82462	3.048
379.984	304.8	38.94667	9.144	3.048	4.064	24.80733	3.048
422.2044	406.4	58.928	10.16	3.386667	4.515556	36.576	3.386667
422.2044	406.4	32.14255	10.16	3.386667	4.515556	19.95055	3.386667
422.2044	406.4	32.14255	10.16	3.386667	4.515556	19.95055	3.386667
422.2044	406.4	32.14255	10.16	3.386667	4.515556	19.95055	3.386667
388.3378	406.4	13.72973	10.16	3.386667	4.515556	8.787027	3.386667
132.08	180.6222	4.501662	5.08	1.693333	2.257778	3.001108	1.693333
422.2044	406.4	49.23692	10.16	3.386667	4.515556	32.82462	3.386667
444.7822	406.4	10.71418	10.16	3.386667	4.515556	6.650182	3.386667
417.83	457.2	81.28	11.43	4.445	5.08	60.96	4.445
443.23	457.2	40.64	11.43	4.445	5.08	31.15733	4.445
417.83	457.2	4.105469	11.43	4.445	5.08	2.799184	4.445
435.61	457.2	40.64	11.43	3.81	3.81	26.1257	3.81

						1	
148.59	203.2	24.384	5.715	1.905	2.54	16.256	1.905
474.98	381	4.689231	11.43	3.81	5.08	3.001108	3.81
435.61	457.2	9.7536	11.43	3.81	3.81	6.270171	3.81
435.61	266.7	46.89231	11.43	3.81	3.81	32.82462	3.81
381.7257	470.2629	58.928	13.06286	3.265714	4.354286	36.576	3.265714
381.7257	470.2629	32.14255	13.06286	3.265714	4.354286	19.95055	3.265714
497.84	522.5143	16.13647	13.06286	4.354286	4.354286	11.65412	4.354286
381.7257	470.2629	49.23692	13.06286	3.265714	4.354286	32.82462	3.265714
410.7543	470.2629	10.71418	13.06286	3.265714	4.354286	6.650182	3.265714
410.7543	470.2629	10.71418	13.06286	3.265714	4.354286	6.650182	3.265714
394.5467	548.64	86.36	15.24	3.81	5.08	60.96	3.81
62.65333	143.9333	81.28	7.62	2.54	3.386667	60.96	2.54
445.3467	548.64	58.928	15.24	3.81	5.08	36.576	3.81
428.4133	558.8	43.34933	15.24	3.81	5.08	31.15733	3.81
394.5467	548.64	4.292082	15.24	3.81	5.08	2.799184	3.81
445.3467	548.64	32.14255	15.24	3.81	5.08	19.95055	3.81
445.3467	548.64	42.09143	15.24	3.81	5.08	26.12571	3.81
580.8133	508	24.384	15.24	5.08	5.08	16.256	5.08
394.5467	548.64	13.72973	15.24	3.81	5.08	8.787027	3.81
580.8133	508	4.501662	15.24	5.08	5.08	3.001108	5.08
445.3467	548.64	17.03294	15.24	3.81	5.08	11.65412	3.81
445.3467	548.64	10.10194	15.24	3.81	5.08	6.270171	3.81

445.3467	548.64	49.23692	15.24	3.81	5.08	32.82462	3.81
580.8133	508	37.42267	15.24	5.08	5.08	24.80733	5.08
580.8133	355.6	10.34473	15.24	5.08	5.08	6.650182	5.08
716.9509	460.0755	24.384	17.25283	6.709434	7.667925	16.256	6.709434
716.9509	460.0755	37.42267	17.25283	6.709434	7.667925	24.80733	6.709434
75.184	172.72	81.28	9.144	3.048	4.064	60.96	3.048
696.976	609.6	56.896	18.288	6.096	6.096	36.576	6.096
696.976	609.6	31.03418	18.288	6.096	6.096	19.95055	6.096
351.536	658.368	42.09143	18.288	4.572	6.096	26.12571	4.572
351.536	658.368	42.09143	18.288	4.572	6.096	26.12571	4.572
473.456	658.368	13.72973	18.288	4.572	6.096	8.787027	4.572
351.536	658.368	17.03294	18.288	4.572	6.096	11.65412	4.572
351.536	658.368	17.03294	18.288	4.572	6.096	11.65412	4.572
351.536	658.368	10.10194	18.288	4.572	6.096	6.270171	4.572
351.536	658.368	10.10194	18.288	4.572	6.096	6.270171	4.572
93.98	215.9	81.28	11.43	3.81	5.08	60.96	3.81
93.98	177.8	81.28	11.43	3.81	5.08	60.96	3.81
109.22	190.5	56.896	15.24	5.08	7.62	36.576	5.08
109.22	190.5	56.896	15.24	5.08	7.62	36.576	5.08
151.13	215.9	40.64	11.43	3.81	5.08	31.15733	3.81
132.08	203.2	40.64	11.43	3.81	5.08	31.15733	3.81
109.22	190.5	31.03418	15.24	5.08	7.62	19.95055	5.08
109.22	190.5	31.03418	15.24	5.08	7.62	19.95055	5.08
668.02	594.36	25.4	22.86	5.715	7.62	16.256	5.715

414.02	571.5	13.18054	22.86	7.62	7.62	8.787027	7.62
109.22	495.3	13.18054	15.24	5.08	7.62	8.787027	5.08
949.96	609.6	4.501662	22.86	8.89	10.16	3.001108	8.89
668.02	594.36	4.689231	22.86	5.715	7.62	3.001108	5.715
109.22	190.5	46.89231	15.24	5.08	7.62	32.82462	5.08
109.22	190.5	46.89231	15.24	5.08	7.62	32.82462	5.08
668.02	594.36	38.94667	22.86	5.715	7.62	24.80733	5.715
109.22	190.5	10.34473	15.24	5.08	7.62	6.650182	5.08
109.22	190.5	10.34473	15.24	5.08	7.62	6.650182	5.08
534.1257	232.2286	4.689231	17.41714	5.805714	11.61143	3.001108	5.805714
91.44	186.2667	81.28	15.24	5.08	6.773333	60.96	5.08
125.3067	135.4667	56.896	15.24	5.08	6.773333	36.576	5.08
116.84	169.3333	40.64	15.24	5.08	6.773333	31.15733	5.08
116.84	169.3333	40.64	15.24	5.08	6.773333	31.15733	5.08
125.3067	135.4667	4.105469	15.24	5.08	6.773333	2.799184	5.08
125.3067	135.4667	4.105469	15.24	5.08	6.773333	2.799184	5.08

APPENDIX VI

Energy requirement in each operation.

Diesl l/ Ha		fertilizer kg/ Ha			Cemicals kg/ Ha		Electricity Kwh/Ha
land Preparation	**harvesting**	**P**	**N**	**K**	**Lime Kg/ha**	**pesticide l/ha**	**water treatment**
10.5363	7.902222	146.7556	188.1481	146.7556	254	0.225778	445.8946909
10.94154	8.206154	140.6769	175.8462	140.6769	195.3846	0.195385	490.9751351
11.85333	8.89	165.1	211.6667	165.1	254	0.254	978.1735385
5.926667	4.445	152.4	190.5	165.1	254	0.211667	462.0365833
5.926667	4.445	165.1	190.5	152.4	254	0.169333	462.0365833
12.93091	9.698182	166.2545	207.8182	166.2545	277.0909	0.277091	348.1832
6.465455	4.849091	166.2545	207.8182	180.1091	207.8182	0.230909	279.4781538
12.93091	9.698182	166.2545	207.8182	166.2545	230.9091	0.230909	445.8946909
14.224	10.668	182.88	228.6	182.88	254	0.3048	908.304
10.668	10.668	162.56	198.12	162.56	254	0.24384	908.304
14.224	10.668	182.88	228.6	182.88	304.8	0.3048	681.228
14.224	10.668	182.88	228.6	182.88	254	0.254	681.228
10.668	10.668	162.56	198.12	162.56	254	0.24384	348.1832
14.224	10.668	182.88	228.6	182.88	254	0.3048	312.8087755
10.668	10.668	152.4	198.12	152.4	254	0.24384	312.8087755
14.224	10.668	182.88	228.6	182.88	254	0.254	486.5914286
14.224	10.668	182.88	228.6	182.88	254	0.254	486.5914286
7.112	5.334	182.88	228.6	198.12	254	0.254	484.4288
14.224	10.668	182.88	228.6	182.88	254	0.254	484.4288
14.224	10.668	182.88	228.6	182.88	254	0.254	490.9751351
14.224	10.668	182.88	228.6	182.88	254	0.254	781.4085882
14.224	10.668	182.88	228.6	182.88	254	0.254	781.4085882
14.224	10.668	182.88	228.6	182.88	254	0.254	420.4149943
14.224	10.668	182.88	228.6	182.88	254	0.254	420.4149943
14.224	10.668	182.88	228.6	182.88	254	0.254	978.1735385
14.224	10.668	182.88	228.6	182.88	254	0.254	462.0365833
15.80444	11.85333	203.2	254	203.2	225.7778	0.225778	681.228
15.80444	11.85333	203.2	254	203.2	338.6667	0.338667	371.5789091
15.80444	11.85333	203.2	254	203.2	282.2222	0.282222	371.5789091

15.80444	11.85333	203.2	254	203.2	225.7778	0.225778	371.5789091
15.80444	11.85333	203.2	254	203.2	282.2222	0.282222	490.9751351
7.902222	5.926667	220.1333	254	203.2	225.7778	0.225778	279.4781538
15.80444	11.85333	203.2	254	203.2	254	0.254	978.1735385
15.80444	11.85333	203.2	254	203.2	254	0.254	445.8946909
17.78	15.5575	215.9	266.7	215.9	254	0.381	908.304
17.78	15.5575	215.9	266.7	215.9	254	0.381	348.1832
17.78	15.5575	215.9	266.7	215.9	254	0.381	312.8087755
13.335	13.335	190.5	228.6	190.5	254	0.28575	486.5914286
8.89	6.6675	247.65	285.75	228.6	254	0.254	484.4288
17.78	13.335	228.6	285.75	228.6	285.75	0.3175	279.4781538
13.335	13.335	190.5	228.6	190.5	254	0.28575	420.4149943
13.335	13.335	190.5	228.6	190.5	254	0.254	978.1735385
15.24	11.43	195.9429	326.5714	195.9429	254	0.254	681.228
15.24	11.43	195.9429	326.5714	195.9429	254	0.254	371.5789091
15.24	15.24	217.7143	261.2571	217.7143	290.2857	0.326571	781.4085882
15.24	11.43	195.9429	326.5714	195.9429	254	0.254	978.1735385
15.24	11.43	195.9429	326.5714	195.9429	254	0.254	445.8946909
15.24	11.43	195.9429	326.5714	195.9429	217.7143	0.217714	445.8946909
17.78	13.335	228.6	381	228.6	254	0.3048	908.304
11.85333	8.89	127	169.3333	127	211.6667	0.211667	908.304
17.78	13.335	228.6	381	228.6	254	0.254	681.228
17.78	13.335	228.6	381	228.6	254	0.3048	348.1832
17.78	13.335	228.6	381	228.6	254	0.3048	312.8087755
17.78	13.335	228.6	381	228.6	254	0.254	371.5789091
17.78	13.335	228.6	381	228.6	254	0.254	486.5914286
17.78	17.78	254	304.8	254	254	0.254	484.4288
17.78	13.335	228.6	381	228.6	254	0.254	490.9751351
17.78	17.78	254	304.8	254	254	0.254	279.4781538
17.78	13.335	228.6	381	228.6	254	0.254	781.4085882
17.78	13.335	228.6	381	228.6	254	0.254	420.4149943
17.78	13.335	228.6	381	228.6	254	0.254	978.1735385
17.78	17.78	254	304.8	254	254	0.254	462.0365833
17.78	17.78	254	304.8	254	338.6667	0.338667	445.8946909
26.83774	23.48302	325.8868	431.3208	345.0566	254	0.239623	484.4288
26.83774	23.48302	325.8868	431.3208	345.0566	254	0.239623	462.0365833

14.224	10.668	152.4	203.2	152.4	203.2	0.2032	908.304
21.336	21.336	182.88	228.6	182.88	254	0.254	681.228
21.336	21.336	182.88	228.6	182.88	254	0.254	371.5789091
21.336	16.002	228.6	304.8	228.6	254	0.254	486.5914286
21.336	16.002	228.6	304.8	228.6	254	0.254	486.5914286
21.336	16.002	274.32	457.2	274.32	304.8	0.3048	490.9751351
21.336	16.002	228.6	304.8	228.6	254	0.254	781.4085882
21.336	16.002	228.6	304.8	228.6	254	0.254	781.4085882
21.336	16.002	228.6	304.8	228.6	254	0.254	420.4149943
21.336	16.002	228.6	304.8	228.6	254	0.254	420.4149943
17.78	13.335	165.1	222.25	165.1	190.5	0.3175	908.304
17.78	13.335	165.1	222.25	165.1	190.5	0.254	908.304
26.67	17.78	190.5	247.65	190.5	254	0.254	681.228
26.67	17.78	190.5	247.65	190.5	254	0.254	681.228
17.78	13.335	165.1	222.25	165.1	254	0.254	348.1832
17.78	13.335	165.1	222.25	165.1	254	0.254	348.1832
26.67	17.78	190.5	247.65	190.5	254	0.254	371.5789091
26.67	17.78	190.5	247.65	190.5	254	0.254	371.5789091
26.67	20.0025	292.1	476.25	292.1	254	0.254	484.4288
26.67	26.67	266.7	381	266.7	254	0.254	490.9751351
26.67	17.78	190.5	247.65	190.5	254	0.254	490.9751351
35.56	31.115	431.8	571.5	457.2	336.55	0.3175	279.4781538
26.67	20.0025	292.1	476.25	292.1	254	0.254	279.4781538
26.67	17.78	190.5	247.65	190.5	254	0.254	978.1735385
26.67	17.78	190.5	247.65	190.5	254	0.254	978.1735385
26.67	20.0025	292.1	476.25	292.1	254	0.254	462.0365833
26.67	17.78	190.5	247.65	190.5	254	0.254	445.8946909
26.67	17.78	190.5	247.65	190.5	254	0.254	445.8946909
40.64	20.32	145.1429	232.2286	145.1429	217.7143	0.217714	279.4781538
23.70667	17.78	177.8	254	177.8	254	0.254	908.304
23.70667	17.78	203.2	254	203.2	254	0.254	681.228
23.70667	17.78	177.8	254	152.4	254	0.254	348.1832
23.70667	17.78	93.13333	152.4	93.13333	254	0.254	348.1832
23.70667	17.78	220.1333	296.3333	220.1333	254	0.254	312.8087755
23.70667	17.78	220.1333	296.3333	220.1333	254	0.254	312.8087755

Abstract

A study was conducted to determine the energy inputs, energy outputs and energy indices in the Kuttanad region on Punja session of 2016-17. Seven hundred and thirty one farmers were selected for the different agro-ecological zones of Kuttanad for the study. The results shows that total input and output energy in the Kuttanad region were about 27305.87 and 114346.90 $MJha^{-1}$ respectively. The energy pattern consists of 43 per cent fertilizers, 18 per cent electricity, 17 per cent human labour, 11 per cent fuel, 7 per cent seed, 2 per cent machinery, and 1 per cent plant protection chemicals. The specific energy, net energy, energy efficiency and energy productivity in this region was 5.09 $MJkg^{-1}$, 87020.97 $MJha^{-1}$, 4.20 and 0.19 $kgMJ^{-1}$ respectively.

ANN modeling is done on the data collected to find out the changes occurring in zone wise and farm size wise and find out that all the models performed relatively well in all the regions compared to the training and testing data sets, with relatively less variability in RMSE. Model performance was best for Kayal region with very less variability in large holding and marginal holdings group, while models performed well for Vaikom Kari in medium and small holdings. The performance of the models in the remaining four regions is similar in all the holdings. The r-square performance measure for different regions showed that Northern Kuttanad, Purakad Kari and Upper Kuttanad performed well in large holding farms with majority of the simulations having r^2 closer to 1. While Kayal and Vaikom Kari had relatively less RMSE in large land holdings, the variability in r-square was found to be more. However, performance was good with less variability for both Kayal and Vaikom

Kari for marginal and medium land holdings respectively. In small land holdings, models performed well in Purakad Kari region with r-square close to one.

The results showed that the input energy for fertilizer is higher in the Kuttanad region. This higher input was because of the farmers practice to use high rate of fertilizer application above the PoP recommendation. By using recommended amount of fertilizer, the energy consumption and cost of production can be reduced. The second highest energy input, the electricity which can be reduced by using more efficient pump for water management. The introduction of power drum seeder will reduce the human energy input and the high cost associated with it.